# Appendix G | **Edwards Aquifer Authority Reports**

# Appendix G1 | **2023 Water Quality Monitoring Report**

*Comal System - Spring Run 3 – Summer 2023*

# 2023 EAHCP Expanded Water Quality Annual Report

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# 1 | **Introduction**

The Edwards Aquifer Habitat Conservation Plan (EAHCP) Expanded Water Quality Monitoring Program was developed to monitor surface water and groundwater quality of the San Marcos and Comal spring systems and act as an early detection mechanism for water impairments that may negatively affect EAHCP Covered Species. From 2013 – 2016, the Expanded Water Quality Program deployed a broad range of sampling activities including surface water (base flow) sampling, groundwater sampling, sediment sampling, real-time water quality monitoring, and stormwater sampling. A Work Group was assembled in 2016 and charged to review the expanded water quality monitoring program and evaluate the recommendations from the National Academies of Sciences review of the EAHCP. The Work Group prepared a final report that included adjustments to the program including the incorporation of fish tissue analysis, reduced sampling frequency of sediment and stormwater sampling, removal of surface water and groundwater sampling, and the addition of one real-time water quality monitoring station per system. More information can be found in the *Report of the 2016 Expanded Water Quality Monitoring Program Work Group*. During the transition from Phase I to Phase II of the EAHCP, a second review of the program was conducted in 2020 that analyzed the results of contaminant detections among stormwater, sediment, and passive diffusion sampling activities and evaluated the parameters monitored in the real-time water quality network. Overall, the number of contaminant detections was low among sampling events 2013-2020. This is in part due to the focus on industrial and commercial contaminants that may not pose substantial risks to the Edwards Aquifer spring communities. Therefore, suggestions from the EAHCP Science Committee were implemented in 2021 that shifted sampling to focus on nutrients and pharmaceutical and personal care products (PPCPs). Additionally, sampling for sucralose, an artificial sweetener, was initiated in 2021 as measure of human and wastewater influence on the San Marcos and Comal spring systems. The current sampling type and activities can be viewed in Table 1-1. Sampling location and activity are displayed in Figure 1-1 for the San Marcos system and Figure 1-2 for the Comal system.

Table 1-1. EAHCP Expanded Water Quality Monitoring Program Sampling Activities

| Sample Type | Activities and Sampling Locations |
|---|---|
| Real-Time Network | Continuous 15-minute interval, telemetered measurements<br>Analytes include temperature, dissolved oxygen, and conductivity<br>Locations include 3 San Marcos and 3 Comal stations |
| Surface water | Twice annual sampling in conjunction with Biological Monitoring activities<br>Laboratory analyses are focused on nutrients including total phosphorus, orthophosphate, orthophosphate as P, TOC, DOC, DIC, kjeldahl nitrogen, nitrate at N, and ammonia<br>Locations include upper and lower stations at each spring system |
| Groundwater | Twice annual sampling in conjunction with EAA springs sampling activities<br>Laboratory analyses are focused on geochemical analytes and industrial, commercial, and emerging contaminants. The analytes include cations, anions, nutrients, metals, VOCs, SVOCs, herbicides, pesticides, bacteria, TOC, PCBs, and PPCPs<br>Locations include Spring 1, Spring 3, and Spring 7 (Comal), Hotel, and Deep (San Marcos) |
| Sediment | Every other year sampling in even numbered years<br>Laboratory analyses are focused on PAHs<br>Locations include 6 San Marcos and 5 Comal stations |
| Fish Tissue | Every other year sampling in odd numbered years<br>Laboratory analyses are focused on metals and PPCPs in two fish species<br>Locations include upper and lower stations at each spring system |

## 1.1 Real-Time Network

Real-time water quality (RTWQ) instruments have been deployed within the San Marcos and Comal systems for the entirety of the water quality monitoring program. From 2013-2020, real-time instruments consisted of Eureka Manta+ 30s containing five water quality sensors including, dissolved oxygen (mg/l), specific conductivity (µs/cm), turbidity (NTU), water temperature (°C), and pH (SU). Turbidity sensors were discontinued in 2020, excluding Sessom Creek, due to the high rate of malfunction and cost of replacement. In 2021, pH sensors were also discontinued due to the sensor variability being greater than environmental variability. In 2021, Eureka Manta+30s were replaced with InSitu AT 600 real-time instruments. Measurements are recorded every 15 minutes (excluding the Sessom Creek site that is measured every five minutes) and subjected to quality control measures prior to storage in EAHCP and EAA databases. Table 1-2 describes the stations within each river system including station ID, location from headwaters (i.e., Spring Lake Hotel at San Marcos and Headwaters of Landa Lake at Comal River), and period of data record.

Presently, three RTWQ sites are located in the San Marcos system, including Aquarena Springs Drive (ASD), Texas Parks and Wildlife Department (TPWD) hatchery, and Sessom Creek (Figure 1-1). ASD was deployed and brought online by late May 2013, the TPWD hatchery site was installed in January 2016, and the Sessom Creek station began collecting data in January 2018.

Three RTWQ sites are located in the Comal system, including two locations in Landa Lake (i.e., Spring run 3 (SR 3), and Spring run 7 (SR 7)), and one site in the Old Channel (OC, Figure 1-2). Spring run 3 and SR 7 were installed in 2013 whereas the OC station was installed in April 2018.

Table 1-2. EAA real-time water quality station ID, location, and period of record for the San Marcos and Comal spring systems.

| River system | Station ID | Location (river km from headwaters) | Period of record |
|---|---|---|---|
| San Marcos | Sessom Creek | 0.5 rkm from SMR confluence | 1/1/2018 - present |
| | Aquarena Springs | 0.8 | 5/30/2013 - present |
| | Rio Vista | 1.9 | 5/30/2013 – 12/31/2020 |
| | TPWD hatchery | 4 | 1/8/2016 - present |
| Comal | Upper Spring Run | 0.1 | 4/1/2019 – 12/31/2020 |
| | Spring Run 7 | 1.0 | 9/10/2013 - present |
| | Spring Run 3 | 1.2 | 4/11/2013 - present |
| | Landa Lake | 1.2 | 6/10/2013 – 3/31/2018 |
| | Old Channel | 1.5 | 4/20/2018 - present |
| | New Channel | 2.7 | 5/30/2013 – 12/31/2020 |

Real-time water quality stations assist in discerning when and what river conditions result in water quality exceeding critical biological standards. One of EAHCP's long-term management objectives is to maintain water quality conditions that do not deviate > 10% from historical water quality conditions recorded during the EAA Variable Flow Study. Additionally, specific EAHCP water quality thresholds include, maintaining water temperature < 25°C as to not inhibit fountain darter reproduction and recruitment rates (McDonald et al. 2007) and maintaining dissolved oxygen concentrations > 4.0 mg/L throughout fountain darter habitat. EAHCP's RTWQ stations are designed to track water quality conditions within the San Marcos and Comal systems to monitor whether river conditions remain within historic conditions and under specific thresholds.


Figure 1-1. Expanded Water Quality Sampling Locations in the San Marcos system.

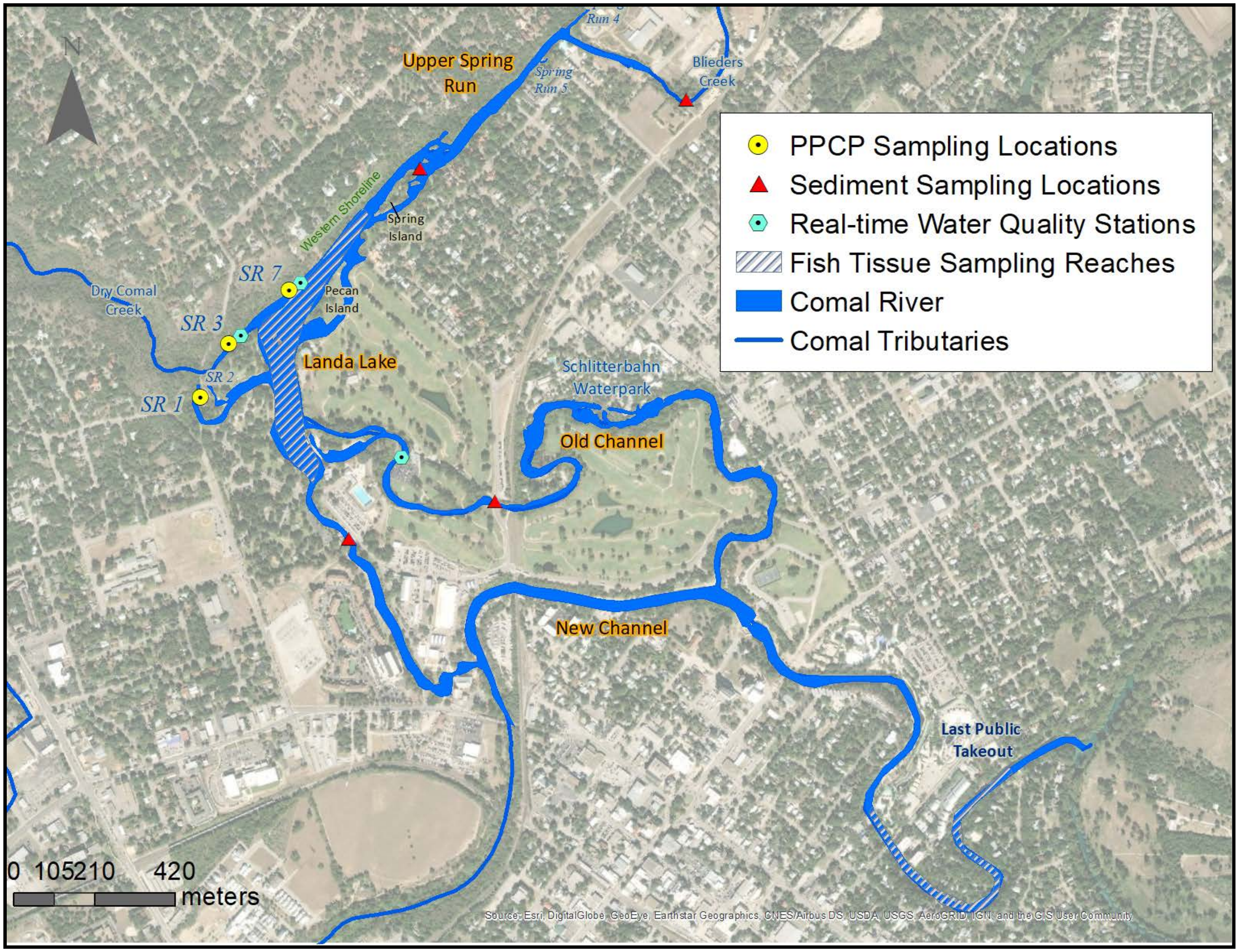


Figure 1-2. Expanded Water Quality Sampling Locations in the Comal system.

## 1.2 Surface water sampling

Monthly sucralose sampling occurs at one location in each spring system (i.e., Hotel Spring in San Marcos and Spring Run 3 in Comal). Sucralose, an artificial sweetener found in many diet beverages and candies, is not efficiently processed by the body, and subsequently ends up in septic and city wastewater effluent (Whitall et al. 2021). Sucralose has shown minimal degradation when processed through wastewater facilities, is relatively stable in the environment, and has demonstrated reliable detection rates (Oppenheimer et al. 2011). Therefore, monitoring the occurrence and levels of sucralose systems has proven to be a suitable indicator of wastewater input among rivers and groundwater systems.

Additional surface water samples are collected on a biannual basis under normal flow conditions in conjunction with the Biological Monitoring program (Spring and Fall). Sampling locations consist of upper and lower river stations in both systems. For the Comal system, Landa Lake near Spring Island serves as the upper location, and the lower station is located at the last public river take out just upstream of the confluence with the Guadalupe River. In San Marcos, Hotel Spring in Spring Lake serves as the upper location, and the downstream location is located at the most downstream real-time water quality monitoring station (i.e., TPWD hatchery). Samples are submitted to a laboratory for analysis of nutrients (Table 1-3). During the collection event, field parameters are collected that include dissolved oxygen, pH, conductivity, and temperature.

Table 1-3. List of Nutrients Analyzed during Surface Water Sampling

| **Analyte** |
|---|
| Ortho-phosphate |
| Ortho-phosphate as P |
| Phosphorus (total) |
| Dissolved Inorganic Carbon (DIC) |
| Dissolved Organic Carbon (DOC) |
| Kjeldahl Nitrogen |
| Nitrate as N |
| Ammonia |

## 1.3 Groundwater sampling

Groundwater sampling is conducted by the EAA Aquifer Science Division and is part of their routine water quality monitoring of streams, wells, and springs in the Edwards Aquifer Region (Edwards

Aquifer Water Quality Summary 2020 Report). Two spring orifices in the San Marcos system (i.e., Hotel Spring and Deep Hole) and three springs within the Comal system (ie., Spring Run 1, Spring Run 3, and Spring Run 7) are sampled on a biannual basis in conjunction with the EAHCP Biological Monitoring program (i.e, Spring and Fall). Beginning in 2022, PPCP samples were also collected every other month at Hotel Spring and Spring Run 3 locations. Groundwater samples are submitted to a laboratory for analysis of cations, anions, nutrients, metals, VOCs, SVOCs, herbicides and pesticides, bacteria, TOC, PCBs, and PPCPs. The analyte list for laboratory analyses along with the methods are shown in Table 1-4. During the collection event, field parameters will be collected that include dissolved oxygen, pH, conductivity, temperature, and alkalinity.

Table 1-4. List of Items Analyzed during Groundwater Sampling

| **Analyte** |
|---|
| Volatile Organic Compounds (VOCs) |
| Semi-volatile Organic Compounds (SVOCs) |
| Organochlorine Pesticides |
| Polychlorinated Biphenyls (PCBs) |
| Organophosphorous Pesticides |
| Herbicides |
| Metals (Al, Sb, As, Ba, Be, B, Cd, Cr (total), Cu, Fe, Pb, Mn, Hg, Ni, Se, Ag, Tl, V, and Zn) |
| General Chemistry (GWQP) Total Alkalinity (as CaCO3), Bicarbonate Alkalinity (as CaCO3), Carbonate Alkalinity (as CaCO3); (Cl, Br, $NO_3$, $SO_4$, Fl, pH, TDS, TSS, Ca, Mg, Na, K, Si, Sr, $CO_3$,)), and Total Suspended Solids (TSS). |
| Phosphorus (total) |
| Total Organic Carbon (TOC), |
| Dissolved Organic Carbon (DOC) |
| Kjeldahl Nitrogen |
| Bacteria Testing (*E coli*) |
| PPCPs |

| **Method** | **Method Description** | **Protocol** |
|---|---|---|
| 8260B | Volatile Organic Compounds | (GC/MS) SW846 |
| 8270C | Semivolatile Organic Compounds | (GC/MS) SW846 |
| 8081B | Organochlorine Pesticides | (GC) SW846 |
| 8082A | Polychlorinated Biphenyls (PCBs) | by Gas Chromatography SW846 |
| 8141A | Organophosphorous Pesticides | (GC) SW846 |
| 8151A | Herbicides | (GC) SW846 |
| 6010B | Metals | (ICP) SW846 |
| 6020 | Metals | (ICP/MS) SW846 |
| 7470A | Mercury | (CVAA) SW846 |
| 300.0 | Anions, | Ion Chromatography |
| 340.2 | Fluoride | MCAWW |
| 365.4 | Phosphorus, | Total EPA |
| 9040C | pH | SW846 |
| 9060 | Organic Carbon, | Total (TOC) SW846 |
| SM 2320B | Alkalinity | SM |
| SM 2540C | Solids, | Total Dissolved (TDS) SM |
| SM 2540D | Solids, Total Suspended (TSS) | SM |
| 351.2 | Nitrogen, Total Kjeldahl | MCAWW |
| 1694 | PPCPs | LC-MS/MS |

**Protocol References:**
EPA = US Environmental Protection Agency
MCAWW = "Methods For Chemical Analysis Of Water And Wastes", EPA-600/4-79-020, March 1983 And Subsequent Revisions.
SM = "Standard Methods For The Examination Of Water And Wastewater",
SW846 = "Test Methods For Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, November 1986 And Its Updates.

## 1.4 Sediment and Fish Tissue sampling

Sediment and fish tissue sampling occurs on an every other year basis with sediment sampling completed in even years and fish tissue sampling in odd years. Sampling collections for sediment and fish tissue occur in the Spring during the EAHCP Biological Monitoring surveys.

Collection of sediment samples within in each spring system was included in the program to help determine potential effects on EAHCP covered species via direct or indirect exposure to sediment contaminants. Sediment samples are collected once from four locations within the Comal system and six locations in San Marcos system (Figures 1-1 and 1-2). Samples are collected at each sample site and composited into one sample for analysis. Sediment samples are analyzed for polycyclic aromatic hydrocarbons (PAHs) and other contaminants listed in Table 1-5.

Table 1-5. List of Contaminants Analyzed during Sediment Sampling.

| **Analyte** |
|---|
| Benzo[a]anthracene |
| Chrysene |
| Benzo[a]pyrene |
| Benzo[b]fluoranthene |
| Benzo[k]fluoranthene |
| Fluoranthene |
| Dibenz(a,h)anthracene |
| Indeno[1,2,3-cd]pyrene |
| Pyrene |
| Phenanthrene |
| Fluorene |
| Benzo[g,h,i]perylene |
| Anthracene |
| Acenaphthene |
| Acenaphthylene |
| Benzo[g,h,i]perylene |
| Carbazole |
| 2-Methylnaphthalene |
| Naphthalene |
| Total Organic Carbon (TOC) |

Fish tissue sampling within in each spring system was included to the program in 2017 to serve as a direct link between water quality impairments and their potential effects on EAHCP covered species. Prior to 2017, the linkage between contaminants and metals found in the spring systems and their accumulation in EAHCP covered species was unknown. Surrogate species were selected to represent EAHCP covered species and the two species selected for analysis are *Gambusia* (mosquito fish) and *Micropterus salmoides* (largemouth bass). The mosquito fish serves as a short-lived species, similar to the EAHCP covered fountain darter, whereas the largemouth bass represents the longer-lived species. Mosquito fish and largemouth bass are collected from upper and lower sections in both spring systems. In the San Marcos, fish are collected in Spring Lake (i.e., upper section) and in the San Marcos River near IH35 (i.e., lower section). For the Comal, both species are collected from Landa Lake (i.e., upper section) and in the Comal River near the last public take out (i.e., lower section). For each section, whole body organisms are combined to create a mosquito fish composite sample.  Composites for largemouth bass are created from individual fillet aliquots from each fish. Tissue samples are submitted to a laboratory and analyzed for metals and PPCP contaminants listed in Table 1-6.

Table 1-6. List of Metals and Contaminants Analyzed among Fish Tissue Samples.

| Analyte |
|---|
| Metals (Al, Sb, As, Ba, Be, B, Cd, Cr (total), Cu, Fe, Pb, Mn, Hg, Ni, Se, Ag, Tl, V, and Zn) |
| PPCPs |

| Method | Method Description | Protocol |
|---|---|---|
| 6010B | Metals | (ICP) SW846 |
| 6020 | Metals | (ICP/MS) SW846 |
| 7470A | Mercury | (CVAA) SW846 |
| 1694 | PPCPs | LC-MS/MS |

**Protocol References:**
EPA = US Environmental Protection Agency
MCAWW = "Methods For Chemical Analysis Of Water And Wastes", EPA-600/4-79-020, March 1983 And Subsequent Revisions.
SM = "Standard Methods For The Examination Of Water And Wastewater",
SW846 = "Test Methods For Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, November 1986 And Its Updates

# 2 | **Methods**

## 2.1 Real-Time Network

The near continuous (15-minute interval) raw data collected at San Marcos River and Comal system RTWQ sites underwent a quality assurance review process before being utilized for this assessment. Water quality sonde data was overlayed with river streamflow and precipitation data to verify significant increases and decreases in measured values. The data from each site within the basins were also compared to ensure validity. The multiparameter water quality instruments were switched out at 5 to 6-week intervals, with the unit returned to the EAA office for data download, calibration checks, and cleaning. Data obtained from independent field visit measurements and post-deployment sensor calibration checks were used to determine any necessary adjustments to the near continuous raw data sets. Additional quality control was completed to the data in the Power BI Pro License software.

Turbidity data recorded at Sessom Creek were edited for any values in the continuous raw data interpreted as not being representative of actual ambient water quality conditions. Sporadic spikes in turbidity values without any corresponding change in other parameters (i.e. Specific Conductance, Temperature, or Dissolved Oxygen) were deleted from the finalized continuous data sets before their use in this assessment.

Mean daily, maximum daily, and minimum daily values for water quality parameters at each of the San Marcos River and Comal system RTWQ sites were exported from AQUARIUS database. Hydrographs since the start of the EAHCP (2013) for the two systems were constructed using surface water discharge data (recorded in 15 minute intervals) obtained for the San Marcos River at San Marcos (USGS Station 08170500) and the Comal River at New Braunfels (USGS Station 0816900). Mean daily springflow (cfs) for the San Marcos springs (USGS Station 08178710) and the Comal springs (USGS Station 0816900) were used to construct springflow hydrographs for 2013-2021. Differences in maximum daily temperatures and minimum daily dissolved oxygen among sites and seasons were assessed using boxplots. Seasons were defined as: Winter (January, February, December), Spring (March – May), Summer (June – August), and Fall (September – November). For sites exceeding water temperatures > 25°C, 15-minute interval data (5 minute interval data for Sessom Creek) were used to assess the number of days and percent of day a site exceeded 25°C. Similar analysis was completed for sites that dropped below the 4.0 mg/L dissolved oxygen threshold.

## 2.2 Surface water sampling

Water samples for sucralose were collected from Hotel Spring in the San Marcos system and Spring run 3 in the Comal system monthly January – December 2023. Prior to water sample collection, an Insitu AquaTroll 600 water quality sonde was placed directly in each location to measure water quality parameters (i.e., pH, specific conductivity, dissolved oxygen, and temperature) for a ten-minute period. Sample bottles were submerged directly into the springs to be filled. Field duplicates and field blanks (i.e., bottles filled with DI water) were also filled following sampling protocols. All sample bottles were kept chilled during transport in an ice chest and placed in a freezer until later shipment to the laboratory that occurred on a quarterly basis.

Surface water samples for nutrient analysis were collected in May and October 2023 at upper and lower sites in the San Marcos and Comal systems. During sampling collections, water quality parameters were measured following same protocols as monthly sucralose sampling. Filtration for methods 6010B (metals), 6020 (metals), and 7470A (mercury) were performed at the sample locations by using a 0.45 micron high capacity cartridge filter inserted into syringe. Preservatives were placed in the bottles (as appropriate) by the contracted laboratory. Field duplicates and field blanks were also filled following sampling protocols. All sample bottles were kept chilled during transport in an ice chest frozen and immediately shipped to the contract laboratory for analysis.

All water quality data were exported to excel and medians values were calculated for water quality parameters collected during sucralose and bi-annual surface water sampling collections.

## 2.3 Groundwater sampling

Groundwater samples for PPCPs and other analyses were collected from Hotel and Deep Hole springs in the San Marcos system and from Spring Run 1, 3, and 7 within the Comal Spring system in April and October 2023. Additional PPCP samples were also collected for four additional months (i.e., January, June, July, and December) at Hotel and Spring Run 3 locations. Prior to groundwater collections, an Insitu AquaTroll 600 water quality sonde was placed directly into the spring orifice to measure water quality parameters (i.e., pH, specific conductivity, dissolved oxygen, and temperature). Sample bottles were then submerged directly into the spring to obtain samples, except for Deep Hole Spring where EAA staff utilized a peristaltic pump with 30 feet of sample tubing inserted into the spring orifice to collect field parameters and fill sample bottles. Samples were collected in accordance with the criteria set forth in the *EAA Groundwater Monitoring Plan*.

Filtration for methods 6010B (metals), 6020 (metals), 7470A (mercury) and field alkalinity were performed at the sample locations by utilizing a 0.45 micron high capacity cartridge filter inserted into a weighted single sample disposable bailer or sample tubing (if peristaltic pump was used). Preservatives were placed in the bottles (as appropriate) by the contracted laboratory. Ice was placed into the cooler immediately after sampling and later shipped to the contract laboratory. When not in use or after collection, sampling equipment and/or coolers containing samples were secured inside the EAA vehicles to maintain appropriate sample custody and security.

Analyses for field alkalinity were conducted at EAA's Camden Building using Hach Titralab® AT1000. The method used for field alkalinity is discussed in detail in the *EAA Groundwater Monitoring Plan.*

A full report of groundwater sampling results at Hotel and Deep Hole springs will be available under the Science and Aquifer Protection section on the EAA website and entitled Water Quality Summary Report 2023. Sampling results for PPCPs are reported in Section 3.3.

## 2.4 Fish Tissue sampling

Fish tissue samples were collected in May-June 2023. No mosquitofish were sent for analysis due to shipping restrictions on whole specimens. Largemouth bass were collected from the upper and lower sites in the San Marcos system (i.e., Spring Lake and the lower San Marcos River near IH35) and the Comal system (i.e., Landa Lake and Comal River near the last public take out). Largemouth bass were collected via hook and line and humanely euthanized by being placed in a cooler with ice. Collected specimens were frozen until further processing. Largemouth bass composite samples were made by grinding frozen fillets with stainless steel implements and processing implements were cleaned and rinsed with DI prior to use. Composite samples were then shipped off to the contract laboratory.

# 3 | **Results and Discussion**

## 3.1 Real-Time Network

### 3.1.1 San Marcos

*Hydrology*

Average springflow for the San Marcos Springs calculated from the period of record (i.e., 1956 – present) was 175 cfs. Since 2013, San Marcos springflow ranged from below average in 2013-2014 to above average from mid-2015-2017 (Figure 3-1). During 2013, the San Marcos springflow dropped down to as low as 99 cfs on May 21st. A flow pulse on October 30th, 2013, estimated at 5,400 cfs, resulted in a temporary spike in above average springflow. No substantial rain events occurred in 2014 and consequently, springflow dropped below average. Increased springflow in 2015 occurred following two large precipitation events in late May and October with above average springflow continued into 2016 - 2017. In 2018, springflows dropped below average, reaching 117 cfs in late August. However, several small rain events in the early fall resulted in springflows increasing and becoming above average (~250 cfs). Springflows were largely above average in 2019, but with a lack of large flow pulses (> 500 cfs), springflows lessened throughout the year and dropped just below average beginning in October. With no large flow pulses in 2020, springflows continued to decrease and dropped below 120 cfs by December. Springflow in early 2021 continued to decline and dropped briefly below 100 cfs in April before rain events in late spring resulted in springflow rising to average flows. Springflows dropped slightly during early fall but increased again after significant rain events (i.e., 1,070 cfs pulse in October) to end 2021 at average springflow. No significant rainfall events occurred in 2022 with springflows at critical period monitoring levels during most of the year, declining down to ~85 cfs from September-December. Springflows remained below 100 cfs during all of 2023 (median 88 cfs), dropping in August to the lowest observed springflow (66cfs) since 1956.

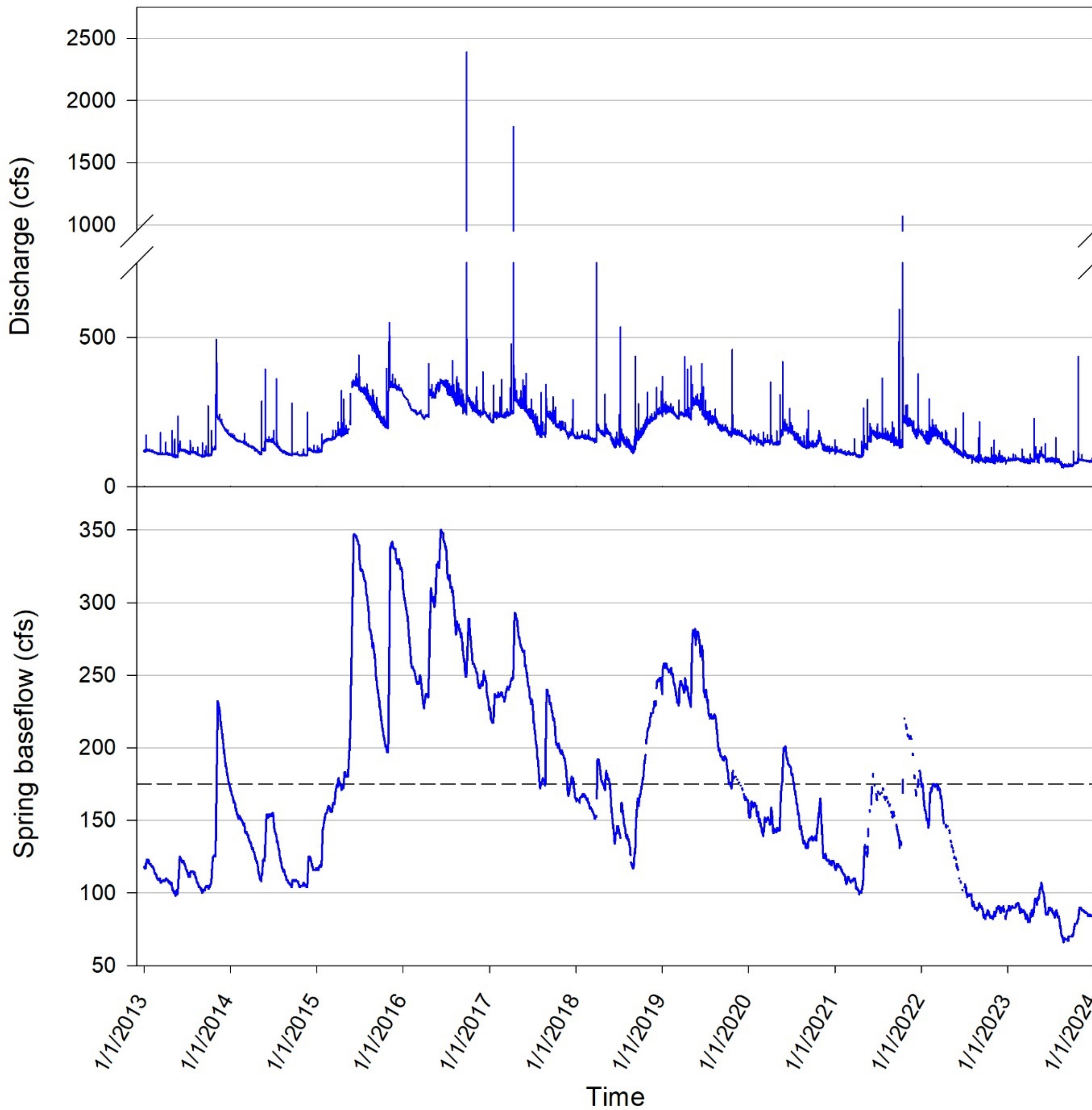


Figure 3.1-1. Hydrographs for the San Marcos River at San Marcos (USGS station 08170500) and mean daily springflow for the San Marcos springs (USGS Station 08170000) 2013 – 2023. Dashed line denotes the long-term average springflow (175 cfs) in the San Marcos River.

*Temperature*

Table 3.1-1 displays monthly summary statistics (i.e., monthly mean and 15 minute minimum and maximum values reported that month) for water temperatures recorded in 2023 at the San Marcos River RTWQ sites. Slightly more variation in mean water temperatures (~3-4 °C) was observed this year and is attributed to the continued lower than average springflows in the system during 2023. The TPWD hatchery site displayed greater variability in water temperature with minimum daily water temperatures reaching lower temperatures in winter months and warmer maximum daily water temperatures during summer months. Maximum daily water temperatures recorded in 2023 reached the 25°C threshold with the highest temperature (26.60°C) recorded at the TPWD hatchery in August. The lowest temperature (10.49°C) in 2023 was observed at the TPWD hatchery site in March.

Table 3.1-1. Monthly mean, minimum, and maximum water temperatures among San Marcos River RTWQ (2023).

| | **Water temperature (°C) at San Marcos Water Quality Sites** | | | | | |
|---|---|---|---|---|---|---|
| **Month (2023)** | **Aquarena Springs** | | | **TPWD hatchery** | | |
| | Mean | Min | Max | Mean | Min | Max |
| **Jan** | 20.80 | 18.67 | 22.69 | 20.26 | 16.77 | 22.87 |
| **Feb** | 20.87 | 16.81 | 23.00 | 20.32 | 13.03 | 23.75 |
| **Mar** | 21.71 | 19.50 | 23.78 | 21.66 | 10.49 | 24.62 |
| **Apr** | 22.00 | 19.42 | 24.03 | 21.95 | 16.69 | 24.98 |
| **May** | 22.81 | 21.42 | 24.36 | 23.13 | 21.15 | 25.52 |
| **Jun** | 23.32 | 22.03 | 24.83 | 24.09 | 22.03 | 26.37 |
| **Jul** | 23.57 | 22.53 | 25.06 | 24.48 | 22.84 | 26.53 |
| **Aug** | 23.65 | 22.28 | 25.08 | 24.63 | 22.59 | 26.60 |
| **Sept** | 23.34 | 22.23 | 24.95 | 24.18 | 22.42 | 26.32 |
| **Oct** | 22.21 | 18.82 | 24.35 | 22.36 | 18.35 | 25.15 |
| **Nov** | 21.23 | 19.71 | 23.53 | 20.87 | 18.78 | 23.58 |
| **Dec** | 20.79 | 19.22 | 22.55 | 20.18 | 17.80 | 22.41 |

Box plots for maximum daily temperatures (i.e., highest 15 minute interval recorded daily) observed at San Marcos RTWQ sites from time of equipment deployment (i.e., 2013 for Aquarena Springs Drive (ASD) and 2016 for TPWD hatchery) through 2023 compared to maximum daily temperature observed in 2023 are shown in Figure 3.1-2. The median of maximum daily temperatures for 2023 were slightly higher and exhibited more variability than the median of maximum daily temperatures from time of equipment deployment at both San Marcos sites but this was not unexpected with the lower springflows experienced throughout 2023.

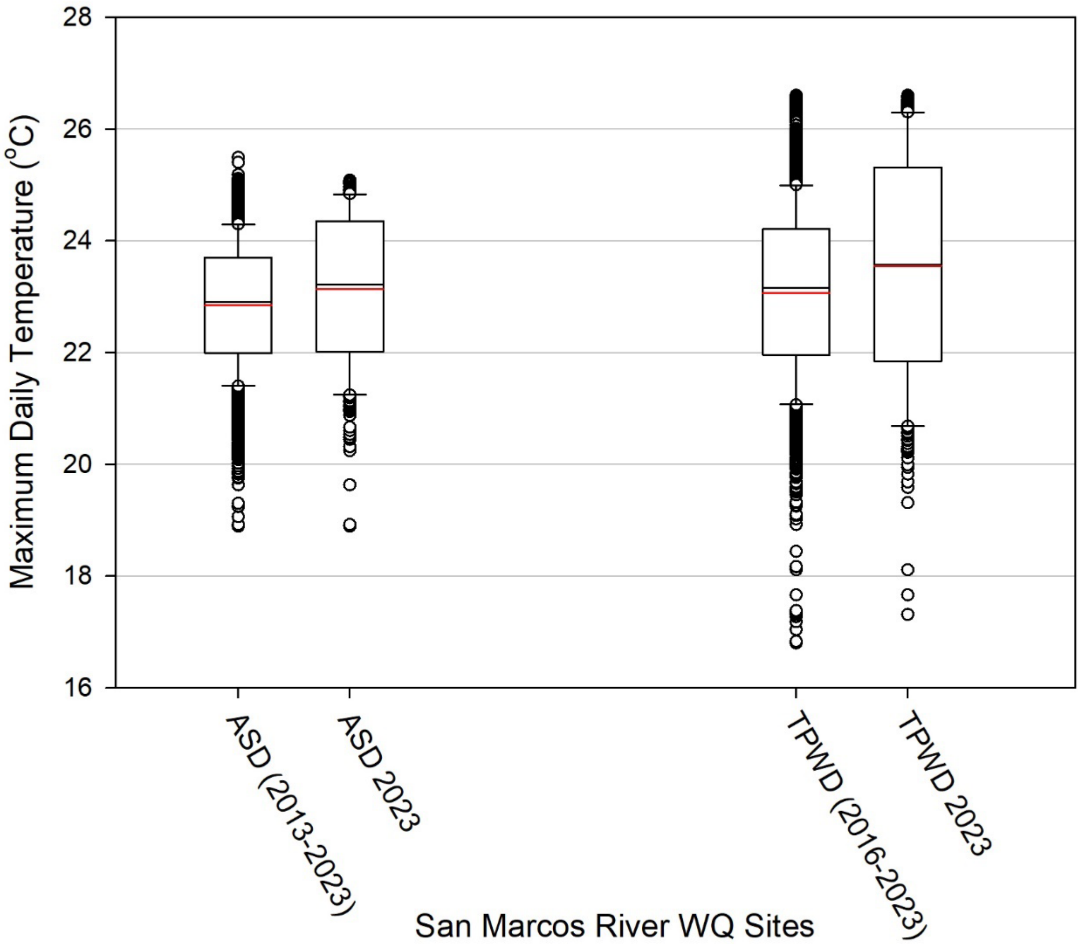


Figure 3.1-2. Box plots of maximum water daily temperatures (°C) among San Marcos River RTWQ sites from time of equipment deployment through 2023 compared to 2023 values. Black lines represent median values and red lines denote mean values. Whiskers represent maximum and minimum temperature values, excluding outliers (open circles).

Maximum daily water temperatures were plotted for San Marcos River RTWQ sites for 2023 (Figure 3.1-3). Throughout 2023, maximum daily temperatures were more variable at the TPWD hatchery site compared to the upstream ASD site. Maximum daily temperatures reached or exceeded 25°C at the TPWD hatchery site for 112 days during the months of May - October in 2023. Among those 112 days, time spent at or above 25°C ranged from 1.5 hrs – 11.0 hrs (mean = 7.82 hrs and median = 8.75 hrs). At the Aquarena Springs Drive site, maximum daily water temperature reached 25°C 16 days in 2023 (7/30/2023 - 8/27/2023) for a period of 0.25-1.75 hours per day.

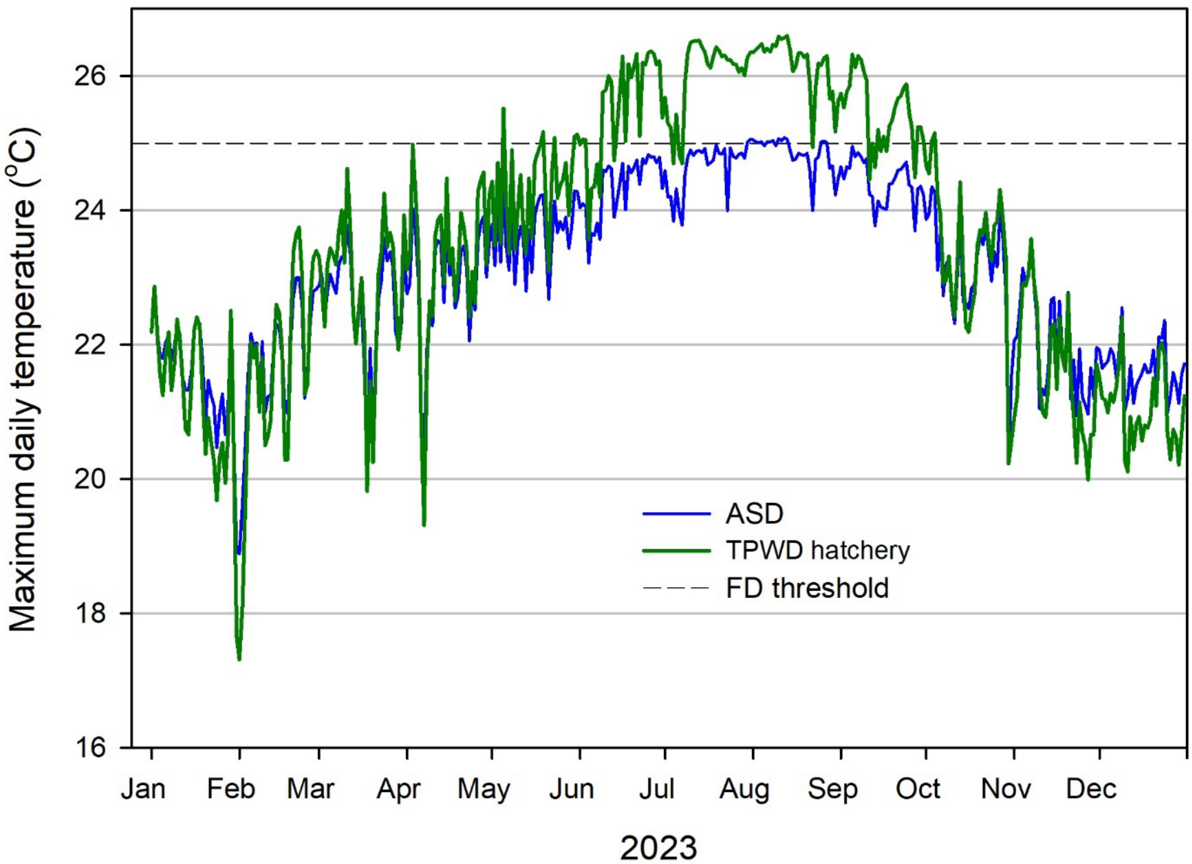


Figure 3.1-3. Maximum daily water temperatures (°C) among San Marcos River RTWQ sites (2023). Dashed line represents temperature threshold for reduced reproduction for the fountain darter (25°C).

Box plots for seasonal maximum daily water temperatures at San Marcos RTWQ sites for 2023 are shown in Figure 3.1-4. Across seasons, median maximum daily temperatures varied by ~3-4°C among San Marcos River WQ sites with some more outlier temperatures observed in winter. Greater variability in maximum daily temperatures across seasons corresponds with the continued lower springflows experienced throughout all of 2023. Fall continues to show the greatest range in maximum daily temperatures for San Marcos WQ sites.

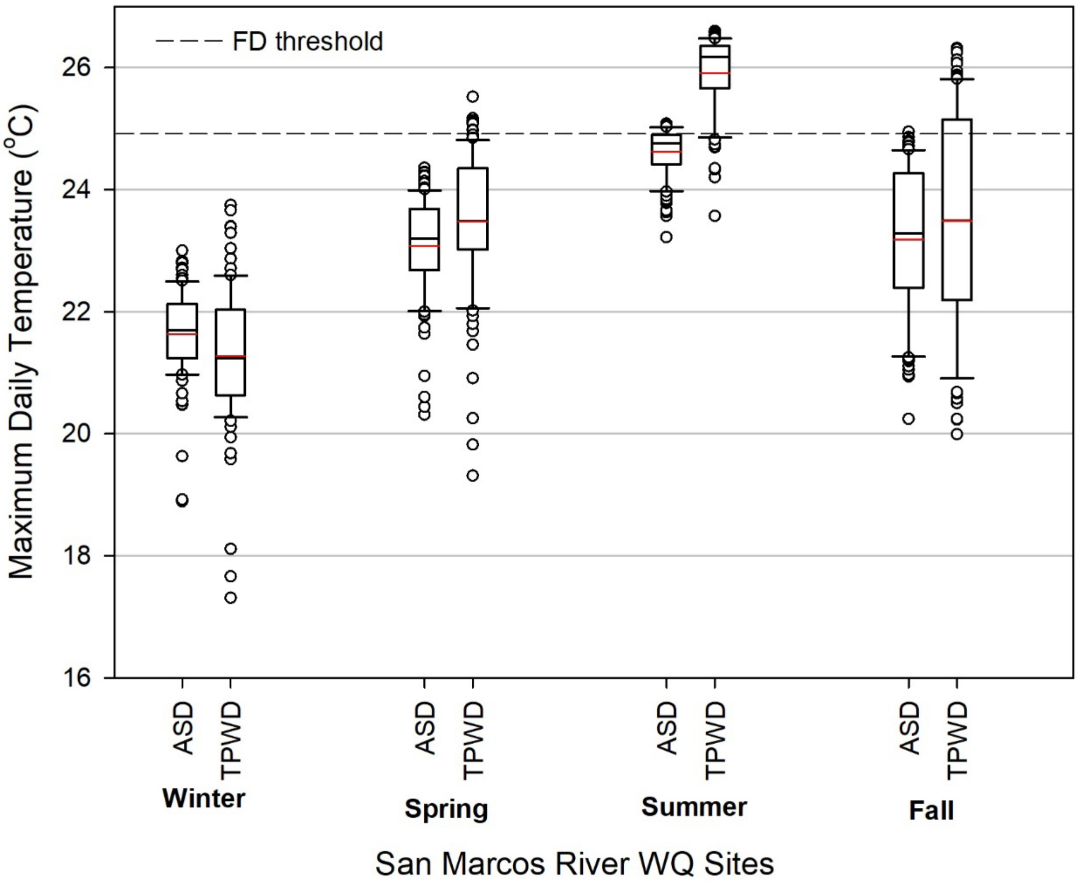


Figure 3.1-4. Box plots of maximum daily water temperatures (°C) among seasons at San Marcos River RTWQ sites in 2023. Black lines represent median values and red lines denote mean values. Whiskers represent maximum and minimum temperature values, excluding outliers (open circles).

*Dissolved Oxygen*

Table 3.1-2 displays monthly summary statistics for dissolved oxygen (DO) recorded in 2023 at the San Marcos River RTWQ sites. Mean monthly DO remained relatively consistent with variations averaging 1 mg/l within a site and did not vary greatly between the two sites. The TWPD hatchery site demonstrated greater variability in DO in 2023 with minimum DO at ~6 mg/l and maximum DOs slightly higher than 11 mg/l. The highest DO recorded in 2023 was 11.08 mg/l at TPWD hatchery in March, and the lowest DO (6.00mg/l) also occurred in July.

Table 3.1-2. Monthly mean, minimum, and maximum DO (mg/l) among San Marcos River RTWQ sites (2023).

| | Dissolved oxygen (mg/l) at San Marcos Water Quality Sites | | | | | |
|---|---|---|---|---|---|---|
| **Month (2023)** | **Aquarena Springs** | | | **TPWD hatchery** | | |
| | Mean | Min | Max | Mean | Min | Max |
| **Jan** | 8.23 | 7.04 | 9.95 | 8.73 | 7.47 | 10.84 |
| **Feb** | 8.41 | 7.02 | 10.32 | 8.91 | 7.27 | 11.03 |
| **Mar** | 8.01 | 6.71 | 10.33 | 8.42 | 6.90 | 11.08 |
| **Apr** | 7.85 | 6.70 | 9.63 | 8.19 | 6.84 | 10.08 |
| **May** | 7.69 | 6.75 | 9.08 | 8.05 | 6.95 | 9.79 |
| **Jun** | 7.57 | 6.68 | 8.77 | 7.77 | 6.55 | 9.49 |
| **Jul** | 7.63 | 6.85 | 8.81 | 7.62 | 6.00 | 9.02 |
| **Aug** | 7.62 | 6.84 | 8.78 | 7.72 | 6.88 | 9.28 |
| **Sept** | 7.66 | 6.84 | 8.84 | 7.82 | 6.57 | 9.38 |
| **Oct** | 7.83 | 6.86 | 9.51 | 8.03 | 6.77 | 9.61 |
| **Nov** | 8.03 | 6.96 | 9.80 | 8.28 | 7.21 | 9.62 |
| **Dec** | 8.09 | 7.10 | 9.78 | 8.49 | 7.40 | 10.00 |

Box plots for minimum daily DO (i.e., lowest DO reported for one 15-minute interval in a 24-hour period) observed at San Marcos RTWQ sites from time of equipment deployment (i.e., 2013 for ASD and 2016 for TPWD hatchery) through 2023 compared to minimum daily DO observed in 2023 are shown in Figure 3.1-5. The medians of minimum daily DO for 2032 were lower than the medians of minimum daily DO from time of equipment deployment for San Marcos River RTWQ sites, dropping below the 25th percentile for to the comprehensive minimum daily DO dataset.

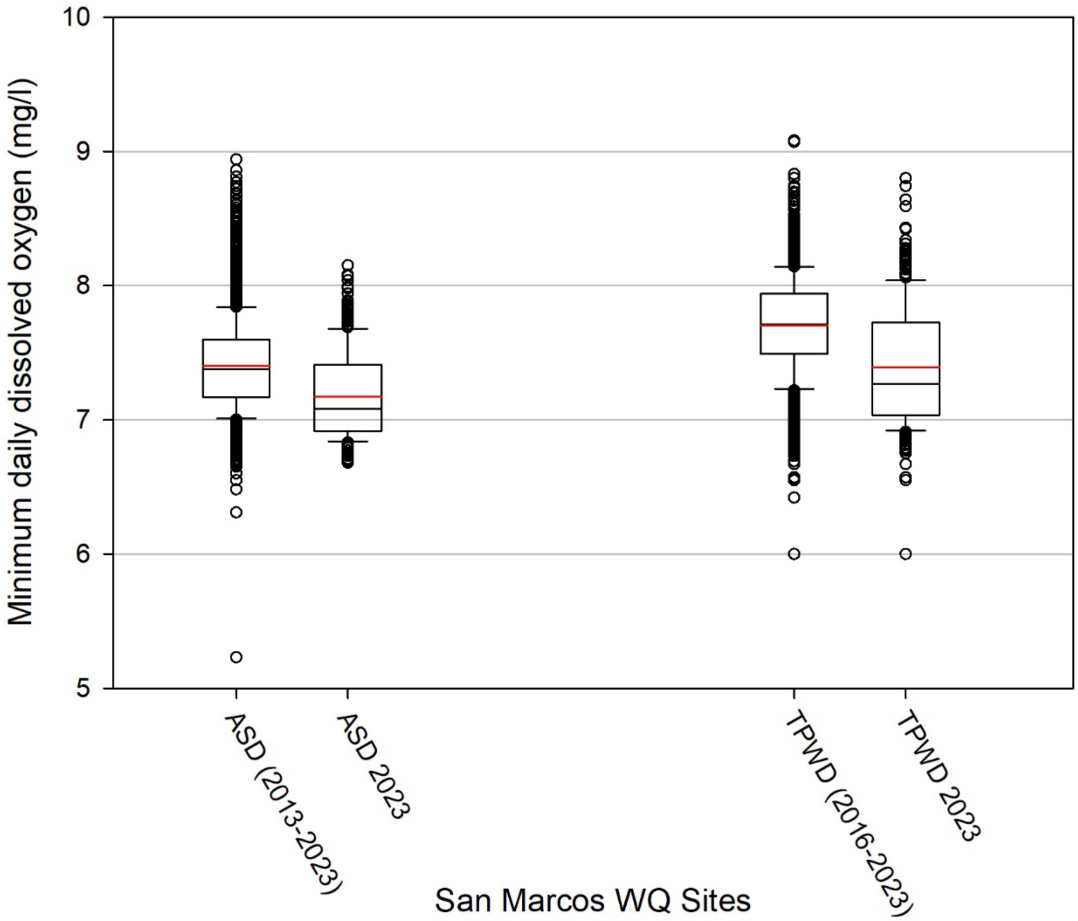


Figure 3.1-5. Box plots of minimum daily DO (mg/l) among RTWQ sites in the San Marcos River from time of equipment deployment through 2023 compared to 2023 only. Black lines represent median values and red lines denote mean values. Whiskers represent maximum and minimum DO values, excluding outliers (open circles).

Minimum daily DO recorded in 2023 were plotted for San Marcos River RTWQ sites (Figure 3.1-6). Similar to previous years, the TPWD hatchery site maintained higher minimum daily DO levels compared to the ASD site, but the seasonal trends in minimum daily DO levels were analogous among the two sites. The minimum DO threshold (4 mg/l) was not reached at either San Marcos River RTWQ site in 2023.

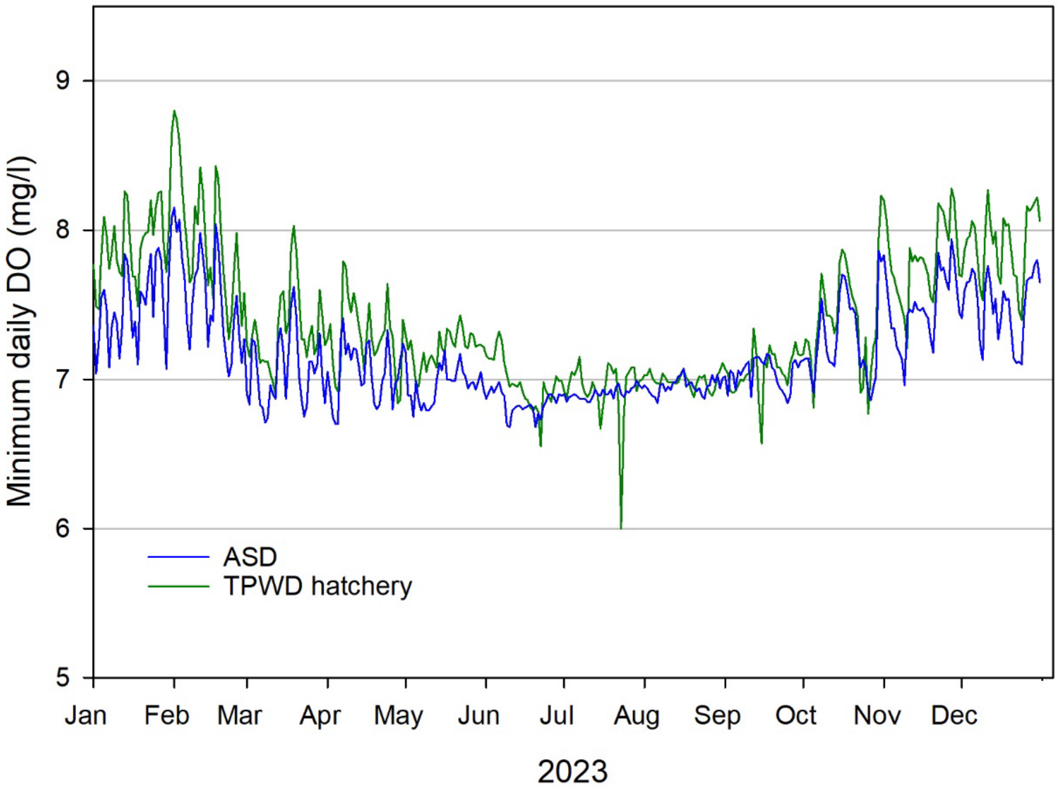


Figure 3.1-6. Minimum daily DO (mg/l) among San Marcos River water quality stations (2023).

*Conductivity*

Table 3.1-3 displays monthly summary statistics for conductivity (µs/cm) recorded in 2023 at the San Marcos River RTWQ sites. Mean monthly conductivity remained consistent among sites and throughout the year. The highest conductivity in 2023 was recorded at the ASD site in October (658 µs/cm) and the lowest conductivity (99 µs/cm) was also recorded in October at the TPWD hatchery.

San Marcos River discharge and mean daily conductivity were plotted for San Marcos River RTWQ sites for 2023 (Figure 3.1-7). Mean daily conductivity was influenced by rain events in the San Marcos River with decreases in conductivity corresponding with influxes of run-off entering the river. Outside of rain events, mean conductivity generally ranged between 620-635 µs/cm at the two San Marcos RTWQ sites.

Table 3.1-3. Monthly mean, minimum, and maximum conductivity (µs/cm) among San Marcos River RTWQ sites (2023).

| | Conductivity (µs/cm) at San Marcos Water Quality Sites | | | | | |
|---|---|---|---|---|---|---|
| **Month (2023)** | **Aquarena Springs** | | | **TPWD hatchery** | | |
| | Mean | Min | Max | Mean | Min | Max |
| **Jan** | 631 | 541 | 635 | 630 | 465 | 639 |
| **Feb** | 631 | 563 | 639 | 631 | 484 | 641 |
| **Mar** | 633 | 540 | 641 | 631 | 320 | 642 |
| **Apr** | 632 | 486 | 638 | 617 | 182 | 639 |
| **May** | 632 | 540 | 639 | 630 | 440 | 644 |
| **Jun** | 633 | 513 | 643 | 637 | 477 | 644 |
| **Jul** | 635 | 623 | 644 | 634 | 372 | 642 |
| **Aug** | 637 | 613 | 647 | 635 | 617 | 642 |
| **Sept** | 641 | 468 | 652 | 630 | 498 | 640 |
| **Oct** | 628 | 161 | 658 | 609 | 99 | 634 |
| **Nov** | 632 | 409 | 641 | 621 | 424 | 630 |
| **Dec** | 633 | 474 | 645 | 619 | 474 | 629 |

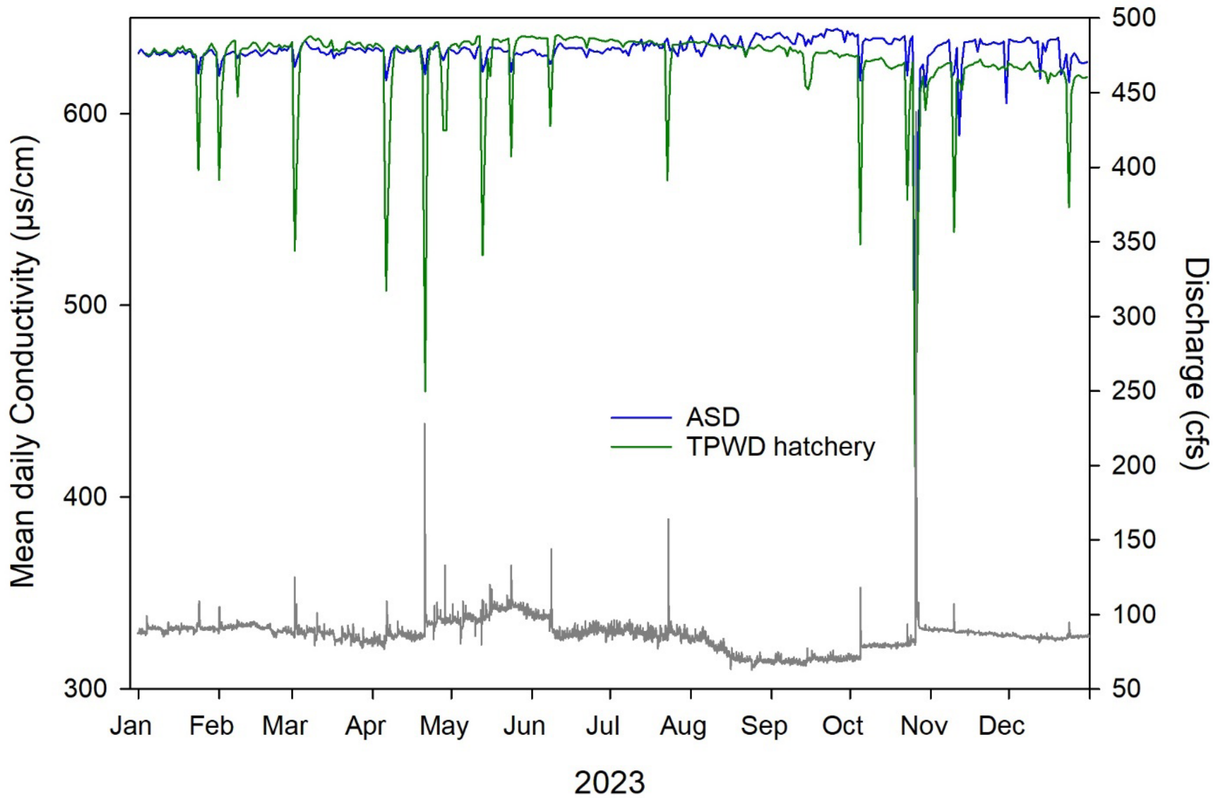


Figure 3.1-7. Mean daily conductivity (µs/cm) among San Marcos River RTWQ sites and San Marcos River discharge (USGS Gage#08170500) in 2023.

*Sessom Creek Water Quality Characterization*

Table 3.1-4 displays monthly summary statistics for water quality parameters measured in Sessom Creek for 2023. Figures 3.1-8 to 3.1-10 illustrate the daily values for water quality parameters in Sessom Creek (maximum daily temperature, minimum daily DO, mean daily turbidity and conductivity, respectively). Sessom Creek displayed more variability in water quality conditions than the San Marcos River RTWQ sites. The highest maximum daily water temperature reported in Sessom Creek for 2023 was 31.64°C in August. Maximum daily water temperatures exceeded 25°C for 119 days (June – October) in 2023, ranging from 0.1 hours – 24.0 hours (mean = 8.13 hours, median = 7.75 hours) at or above 25°C during those 119 days. DO dropped below 4.0 mg/l in Sessom Creek for 169 days in January – December ranging from 0.1 hours – 24.0 hours (median = 8.0 hours, mean = 8.75 hours). The lower minimum daily DOs observed in Sessom Creek in part corresponded with rainfall events during months when instream springflow was minimal and run-off dominated creek water volume. Spikes in mean daily turbidity were observed with corresponding drops in conductivity, indicating an influx of run-off from a rain event (Figure 3.1-10).

Table 3.1-4. Monthly mean, minimum, and maximum for water quality parameters in Sessom Creek (2023).

| **Month (2023)** | **Temperature (°C)** | | | **DO (mg/l)** | | | **Conductivity (µs/cm)** | | | **Turbidity (NTU)** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Min | Max | Mean | Min | Max | Mean | Min | Max | Mean | Min | Max |
| **Jan** | 17.58 | 10.56 | 22.48 | 4.77 | 2.67 | 10.72 | 621 | 44 | 663 | 12 | 0 | 850 |
| **Feb** | 16.69 | 2.95 | 23.08 | 6.74 | 2.76 | 13.50 | 583 | 60 | 658 | 26 | 0 | 465 |
| **Mar** | 20.08 | 15.23 | 23.91 | 5.38 | 2.47 | 11.38 | 616 | 52 | 667 | 19 | 0 | 1200 |
| **Apr** | 20.40 | 12.30 | 24.89 | 5.46 | 3.09 | 10.22 | 587 | 41 | 665 | 29 | 0 | 1929 |
| **May** | 22.66 | 20.43 | 25.00 | 5.46 | 3.10 | 8.45 | 609 | 48 | 673 | 11 | 0 | 564 |
| **Jun** | 24.03 | 22.00 | 29.02 | 5.81 | 3.45 | 11.83 | 643 | 50 | 786 | 12 | 0 | 892 |
| **Jul** | 24.93 | 23.42 | 30.69 | 5.75 | 2.29 | 11.71 | 654 | 54 | 702 | 14 | 0 | 799 |
| **Aug** | 25.33 | 22.81 | 31.64 | 5.99 | 1.31 | 12.02 | 668 | 218 | 1098 | 9 | 0 | 852 |
| **Sept** | 24.64 | 22.70 | 28.54 | 4.76 | 1.90 | 10.30 | 655 | 88 | 686 | 13 | 0 | 655 |
| **Oct** | 21.80 | 11.88 | 27.19 | 6.01 | 3.41 | 10.81 | 597 | 40 | 704 | 23 | 0 | 1568 |
| **Nov** | 18.96 | 15.44 | 22.93 | 5.22 | 2.93 | 9.93 | 632 | 52 | 686 | 6 | 0 | 226 |
| **Dec** | 17.82 | 13.63 | 21.75 | 4.09 | 1.06 | 8.95 | 625 | 91 | 685 | 6 | 0 | 249 |

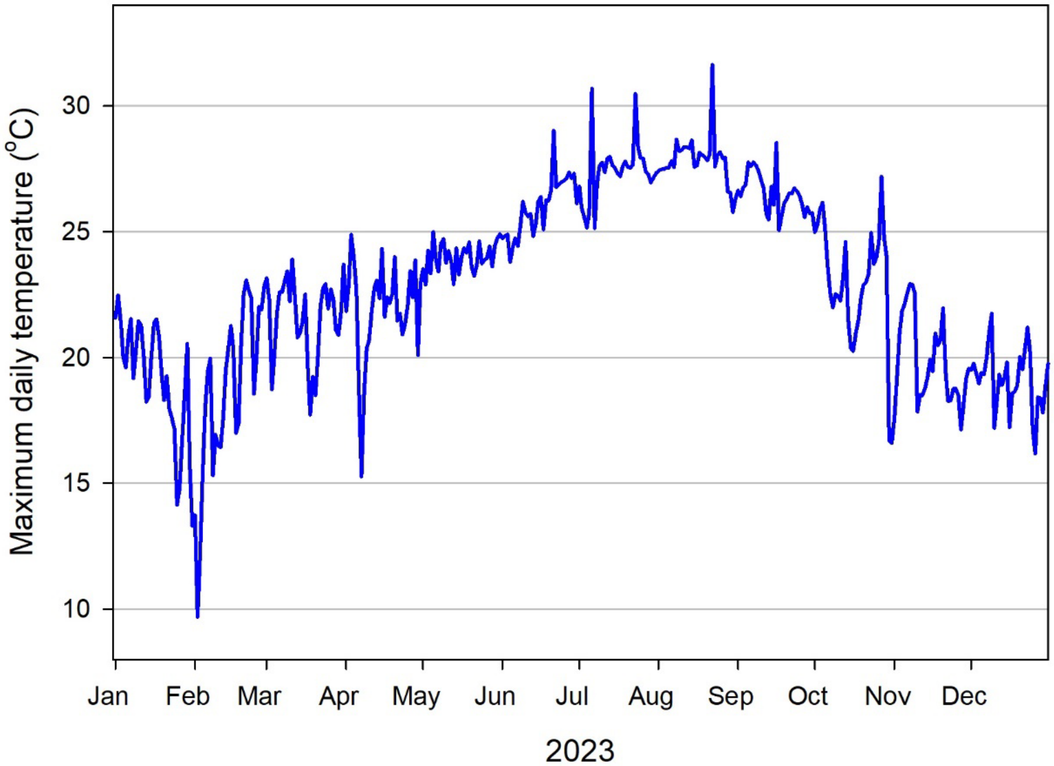


Figure 3.1-8. Maximum daily water temperatures (°C) in Sessom Creek (2023).

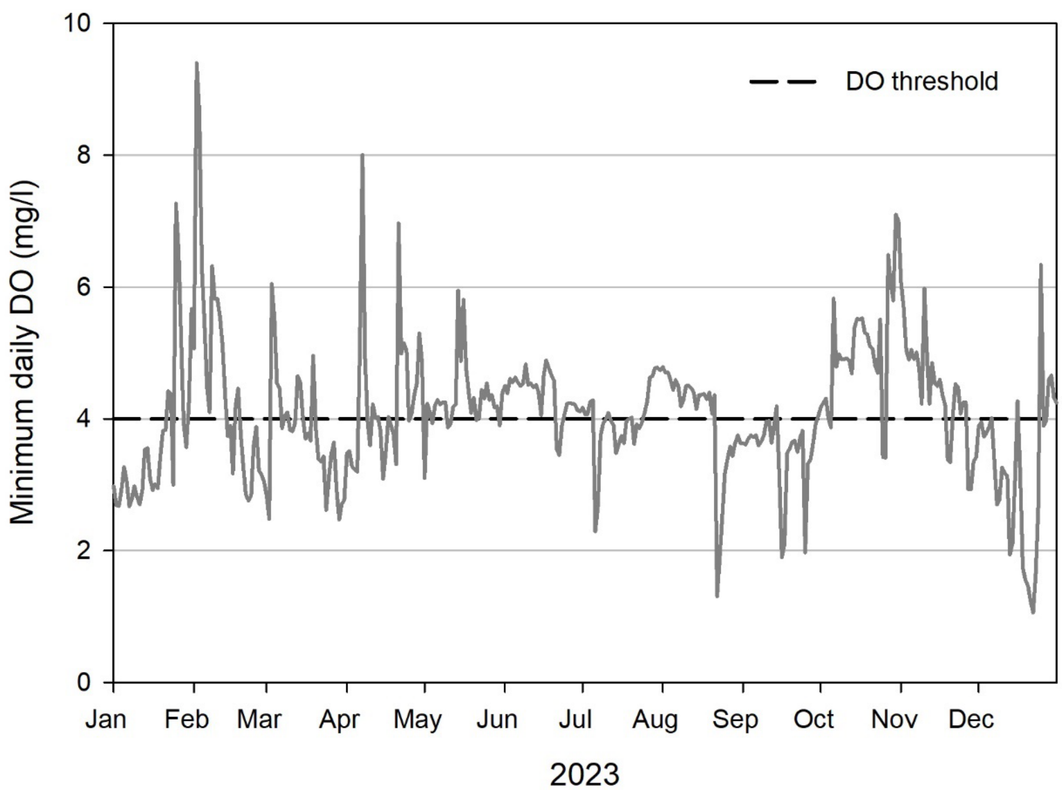


Figure 3.1-9. Minimum daily DO (mg/l) in Sessom Creek (2023).

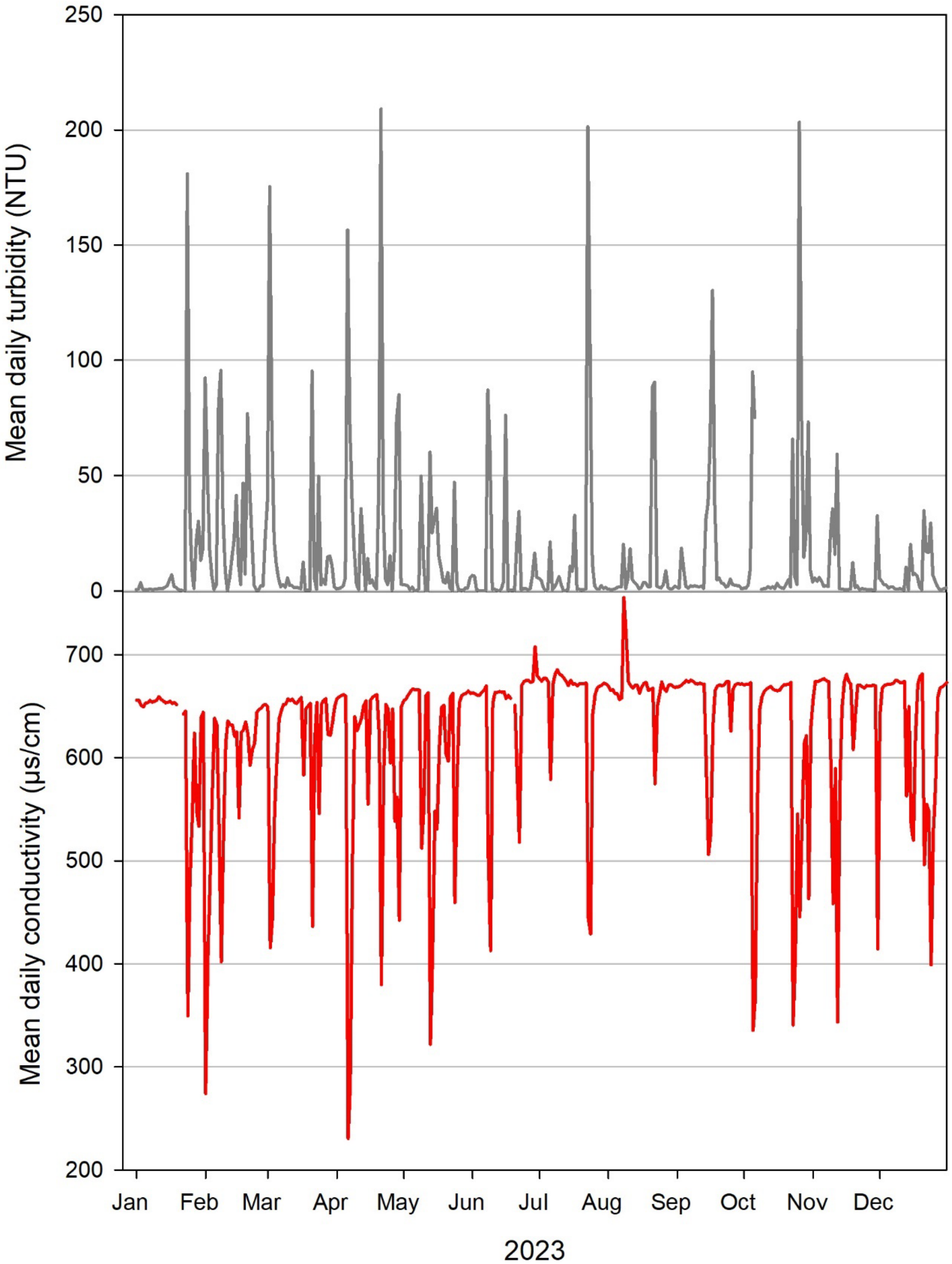


Figure 3.1-10. Mean daily turbidity (NTU) and mean daily conductivity (µs/cm) in Sessom Creek (2023).

### 3.1.2 Comal

*Hydrology*

Average springflow at Comal Springs for the period of record (i.e., 1927 – present) was 288 cfs. Since 2013, Comal springflow ranged from below average in 2013-2014 to above average from mid-2015-2017 (Figure 3.1-11). Extended low flow conditions occurred in 2014 and Comal springflow dropped down to as low as 65 cfs on August 29, 2014. In 2015, rainfall throughout the course of the year, particularly two large precipitation events in late May and October, resulted in above average springflow. The large flood pulse on October 30, 2015 had a peak discharge reaching 14,100 cfs. Springflows remained above average in 2016 through 2017 due to several moderate rain events. In 2018, springflow dropped below average, reaching 161 cfs in late August. However, multiple rain events in the early fall resulted in increased springflow and subsequent above average springflow rates. Springflow in 2019 was generally above 350 cfs until July when springflow decreased to average by mid-August but rose above 300 cfs before the end of the year. No substantial flow events occurred in 2019. The absence of large flow event continued into 2020 and springflows continued to decrease, dropping below the long-term average from May to December. Sprinflows continued to decline in early 2021 to just below 200 cfs in April, but rain events in late spring resulted in sprinflows increasing to above average. Additional rain events in fall (i.e., 5,030 cfs pulse in October) helped maintain near average springflows through December 2021. Springflows decreased and remained below average during 2022, dropping below 100 cfs in July and hitting 90 cfs in mid-August. Similar to the San Marcos system, no major run-off events occurred in 2022. In 2023, no large rain events led to springflows declining to levels not observed since 2014 with the lowest flow of 55 cfs recorded in August.

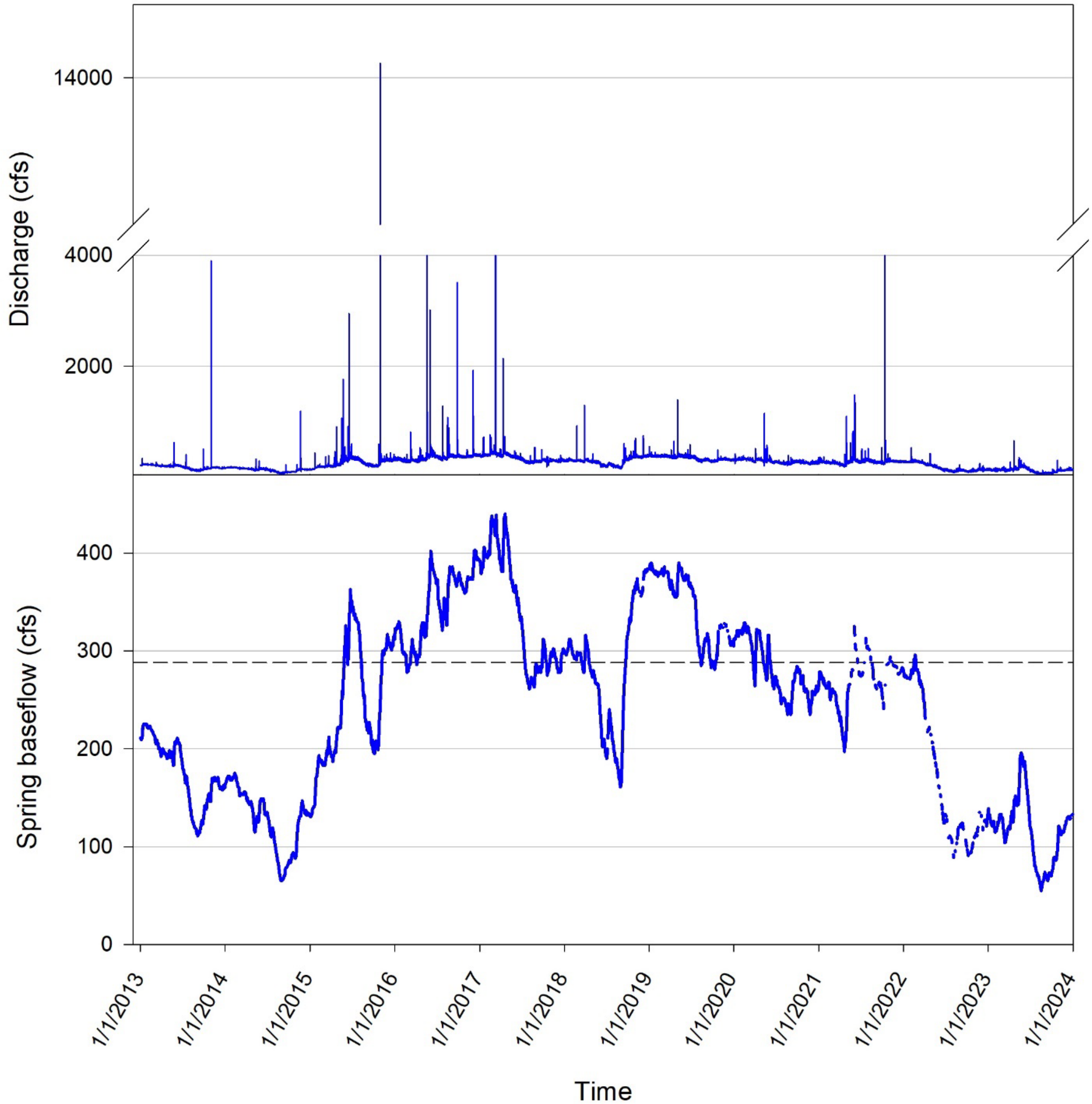


Figure 3.1-11. Hydrographs for th Comal River at New Braunfels (USGS station 08169000) and mean daily springflow for Comal springs (USGS Station 08168710) 2013 – 2023. Dashed line denotes long term average springflow (288 cfs) in the Comal River.

*Temperature*

Table 3.1-5 displays monthly summary statistics for water temperature at Comal RTWQ sites for 2023. In general, mean monthly water temperatures remained fairly stable within a site with deviations averaging ~1-2 °C and did not vary greatly among sites. Between Spring Run sites, water temperature at SR 7 continued to be slightly warmer than SR 3. With the lower springflows observed in 2023, higher maximum water temperatures were observed in the spring runs during the summer months. Outside the direct influx of spring runs, the Old Channel (OC) exhibited more variability in minimum and maximum monthly water temperatures. The highest water temperature recorded in 2023 was 27.03°C in the OC during August whereas the lowest temperature (20.69°C) occurred in the OC during February.

Table 3.1-5. Monthly mean, minimum, and maximum water temperatures (°C) among Comal RTWQ (2023).

| Month (2023) | Spring Run 3 | | | Spring Run 7 | | | Old Channel | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | Min | Max | Mean | Min | Max | Mean | Min | Max |
| **Jan** | 23.46 | 23.36 | 23.56 | 23.81 | 23.79 | 23.83 | 22.64 | 20.86 | 24.56 |
| **Feb** | 23.44 | 23.28 | 23.56 | 23.83 | 23.80 | 23.85 | 22.73 | 20.69 | 25.07 |
| **Mar** | 23.46 | 23.33 | 23.58 | 23.82 | 23.77 | 23.84 | 23.36 | 21.46 | 25.59 |
| **Apr** | 23.48 | 23.23 | 23.60 | 23.78 | 23.74 | 23.85 | 23.56 | 21.57 | 25.89 |
| **May** | 23.53 | 23.44 | 23.62 | 23.82 | 23.74 | 23.87 | 24.08 | 22.77 | 26.20 |
| **Jun** | 23.57 | 23.53 | 23.65 | 23.85 | 23.83 | 23.87 | 24.54 | 23.16 | 26.69 |
| **Jul** | 23.71 | 23.54 | 24.14 | 23.95 | 23.83 | 24.01 | 24.76 | 23.50 | 26.77 |
| **Aug** | 23.99 | 23.60 | 25.68 | 23.93 | 23.87 | 23.96 | 24.90 | 23.39 | 27.03 |
| **Sept** | 23.82 | 23.61 | 24.96 | 23.93 | 23.87 | 23.99 | 24.60 | 23.36 | 26.60 |
| **Oct** | 23.68 | 23.51 | 23.93 | 23.83 | 23.74 | 23.98 | 23.70 | 21.25 | 26.07 |
| **Nov** | 23.67 | 23.59 | 23.78 | 23.90 | 23.86 | 24.09 | 23.00 | 21.71 | 24.90 |
| **Dec** | 23.58 | 23.39 | 23.76 | 23.87 | 23.85 | 23.89 | 22.69 | 21.45 | 24.55 |

Box plots for maximum daily water temperatures observed at Comal RTWQ sites from time of sensor deployment (i.e., 2013 for SR 3, SR 7 and 2018 for OC) through 2023 compared to maximum daily water temperatures observed in 2023 are shown in Figure 3.1-12. The medians of maximum daily temperatures for 2023 were slightly higher than the medians of maximum daily temperatures from time of equipment deployment at Comal RTWQ sites.

Maximum daily temperatures were plotted for Comal system RTWQ sites for 2023 (Figure 3.1-13). Throughout 2023, maximum daily water temperatures were more variable at the OC river site. However, more variability in maximum daily water temperatures was observed this year in SR 3 during the summer months and is associated with the drop in springflows. Similar to previous years, maximum daily water temperatures in 2023 consistently reached and exceeded 25°C at the OC site. Maximum daily temperatures reached or exceeded 25°C at the OC site for 175 days during the months of February - October in 2023. Among those 175 days, time spent at or above 25°C ranged from 0.25 hrs – 11.25 hrs (mean = 7.05 hrs and median = 7.75 hrs). Spring Run 3 reached 25°C for six days in August ranging 0.5 hrs to 3.75 hrs in time of exceedance per day.

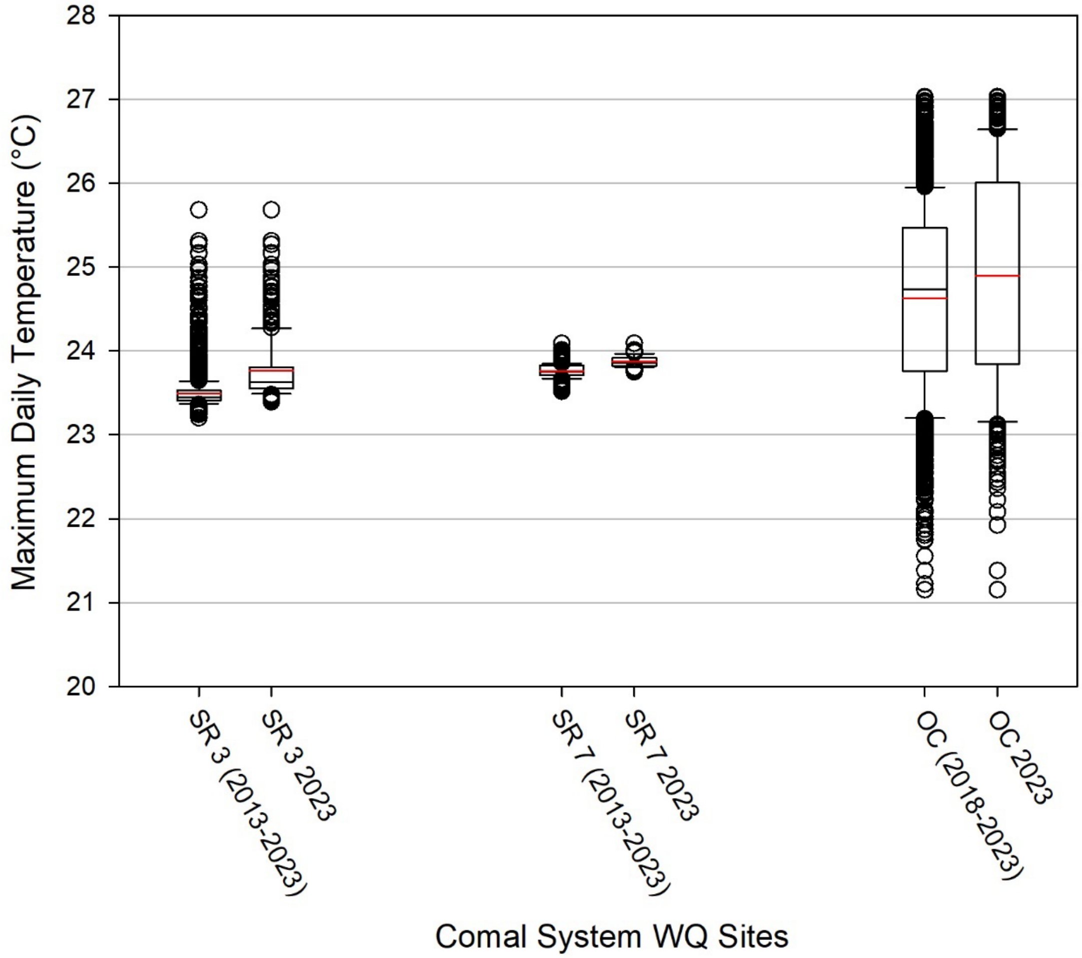


Figure 3.1-12. Box plots of maximum water daily temperatures (°C) among Comal system RTWQ sites from time of deployment through 2023 compared to 2023. Black lines represent median values and red lines denote mean values. Whiskers represent maximum and minimum temperature values, excluding outliers (open circles).

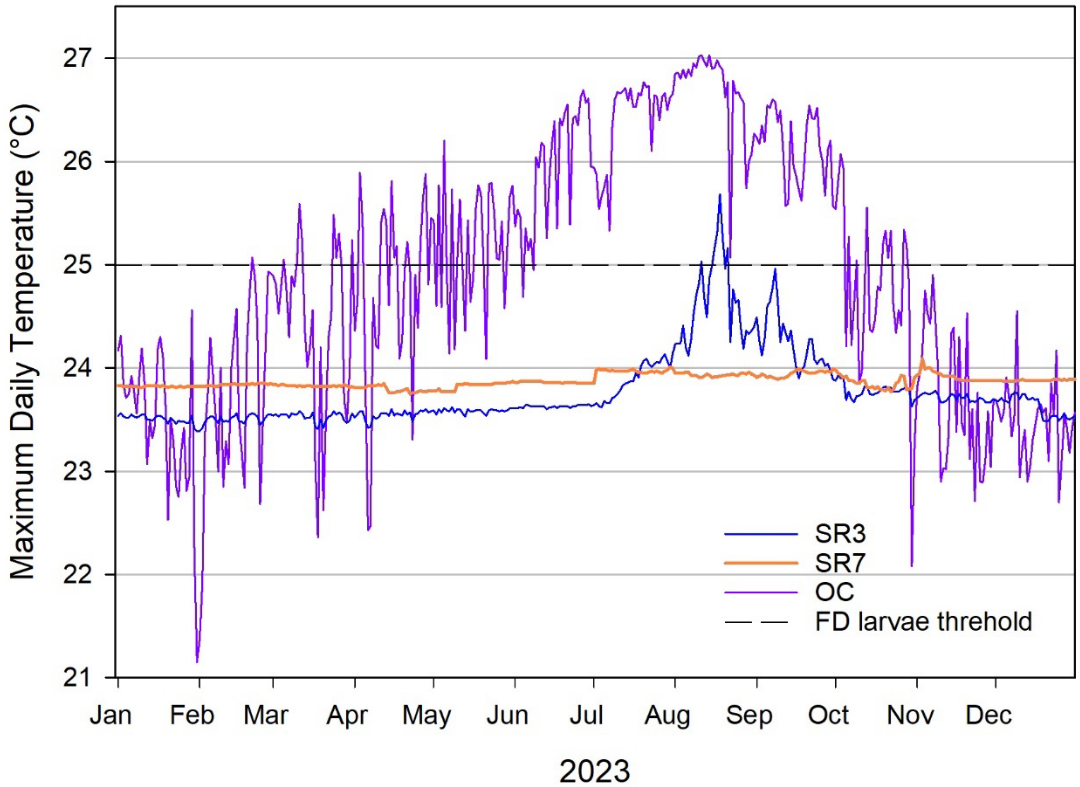


Figure 3.1-13. Maximum daily water temperature (°C) among Comal RTWQ sites (2023).

Box plots for seasonal maximum daily temperatures at the Comal system RTWQ sites for 2023 are shown in Figure 3.1-14. Little seasonal variation in maximum daily temperature (i.e., <0.05°C) was observed at SR 7 but more variability during summer and fall was observed at SR 3 than previous years. The OC river site exhibited a wider range in seasonal variation with median values differing ~3 °C. Spring and fall also showed variability in maximum daily temperature at the OC site while summer months showed less variability but recorded the highest maximum daily temperatures.

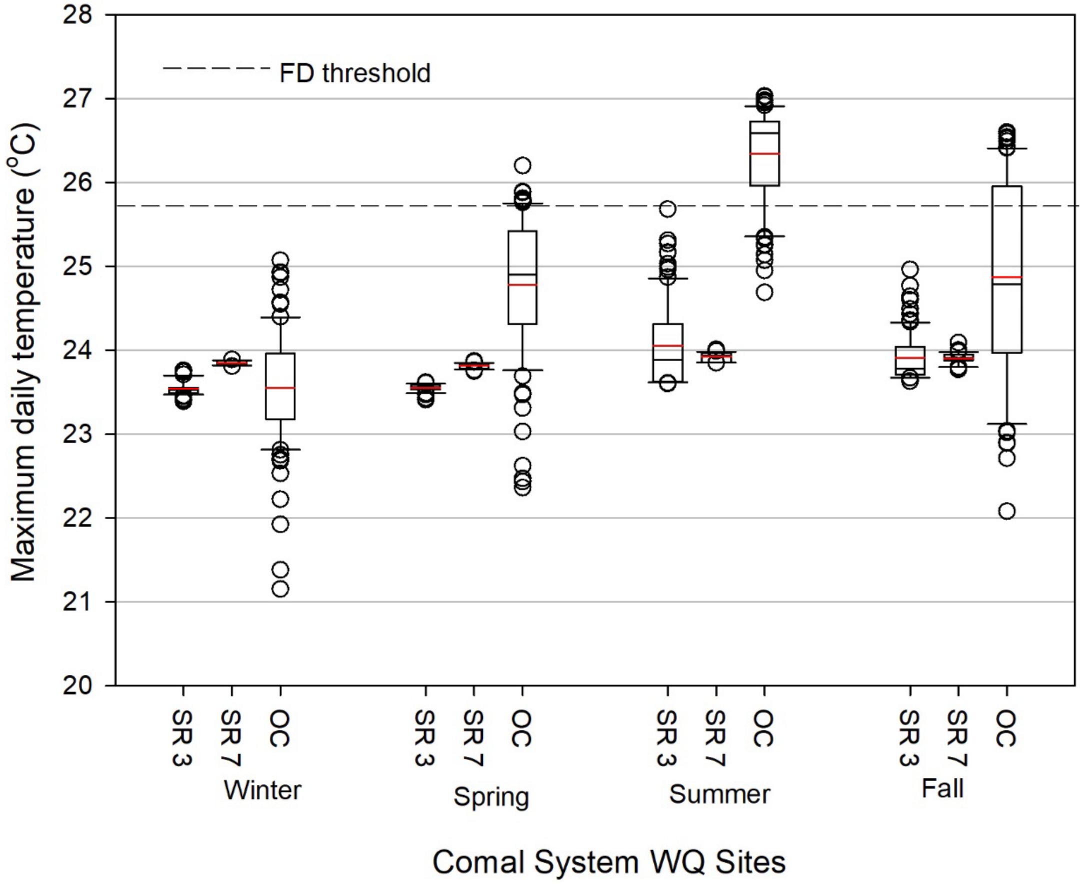


Figure 3.1-14. Box plots of maximum daily water temperatures (°C) among seasons at Comal system RTWQ sites in 2023. Black lines represent median values and red lines denotes mean values. Whiskers represent maximum and minimum temperature values, excluding outliers (open circles).

*Dissolved Oxygen*

Table 3.1-6 displays monthly summary statistics for dissolved oxygen (DO) recorded for Comal RTWQ sites in 2023. Mean monthly dissolved oxygen remained consistent within a site with variations averaging ~ 1 mg/l. Similar to previous years, mean monthly DO was lower in the spring run sites than the OC river site. The highest DO recorded in 2023 was 11.20 mg/l in the OC during May and the lowest DO (4.64 mg/l) occurred at SR 3 in August.

Table 3.1-6. Monthly mean, minimum, and maximum DO (mg/l) among Comal system RTWQ sites (2023).

| Month (2023) | Spring Run 3 | | | Spring Run 7 | | | Old Channel | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | Min | Max | Mean | Min | Max | Mean | Min | Max |
| **Jan** | 5.16 | 5.03 | 5.41 | 5.08 | 5.06 | 5.09 | 7.50 | 5.89 | 10.08 |
| **Feb** | 5.15 | 5.02 | 5.39 | 5.06 | 5.05 | 5.08 | 7.76 | 5.86 | 10.76 |
| **Mar** | 5.13 | 4.98 | 5.44 | 5.06 | 5.01 | 5.07 | 7.46 | 5.65 | 10.88 |
| **Apr** | 5.09 | 4.98 | 5.34 | 5.03 | 4.95 | 5.07 | 7.52 | 5.70 | 11.12 |
| **May** | 5.11 | 5.01 | 5.32 | 5.04 | 4.90 | 5.12 | 7.12 | 5.56 | 11.20 |
| **Jun** | 5.21 | 5.09 | 5.54 | 5.08 | 5.06 | 5.09 | 7.06 | 5.51 | 9.51 |
| **Jul** | 5.41 | 5.22 | 6.25 | 5.09 | 4.95 | 5.35 | 6.98 | 5.29 | 9.30 |
| **Aug** | 5.63 | 4.64 | 7.21 | 5.07 | 4.95 | 5.29 | 7.00 | 5.17 | 9.53 |
| **Sept** | 5.63 | 5.07 | 7.06 | 5.08 | 5.04 | 5.11 | 6.81 | 5.21 | 9.28 |
| **Oct** | 5.33 | 5.13 | 6.02 | 5.04 | 4.96 | 5.09 | 6.89 | 5.53 | 8.94 |
| **Nov** | 5.23 | 5.00 | 5.47 | 5.05 | 4.98 | 5.07 | 7.12 | 6.06 | 9.05 |
| **Dec** | 5.30 | 5.10 | 5.51 | 5.05 | 5.04 | 5.07 | 7.21 | 6.09 | 9.18 |

Box plots for minimum daily DO observed at Comal system RTWQ sites from time of equipment deployment (i.e., 2013 for SR3, SR7 and 2018 for OC) through 2023 compared to minimum daily DO observed in 2023 are shown in Figure 3.1-15. The medians of minimum daily DO for 2023 were generally consistent with medians of minimum daily DO since time of sensor deployment at Comal system RTWQ sites. However, the median minimum daily DO in Spring Run 3 for 2023 was slightly lower than minimum daily DO observed since 2013, and the median minimum daily DO in Spring Run 7 was slightly higher.

Minimum daily DO was plotted for Comal RTWQ sites in 2023. (Figure 3.1-16). Spring run 3, and SR 7 demonstrated relatively constant DO whereas the OC river site was more variable in DO with seasonally drops in minimum daily DO during the summer months. Although greater in variability, the OC maintained higher minimum daily DO compared to the spring run sites and no sites recorded a minimum daily DO below 4.0 mg/l in 2023.

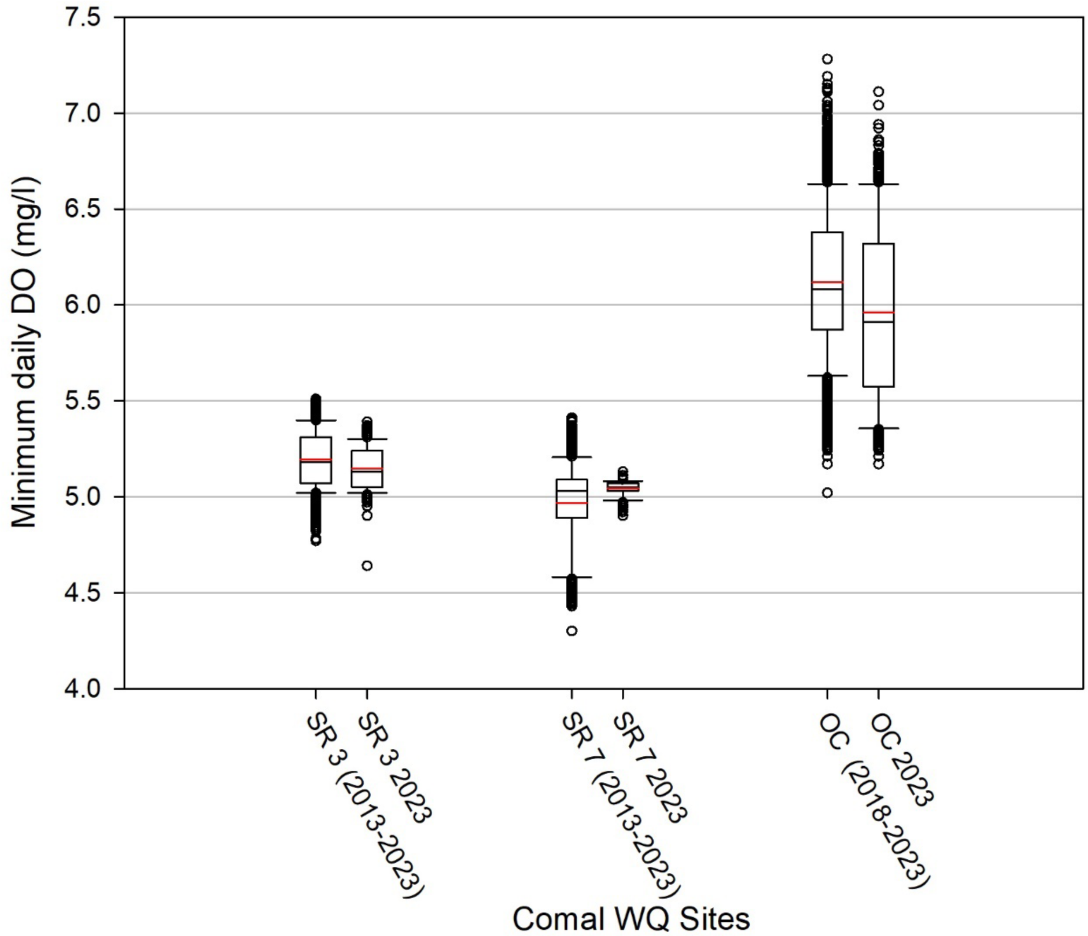


Figure 3.1-15. Box plots of minimum daily DO (mg/l) among Comal system RTWQ sites from time of equipment deployment through 2023 compared to 2023. Black lines represent median values and red lines denotes mean values. Whiskers represent maximum and minimum DO values, excluding outliers (open circles).

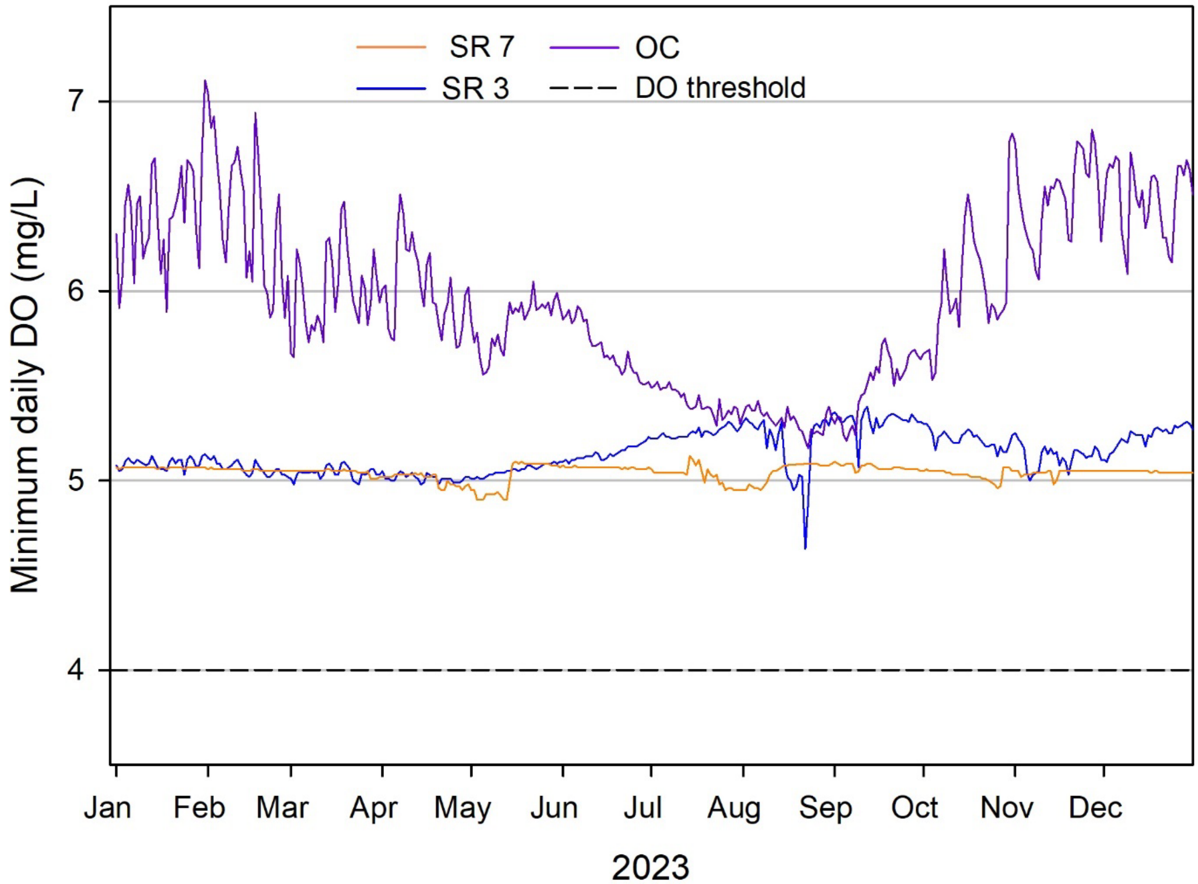


Figure 3.1-16. Minimum daily DO (mg/l) among Comal RTWQ sites (2023).

*Conductivity*

Table 3.1-7 displays monthly summary statistics for conductivity (µs/cm) recorded at Comal system RTWQ sites during 2023. Mean monthly conductivity remained consistent at the three WQ sites throughout the year with little variability between sites. In general, mean conductivity ranged between 565-590 µs/cm among all Comal system RTWQ sites. The lowest conductivity in 2023 was recorded in the OC in March (291 µs/cm) during a run-off event (Figure 3.1-17).

Comal River discharge (cfs) and mean daily conductivity were plotted for Comal system RTWQ sites for 2023 (Figure 3.1-17). Little variation in mean daily conductivity for spring run sites occurred in 2023. However, mean daily conductivity in the OC was influenced by rain events with drops in conductivity values corresponding with influxes of run-off. Since the Comal discharge gage location is located downstream from the confluence of the Old and New Channel of the Comal, some rain events in the system do not result in conductivity drops in the Old Channel. Additionally, the Comal River has slightly lower conductivity than the San Marcos River.

Table 3.1-7. Monthly mean, minimum, and maximum conductivity (µs/cm) among Comal system RTWQ sites (2023).

| Month (2023) | Spring Run 3 | | | Spring Run 7 | | | Old Channel | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | Min | Max | Mean | Min | Max | Mean | Min | Max |
| **Jan** | 596 | 590 | 599 | 569 | 567 | 571 | 567 | 555 | 573 |
| **Feb** | 595 | 590 | 597 | 571 | 569 | 572 | 562 | 520 | 592 |
| **Mar** | 593 | 587 | 596 | 571 | 550 | 573 | 552 | 291 | 581 |
| **Apr** | 590 | 526 | 592 | 566 | 551 | 572 | 565 | 474 | 625 |
| **May** | 588 | 570 | 590 | 568 | 560 | 572 | 558 | 456 | 602 |
| **Jun** | 585 | 575 | 590 | 569 | 562 | 571 | 576 | 505 | 603 |
| **Jul** | 585 | 571 | 590 | 568 | 565 | 575 | 576 | 527 | 584 |
| **Aug** | 584 | 570 | 590 | 572 | 560 | 578 | 575 | 516 | 583 |
| **Sept** | 584 | 570 | 590 | 576 | 564 | 580 | 579 | 568 | 585 |
| **Oct** | 584 | 570 | 590 | 575 | 565 | 578 | 579 | 552 | 589 |
| **Nov** | 583 | 570 | 590 | 577 | 561 | 580 | 577 | 568 | 581 |
| **Dec** | 584 | 570 | 590 | 575 | 563 | 580 | 574 | 561 | 579 |

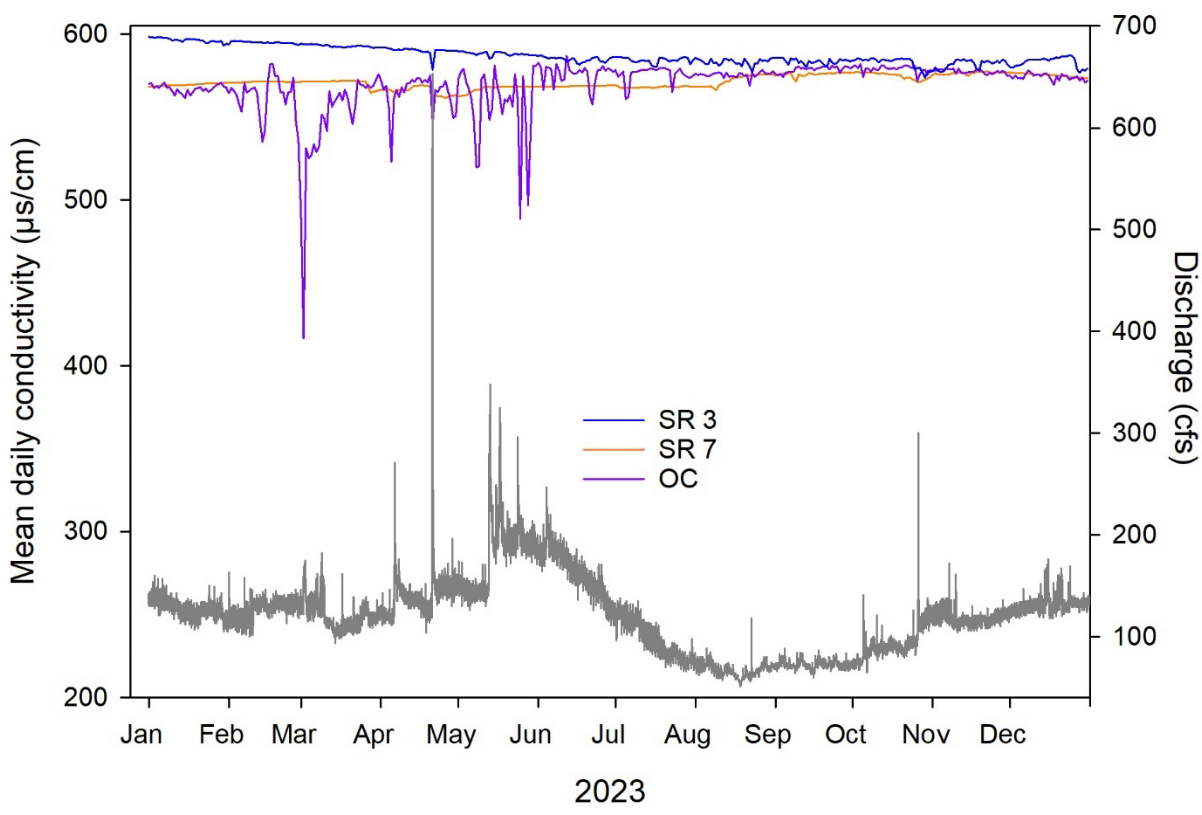


Figure 3.1-17. Mean daily conductivity (µs/cm) among Comal system RTWQ sites and Comal River discharge (Gage#08169000) in 2023.

## 3.2 Surface water sampling

### 3.2.1 San Marcos

Table 3.2-1 denotes the water quality parameters collected at Hotel Spring during monthly sucralose collections. Water quality parameters measured during monthly sampling events were consistent with measurements collected by the RTWQ network station at Aquarena Springs.

Table 3.2-1. Monthly (2023) water quality parameters measured at Hotel Spring (Spring Lake, San Marcos).

| Month | Conductivity (µs/cm) | DO (mg/l) | pH (SU) | Temperature (°C) |
|---|---|---|---|---|
| **Jan** | 610 | 4.58 | 7.04 | 22.09 |
| **Feb** | NA | 4.50 | 7.04 | 22.01 |
| **Mar** | 623 | 4.53 | 6.93 | 22.16 |
| **Apr** | 630 | 4.58 | 7.03 | 22.02 |
| **May** | 620 | 4.53 | 6.99 | 21.95 |
| **Jun** | 662 | 4.56 | 7.03 | 21.88 |
| **Jul** | 636 | 4.33 | 7.33 | 21.96 |
| **Aug** | 648 | 4.67 | 7.15 | 22.01 |
| **Sep** | 652 | 4.71 | 7.10 | 22.07 |
| **Oct** | 651 | 4.78 | 7.11 | 22.06 |
| **Nov** | 631 | 4.47 | 7.05 | 22.06 |
| **Dec** | 633 | 4.51 | 7.03 | 22.10 |

A total of 12 sucralose samples were collected during monthly collections at Hotel Spring in 2023, including one field duplicate and two DI (i.e., deionized water) blanks. Sucralose was detected in all months sampled (still waiting on results from Nov and Dec);. at Hotel Spring in 2023 (Table 3.2-2). Detected sucralose concentrations ranged from 12.8-21.7 ng/L. Quality control spike recoveries for all sampling events were between 62.8 – 105 %. A full table including duplicate samples, field and laboratory blanks can be found in Table A-1 in appendix A.

Table 3.2-2. Sucralose concentrations (ng/L) measured at Hotel Springs in Spring Lake (2023). Samples with detectable concentrations denoted in bold.

| Month | Sample (ng/L) |
|---|---|
| January | **21.7**[B] |
| February | **19.7** |
| March | **19.3**[A] |
| April | **18.6** |
| May | **19.6** |
| June | **16.8** |
| July | **13.6** |
| August | **14.8** |
| September | **12.8**[A] |
| October | **13.2** |
| November | NA |
| December | NA |

[U] Non-detect at reporting limit

[A] Not detected in DI blank

[B] Detected in duplicate sampling

During Spring and Fall sampling events, nutrient samples and one duplicate sample per site per season (i.e., upper in Spring and lower in Fall) were taken. Nutrient concentrations measured at the upper and lower sites (i.e., Hotel Springs and near the TPWD hatchery) in the San Marcos system during Spring and Fall are denoted in Table 3.2-3. Dissolved organic carbon, dissolved inorganic carbon and nitrate as N were reported among each site and sampling event in 2023. Other nutrients detected were total organic carbon at both sites in Spring. Kjeldahl nitrogen was detected during the Fall but was also detected in the equipment or DI blank. Ammonia was detected at the lower site during the Fall. Additional results for duplicate samples, percent difference between sample and duplicate samples, and field and laboratory blank values can be found in Table A-3 and A-4 in appendix A.

Table 3.2-3. Nutrient concentrations (mg/L) measured at the upper and lower sites in the San Marcos system during Spring and Fall (2023). Samples with detectable concentrations denoted in bold.

| | Spring | | Fall | |
|---|---|---|---|---|
| **Nutrients** | **Upper** | **Lower** | **Upper** | **Lower** |
| Total Phosphorus | 0.01[UA] | 0.01[U] | **0.93[C]** | **0.04[BCD]** |
| Orthophosphate as P | **0.01[JHBD]** | 0.004[UH] | 0.006[U] | 0.03[UA] |
| Total Organic Carbon | **1.0[BD]** | **0.89[J]** | 0.5[U] | 0.5[UA] |
| Dissolved Inorganic Carbon | **64.6[BC]** | **62.7[C]** | **64.9[F1C]** | **64.2[BC]** |
| Dissolved Organic Carbon | **1.1[BCD]** | **1.01[C]** | **1.59[C]** | **1.55[BC]** |
| Kjeldahl Nitrogen | 0.09[UAC] | 0.09[UC] | **0.86[C]** | **0.44[BCD]** |
| Nitrate as N | **1.26[HBC]** | **1.35[HC]** | **1.48[C]** | **1.53[BC]** |
| Ammonia | 0.035[UAC] | 0.035[UC] | 0.05[U] | **0.08[JF1BD]** |

[U] Non-detect

[H] Sample was prepped and analyzed past holding time

[F1] MS and/or MSD recovery exceeds control limits

[J] Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.

[A] Not detected in duplicate sample

[B] Detected in duplicate sample

[C] Detected in laboratory or field blank

[D] Greater than 20% Relative Percent Difference between sample and duplicate

## 3.2.2 Comal

Table 3.2-4 denotes the water quality parameters collected at Spring Run 3 in Landa Lake during monthly sucralose collections in 2023. Water quality parameters measured during monthly sampling events were consistent with measurements collected by the RTWQ network station in Spring Run 3.

Table 3.2-4. Monthly (2023) water quality parameters measured at Spring Run 3 (Landa Lake).

| Month | Conductivity (µs/cm) | DO (mg/l) | pH (SU) | Temperature (°C) |
|---|---|---|---|---|
| **Jan** | 579 | 5.24 | 7.07 | 23.42 |
| **Feb** | NA | 5.17 | 7.05 | 23.36 |
| **Mar** | 584 | 5.22 | 6.95 | 23.35 |
| **Apr** | 586 | 5.15 | 7.07 | 23.31 |
| **May** | 578 | NA | 7.10 | 23.33 |
| **Jun** | 612 | 5.17 | 7.05 | 23.35 |
| **Jul** | 586 | 4.90 | 7.24 | 23.31 |
| **Aug** | 592 | 5.76 | 7.30 | 23.70 |
| **Sep** | 595 | 5.72 | 7.22 | 23.69 |
| **Oct** | 596 | 5.28 | 7.20 | 23.59 |
| **Nov** | 577 | 4.97 | 7.10 | 23.63 |
| **Dec** | 577 | 4.97 | 6.98 | 23.64 |

A total of 12 sucralose samples were collected during monthly collections at Spring Run 3 in 2023, including one field duplicate samples and one DI blanks. Among monthly collections, sucralose was detected during one sampling events at Spring Run 3 with a concentration of 9.65 ng/L recorded in April (Table 3.2-5). Quality control spike recoveries for all sampling events were between 66.0 – 107.0 %. A full table including duplicate samples, field and laboratory blanks can be found in Table A-2 appendix A.

Table 3.2-5. Sucralose concentrations (ng/L) measured at Spring Run 3 in Landa Lake (2023). Samples with detectable concentrations denoted in bold.

| Month | Sample (ng/L) |
|---|---|
| January | 8.19[U] |
| February | 9.11[U] |
| March | 7.84[U] |
| April | **9.65** |
| May | 7.93[U] |
| June | 8.92[UA] |
| July | 8.74[UB] |
| August | 8.64[U] |
| September | 9.06[U] |
| October | 8.31[U] |
| November | NA |
| December | NA |

[U] Non-detect at reporting limit

[A] Non detected in DI blank

[B] Detected in duplicate sample

[C] Non-detect in duplicate sample

During Spring and Fall sampling events, nutrient samples and one duplicate sample for each season (i.e., upper in Spring and lower in Fall) were taken. Nutrient concentrations measured at the upper and lower sites (i.e., Spring Run 3 and at the last public exit) in the Comal system during Spring and Fall are denoted in Table 3.2-6. No detections for total phosphorous and orthophosphate as P were reported in 2023. Among nutrients detected, dissolved inorganic carbon, dissolved organic carbon and nitrate as N were reported at both sites for the two sampling events in 2023. Total organic carbon was detected at both sites during the Spring and nitrogen was detected at the upper site in the Spring an both sites during the Fall. Ammonia was detected at both sites in the Fall. Dissolved inorganic carbon, dissolved organic carbon, nitrogen, and nitrate as N were detected in the laboratory or field blank that suggests a false positive. Results for duplicate samples, percent difference between sample and duplicate samples, and field and laboratory blank values can be found in Table A-5 and A-6 in appendix A.

Table 3.2-6. Nutrient concentrations (mg/L) measured at the upper and lower sites in the Comal system during Spring and Fall (2023). Samples with detectable concentrations denoted in bold.

| | Spring | | Fall | |
|---|---|---|---|---|
| **Nutrients** | **Upper** | **Lower** | **Upper** | **Lower** |
| Total Phosphorus | 0.01[UA] | 0.01[U] | 0.009[UF1C] | 0.009[UAC] |
| Orthophosphate as P | 0.004[UHA] | 0.004[UH] | 0.03[U] | 0.006[UA] |
| Total Organic Carbon | **0.85**[JB] | **0.82**[J] | 0.5[U] | 0.5[UF1BD] |
| Dissolved Inorganic Carbon | **58.0**[BC] | **57.6**[C] | **58.8**[C] | **58.2**[BC] |
| Dissolved Organic Carbon | **0.91**[JBC] | **0.79**[JC] | **1.63**[C] | **1.46**[BCD] |
| Kjeldahl Nitrogen | 0.09[UBCD] | **0.19**[JC] | **0.54**[C] | **0.57**[BCD] |
| Nitrate as N | **1.83**[HBC] | **1.83**[HC] | **1.88**[C] | **1.72**[BC] |
| Ammonia | 0.035[UAC] | 0.035[UF1C] | **0.053**[J] | **0.06**[JB] |

[U] Non-detect

[H] Sample was prepped and analyzed past holding time

[F1] MS and/or MSD recovery exceeds control limits

[J] Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.

[A] Not detected in duplicate sample

[B] Detected in duplicate sample

[C] Detected in laboratory or field blank

[D] Greater than 20% Relative Percent Difference between sample and duplicate

## 3.3 Groundwater sampling

### 3.3.1 San Marcos

A total of eight PPCP samples (i.e., one sample at each sampling site and event) were collected during 2023, including two blanks (i.e., one equipment blank in Spring at Hotel and one DI blank at Deep Hole in Fall) and one field duplicate taken at Hotel in Fall. Samples were taken at Hotel in the months of January, April, June, July, October, and December. Deep Hole was only sampled in April and October. Results for PPCP sampling during the regular Spring (April) and Fall sampling (October) events are denoted in Table 3.3-1 and 3.3-2. Results for PPCP sampling at Hotel for January, June, July, and December are denoted in Table 3.3-3 and Table 3.3-4. Overall, few PPCP detections at the reporting limit occurred in 2023 sampling events. DEET was detected at each sampling event for Hotel and Deep Hole; however, it is likely a false positive because they were flagged as "b" indicating that a concentration was also detected in the lab blank in all sampling events. Penicillin G was detected at both sites in Spring, at Hotel in July, and at Deep Hole in Fall, but like DEET, it was detected in the lab blank. Penicillin V was detected at Deep Hole in Fall but was also detected in the blank. Cocaine was detected at Hotel in Spring and July and detected at Deep Hole in the Fall. Other PPCP detections at Hotel included Caffeine in January and July, and Theophylline in January. Results for samples and the equipment, DI, and laboratory blank values can be found in Table A-7 through A-10 in appendix A.

Table 3.3-1. PPCP concentrations (ng/L) measured at Hotel and Deep Hole Spring (Spring Lake, San Marcos) during Spring and Fall sampling events (2023). Samples with detectable concentrations denoted in bold.

| PPCP List | Spring | | | | Fall | | | |
|---|---|---|---|---|---|---|---|---|
| | Hotel spring | | Deep Hole | | Hotel spring | | Deep Hole | |
| Acetaminophen | 3.08 | U | 3.15 | U | 3.02 | U | 3.06 | U |
| Azithromycin | 1.54 | U | 1.58 | U | 1.51 | U | 1.53 | U |
| Caffeine | 6.17 | U | 6.3 | U | 6.04 | UB | 6.11 | UB |
| Carbadox | 0.617 | U | 0.63 | U | 0.604 | U | 0.611 | U |
| Carbamazepine | 0.308 | U | 0.315 | U | 0.302 | U | 0.306 | U |
| Cefotaxime | 6.1 | U | 6.24 | U | 5.98 | U | 6.05 | U |
| Ciprofloxacin | 1.54 | U | 1.58 | U | 1.51 | U | 1.53 | U |
| Clarithromycin | 0.308 | U | 0.315 | U | 0.302 | U | 0.306 | U |
| Clinafloxacin | 2.05 | U | 2.1 | U | 2.01 | U | 2.04 | U |
| Cloxacillin | 3.08 | U H | 3.15 | U H | 3.02 | UBH | 3.06 | UBH |
| Dehydronifedipine | 0.308 | U | 0.315 | U | 0.302 | U | 0.306 | U |
| Digoxigenin | 1.54 | U | 1.58 | U | 1.51 | U | 1.53 | U |
| Digoxin | 6.17 | U | 6.3 | U | 6.04 | U | 6.11 | U |
| Diltiazem | 0.154 | U | 0.158 | U | 0.151 | U | 0.153 | U |
| Diphenhydramine | 0.617 | U | 0.63 | U | 0.604 | U | 0.611 | U |
| Enrofloxacin | 0.617 | U | 0.63 | U | 0.604 | U | 0.611 | U |
| Erythromycin-H2O | 1.54 | U H | 1.58 | U H | 1.51 | U H | 1.53 | U H |
| Flumequine | 0.308 | U | 0.315 | U | 0.302 | U | 0.306 | U |
| Fluoxetine | 0.154 | U | 0.158 | U | 0.151 | U | 0.153 | U |
| Lincomycin | 0.617 | U | 0.63 | U | 0.604 | U | 0.611 | U |
| Lomefloxacin | 0.617 | U | 0.63 | U | 0.604 | U | 0.611 | U |
| Miconazole | 0.308 | U | 0.315 | U | 0.302 | U | 0.306 | U |
| Norfloxacin | 2.05 | U | 2.1 | U | 2.01 | U | 2.04 | U |
| Norgestimate | 1.54 | U | 1.58 | U | 1.51 | U | 1.53 | U |
| Ofloxacin | 0.617 | U | 0.63 | U | 0.604 | U | 0.611 | U |
| Ormetoprim | 0.154 | U | 0.158 | U | 0.151 | U | 0.153 | U |
| Oxacillin | 1.54 | U H | 1.58 | U H | 1.51 | U H | 1.53 | U H |
| Oxolinic Acid | 0.617 | U | 0.63 | U | 0.604 | U | 0.611 | U |
| Penicillin G | **3.86** | RBH | **11.9** | RBH | 3.02 | UBCH | **20.4** | RBH |
| Penicillin V | 1.54 | U | 1.58 | U | 1.51 | UB | **17.3** | RB |
| Roxithromycin | 0.154 | U | 0.158 | U | 0.151 | U | 0.153 | U |
| Sarafloxacin | 3.08 | U | 3.15 | U | 3.02 | U | 3.06 | U |
| Sulfachloropyridazine | 0.617 | U | 0.63 | U | 0.604 | U | 0.611 | U |
| Sulfadiazine | 0.617 | U | 0.63 | U | 0.604 | U | 0.611 | U |
| Sulfadimethoxine | 0.308 | U | 0.315 | U | 0.302 | U | 0.306 | U |
| Sulfamerazine | 0.617 | U | 0.63 | U | 0.604 | U | 0.611 | U |
| Sulfamethazine | 0.617 | U | 0.63 | U | 0.604 | U | 0.611 | U |
| Sulfamethizole | 0.617 | U | 0.63 | U | 0.604 | U | 0.611 | U |
| Sulfamethoxazole | 0.617 | U | 0.63 | U | 0.604 | U | 0.611 | U |
| Sulfanilamide | 6.17 | U | 6.3 | U | 6.04 | U | 6.11 | U |
| Sulfathiazole | 1.54 | U | 1.58 | U | 1.51 | U | 1.53 | U |
| Thiabendazole | 0.308 | U | 0.315 | U | 0.302 | U | 0.306 | U |
| Trimethoprim | 0.308 | U | 0.315 | U | 0.302 | U | 0.306 | U |
| Tylosin | 0.617 | U | 0.63 | U | 0.604 | U | 0.611 | U |
| Virginiamycin M1 | 0.617 | U | 0.663 | U | 0.604 | U | 0.798 | U |
| 1,7-Dimethylxanthine | 6.17 | U | 6.3 | U | 6.04 | U | 6.11 | U |

[U] Non-detect at reporting limit
[H] Concentration is estimated
[R] Peak detected but did not meet quantification criteria, result reported is estimated maximum possible concentration
[B] Analyte found in associated blank
[C] Detected in duplicate sample

Table 3.3-2. PPCP concentrations (ng/L) measured at Hotel and Deep Hole Spring (Spring Lake, San Marcos) during Spring and Fall sampling events (2023). Samples with detectable concentrations denoted in bold.

| PPCP List | Spring | | | | Fall | | | |
|---|---|---|---|---|---|---|---|---|
| | Hotel spring | | Deep Hole | | Hotel spring | | Deep Hole | |
| Alprazolam | 0.308 | U | 0.315 | U | 0.302 | U | 0.306 | U |
| Amitriptyline | 0.308 | U | 0.315 | U | 0.302 | U | 0.306 | U |
| Amlodipine | 1.03 | U | 1.06 | U | 1.01 | U | 1.03 | U |
| Benzoylecgonine | 0.154 | U | 0.158 | U | 0.151 | U | 0.153 | U |
| Benztropine | 0.719 | U | 0.735 | U | 0.705 | U | 0.713 | U |
| Betamethasone | 1.54 | U | 1.58 | U | 1.51 | U | 1.53 | U |
| Cocaine | **0.164** | | 0.158 | U | 0.151 | UC | **0.569** | |
| DEET | **5.19** | B | **9.44** | B | **9.00** | BC | **7.36** | B |
| Desmethyldiltiazem | 0.154 | U | 0.158 | U | 0.151 | U | 0.153 | U |
| Diazepam | 0.516 | U | 0.527 | U | 0.506 | U | 0.512 | U |
| Fluocinonide | 2.07 | U | 2.11 | U | 2.02 | U | 2.05 | U |
| Fluticasone propionate | 2.07 | U | 2.11 | U | 2.02 | U | 2.05 | U |
| Hydrocortisone | 6.17 | U | 6.3 | U | 6.04 | U | 6.11 | U |
| 10-hydroxy-amitriptyline | 0.154 | U | 0.158 | U | 0.151 | U | 0.153 | U |
| Meprobamate | 1.54 | U | 1.58 | U | 1.51 | U | 1.53 | U |
| Methylprednisolone | 4.11 | U | 4.2 | U | 4.03 | U | 4.08 | U |
| Metoprolol | 0.516 | U | 0.527 | U | 0.506 | U | 0.512 | U |
| Norfluoxetine | 0.516 | U | 0.527 | U | 0.506 | U | 0.512 | U |
| Norverapamil | 0.154 | U | 0.158 | U | 0.151 | U | 0.153 | U |
| Paroxetine | 1.03 | U | 1.06 | U | 1.01 | U | 1.03 | U |
| Prednisolone | 4.11 | U | 4.2 | U | 4.03 | U | 4.08 | U |
| Prednisone | 6.17 | U | 6.3 | U | 6.04 | U | 6.11 | U |
| Promethazine | 0.308 | U | 0.315 | U | 0.302 | U | 0.306 | U |
| Propoxyphene | 0.308 | U | 0.315 | U | 0.302 | U | 0.306 | U |
| Propranolol | 0.308 | U | 0.315 | U | 0.302 | U | 0.306 | U |
| Sertraline | 0.308 | U | 0.315 | U | 0.302 | U | 0.306 | U |
| Simvastatin | 2.07 | U | 2.11 | U | 2.02 | U | 2.05 | U |
| Theophylline | 6.17 | U | 6.3 | U | 6.04 | U | 6.11 | U |
| Trenbolone | 2.07 | U | 2.11 | U | 2.02 | U | 2.05 | U |
| Trenbolone acetate | 0.308 | U | 0.315 | U | 0.302 | U | 0.306 | U |
| Valsartan | 4.11 | U | 4.2 | U | 4.03 | U | 4.08 | U |
| Verapamil | 0.154 | U | 0.158 | U | 0.151 | U | 0.153 | U |

[U] Non-detect at reporting limit
[H] Concentration is estimated
[B] Analyte found in associated blank
[C] Detected in duplicate sample

Table 3.3-3. PPCP concentrations (ng/L) measured at Hotel (Spring Lake, San Marcos) during January, June, and July sampling events (2023). Samples with detectable concentrations denoted in bold.

| PPCP List | January | | June | | July | |
|---|---|---|---|---|---|---|
| Acetaminophen | 3.13 | U | 3.41 | U | 3.38 | U |
| Azithromycin | 1.56 | U | 1.71 | U | 1.69 | U |
| Caffeine | **29** | | 6.82 | U | **7.54** | |
| Carbadox | 0.625 | U | 0.682 | U | 0.677 | U |
| Carbamazepine | 0.313 | U | 0.341 | U | 0.338 | U |
| Cefotaxime | 6.19 | U | 6.75 | U | 6.7 | U |
| Ciprofloxacin | 1.56 | U | 1.71 | U | 1.69 | U |
| Clarithromycin | 0.313 | U | 0.341 | U | 0.338 | U |
| Clinafloxacin | 2.08 | U | 2.27 | U | 2.25 | U |
| Cloxacillin | 3.13 | U H | 3.41 | U H | 3.38 | U H |
| Dehydronifedipine | 0.313 | U | 0.341 | U | 0.338 | U |
| Digoxigenin | 1.56 | U | 1.71 | U | 1.69 | U |
| Digoxin | 6.25 | U | 6.82 | U | 6.77 | U |
| Diltiazem | 0.156 | U | 0.171 | U | 0.169 | U |
| Diphenhydramine | 0.625 | U | 0.682 | U | 0.677 | U |
| Enrofloxacin | 0.625 | U | 0.682 | U | 0.677 | U |
| Erythromycin-H2O | 1.56 | U H | 1.71 | U H | 1.69 | U H |
| Flumequine | 0.313 | U | 0.341 | U | 0.338 | U |
| Fluoxetine | 0.156 | U | 0.171 | U | 0.169 | U |
| Lincomycin | 0.625 | U | 0.682 | U | 0.677 | U |
| Lomefloxacin | 0.625 | U | 0.682 | U | 0.677 | U |
| Miconazole | 0.313 | U | 0.341 | U | 0.338 | U |
| Norfloxacin | 2.08 | U | 2.27 | U | 2.25 | U |
| Norgestimate | 1.56 | U | 1.71 | U | 1.69 | U |
| Ofloxacin | 0.625 | U | 0.682 | U | 0.677 | U |
| Ormetoprim | 0.156 | U | 0.171 | U | 0.169 | U |
| Oxacillin | 1.56 | U H | 1.71 | U H | 1.69 | U H |
| Oxolinic Acid | 0.625 | U | 0.682 | U | 0.677 | U |
| Penicillin G | **4.22** | RBH | **3.84** | RBH | 3.38 | U H |
| Penicillin V | 1.56 | U | 1.71 | U | 1.69 | U |
| Roxithromycin | 0.156 | U | 0.171 | U | 0.169 | U |
| Sarafloxacin | 3.13 | U | 3.41 | U | 3.38 | U |
| Sulfachloropyridazine | 0.625 | U | 0.682 | U | 0.677 | U |
| Sulfadiazine | 0.625 | U | 0.682 | U | 0.677 | U |
| Sulfadimethoxine | 0.313 | U | 0.341 | U | 0.338 | U |
| Sulfamerazine | 0.625 | U | 0.682 | U | 0.677 | U |
| Sulfamethazine | 0.625 | U | 0.682 | U | 0.677 | U |
| Sulfamethizole | 0.625 | U | 0.682 | U | 0.677 | U |
| Sulfamethoxazole | 0.625 | U | 0.682 | U | 0.677 | U |
| Sulfanilamide | 6.25 | U | 6.82 | U | 6.77 | U |
| Sulfathiazole | 1.56 | U | 1.71 | U | 1.69 | U |
| Thiabendazole | 0.313 | U | 0.341 | U | 0.338 | U |
| Trimethoprim | 0.313 | U | 0.341 | U | 0.338 | U |
| Tylosin | 0.625 | U | 0.682 | U | 0.677 | U |
| Virginiamycin M1 | 0.625 | U | 0.682 | U | 0.677 | U |
| 1,7-Dimethylxanthine | 11.4 | | 6.82 | U | 6.77 | U |

[U] Non-detect at reporting limit
[R] Peak detected but did not meet quantification criteria, result reported is estimated maximum possible concentration
[H] Concentration is estimated
[B] Analyte found in associated blank

Table 3.3-4. PPCP concentrations (ng/L) measured at Hotel (Spring Lake, San Marcos) during January, May, July, and November sampling events (2023). Samples with detectable concentrations denoted in bold.

| PPCP List Continued | January | | June | | July | |
|---|---|---|---|---|---|---|
| Alprazolam | 0.313 | U | 0.341 | U | 0.338 | U |
| Amitriptyline | 0.313 | U | 0.341 | U | 0.338 | U |
| Amlodipine | 1.05 | U | 1.14 | U | 1.14 | U |
| Benzoylecgonine | 0.156 | U | 0.171 | U | 0.169 | U |
| Benztropine | 0.729 | U | 0.796 | U | 0.79 | U |
| Betamethasone | 1.56 | U | 1.71 | U | 1.69 | U |
| Cocaine | 0.156 | U | 0.171 | U | **0.413** | |
| DEET | **3.12** | B | **3.5** | B | **2.95** | B |
| Desmethyldiltiazem | 0.156 | U | 0.171 | U | 0.169 | U |
| Diazepam | 0.523 | U | 0.571 | U | 0.566 | U |
| Fluocinonide | 2.09 | U | 2.29 | U | 2.27 | U |
| Fluticasone propionate | 2.09 | U | 2.29 | U | 2.27 | U |
| Hydrocortisone | 6.25 | U | 6.82 | U | 6.77 | U |
| 10-hydroxy-amitriptyline | 0.156 | U | 0.171 | U | 0.169 | U |
| Meprobamate | 1.56 | U | 1.71 | U | 1.69 | U |
| Methylprednisolone | 4.17 | U | 4.55 | U | 4.51 | U |
| Metoprolol | 0.523 | U | 0.571 | U | 0.566 | U |
| Norfluoxetine | 0.523 | U | 0.571 | U | 0.566 | U |
| Norverapamil | 0.156 | U | 0.171 | U | 0.169 | U |
| Paroxetine | 1.05 | U | 1.14 | U | 1.14 | U |
| Prednisolone | 4.17 | U | 4.55 | U | 4.51 | U |
| Prednisone | 6.25 | U | 6.82 | U | 6.77 | U |
| Promethazine | 0.313 | U | 0.341 | U | 0.338 | U |
| Propoxyphene | 0.313 | U | 0.341 | U | 0.338 | U |
| Propranolol | 0.313 | U | 0.341 | U | 0.338 | U |
| Sertraline | 0.313 | U | 0.341 | U | 0.338 | U |
| Simvastatin | 2.09 | U | 2.29 | U | 2.27 | U |
| Theophylline | **23.09** | | 6.82 | U | 6.77 | U |
| Trenbolone | 2.09 | U | 2.29 | U | 2.27 | U |
| Trenbolone acetate | 0.313 | U | 0.341 | U | 0.338 | U |
| Valsartan | 4.17 | U | 4.55 | U | 4.51 | U |
| Verapamil | 0.156 | U | 0.171 | U | 0.169 | U |

U Non-detect at reporting limit
R Peak detected but did not meet quantification criteria, result reported is estimated maximum possible concentration
H Concentration is estimated
B Analyte found in associated blank

### 3.3.2 Comal

A total of ten PPCP samples were collected during Spring and Fall collections in 2023, including one field duplicate sample during the Spring at Spring Run 3. Samples were collected at Spring Run 3 during the months of January, April, June, July, and December. Samples were taken at Spring Run 1 and Spring Run 7 during the standard Spring (April) and Fall (October) sampling events. Results for the Spring and Fall PPCP sampling at Spring Runs 1, 3, and 7 are denoted in Table 3.3-5 and 3.3-6 and PPCP results for Spring Run 3 for January, June, July, and December are noted in Tables 3.3-7 and 3.3-8. Overall, minimal PPCP detections at the reporting limit occurred in 2023 sampling events. DEET was detected at all three sampling sites in Spring and Fall sampling events; however, it is likely a false positive because it was also found in the blank in all sampling events. Penicillin G was detected at all three sites in Spring and at Spring Run 3 in January, June, and July but was also detected in the lab blanks. Cocaine was detected at all three Spring Runs in the Fall. Benzoylecgonine and Hydrocortisone were detected at Spring Runs 1 and 7 during the Fall. Sulfamethoxazole and Sulfamethizole were only detected at Spring Run 7 during the Fall. 1,7-Dimethylxanthine, Caffeine, Acetaminophen, and Theophylline and were detected at Spring Run 1 during the Fall. At Spring Run 3, Caffeine was detected in January and July, and Theophylline and 1,7-Dimethylxanthine were detected in January. Results for samples, duplicate samples, equipment blank, DI blank, and laboratory blank values can be found in Table A-11 through A-14 in appendix A.

Table 3.3-5. PPCP concentrations (ng/L) measured at Spring Run 1, Spring Run 3, and Spring Run 7 (Landa Lake) during Spring and Fall sampling events (2023). Samples with detectable concentrations denoted in bold.

| | Spring | | | Fall | | |
|---|---|---|---|---|---|---|
| PPCP List | Spring Run 1 | Spring Run 3 | Spring Run 7 | Spring Run 1 | Spring Run 3 | Spring Run 7 |
| Acetaminophen | 3.32 U | 3.4 U | 3.18 U | **7.56** | 3.19 U | 3.13 U |
| Azithromycin | 1.66 U | 1.7 U | 1.59 U | 1.7 U | 1.59 U | 1.57 U |
| Caffeine | 6.63 U | 6.8 U | 6.35 U | **21.1** | 6.38 U | 6.26 U |
| Carbadox | 0.663 U | 0.68 U | 0.635 U | 0.681 U | 0.638 U | 0.626 U |
| Carbamazepine | 0.332 U | 0.34 U | 0.318 U | 0.34 U | 0.319 U | 0.313 U |
| Cefotaxime | 6.56 U | 6.73 U | 6.29 U | 6.74 U | 6.31 U | 6.2 U |
| Ciprofloxacin | 1.66 U | 1.7 U | 1.59 U | 1.7 U | 1.59 U | 1.57 U |
| Clarithromycin | 0.332 U | 0.34 U | 0.318 U | 0.34 U | 0.319 U | 0.313 U |
| Clinafloxacin | 2.21 U | 2.27 U | 2.12 U | 2.27 U | 2.12 U | 2.09 U |
| Cloxacillin | 3.32 U H | 3.4 U H | 3.18 U H | 3.4 U H | 3.19 U H | 3.13 U H |
| Dehydronifedipine | 0.332 U | 0.34 U | 0.318 U | 0.34 U | 0.319 U | 0.313 U |
| Digoxigenin | 1.66 U | 1.7 U | 1.59 U | 1.7 U | 1.59 U | 1.57 U |
| Digoxin | 6.63 U | 6.8 U | 6.35 U | 6.81 U | 6.38 U | 6.26 U |
| Diltiazem | 0.166 U | 0.17 U | 0.159 U | 0.17 U | 0.159 U | 0.157 U |
| Diphenhydramine | 0.663 U | 0.68 U | 0.635 U | 0.681 U | 0.638 U | 0.626 U |
| Enrofloxacin | 0.663 U | 0.68 U | 0.635 U | 0.681 U | 0.638 U | 0.626 U |
| Erythromycin-H2O | 1.66 U H | 1.7 U H | 1.59 U H | 1.7 U H | 1.59 U H | 1.57 U H |
| Flumequine | 0.332 U | 0.34 U | 0.318 U | 0.34 U | 0.319 U | 0.313 U |
| Fluoxetine | 0.166 U | 0.17 U | 0.159 U | 0.17 U | 0.159 U | 0.157 U |
| Lincomycin | 0.663 U | 0.68 U | 0.635 U | 0.681 U | 0.638 U | 0.626 U |
| Lomefloxacin | 0.663 U | 0.68 U | 0.635 U | 0.681 U | 0.638 U | 0.626 U |
| Miconazole | 0.332 U | 0.34 U | 0.318 U | 0.34 U | 0.319 U | 0.313 U |
| Norfloxacin | 2.21 U | 2.27 U | 2.12 U | 2.27 U | 2.12 U | 2.09 U |
| Norgestimate | 1.66 U | 1.7 U | 1.59 U | 1.7 U | 1.59 U | 1.57 U |
| Ofloxacin | 0.663 U | 0.68 U | 0.635 U | 0.681 U | 0.638 U | 0.626 U |
| Ormetoprim | 0.166 U | 0.17 U | 0.159 U | 0.17 U | 0.159 U | 0.157 U |
| Oxacillin | 1.66 U H | 1.7 U H | 1.59 U H | 1.7 U H | 1.59 U H | 1.57 U H |
| Oxolinic Acid | 0.663 U | 0.68 U | 0.635 U | 0.681 U | 0.638 U | 0.626 U |
| Penicillin G | **4.65** RBH | **3.84** RBCH | **4.09** RBH | 3.4 U H | 3.19 U H | 3.13 U H |
| Penicillin V | 1.66 U | 1.7 U | 1.59 U | 1.7 U | 1.59 U | 1.57 U |
| Roxithromycin | 0.166 U | 0.17 U | 0.159 U | 0.17 U | 0.159 U | 0.157 U |
| Sarafloxacin | 3.32 U | 3.4 U | 3.18 U | 3.4 U | 3.19 U | 3.13 U |
| Sulfachloropyridazine | 0.663 U | 0.68 U | 0.635 U | 0.681 U | 0.638 U | 0.626 U |
| Sulfadiazine | 0.663 U | 0.68 U | 0.635 U | 0.681 U | 0.638 U | 0.626 U |
| Sulfadimethoxine | 0.332 U | 0.34 U | 0.318 U | 0.34 U | 0.319 U | 0.313 U |
| Sulfamerazine | 0.663 U | 0.68 U | 0.635 U | 0.681 U | 0.638 U | 0.626 U |
| Sulfamethazine | 0.663 U | 0.68 U | 0.635 U | 0.681 U | 0.638 U | 0.626 U |
| Sulfamethizole | 0.663 U | 0.68 U | 0.635 U | 0.745 U | 0.638 U | **0.818** |
| Sulfamethoxazole | 0.663 U | 0.68 U | 0.635 U | 0.681 U | 0.638 U | **0.667** |
| Sulfanilamide | 6.63 U | 6.8 U | 6.35 U | 6.81 U | 6.38 U | 6.26 U |
| Sulfathiazole | 1.66 U | 1.7 U | 1.59 U | 1.7 U | 1.59 U | 1.57 U |
| Thiabendazole | 0.332 U | 0.34 U | 0.318 U | 0.34 U | 0.319 U | 0.313 U |
| Trimethoprim | 0.332 U | 0.34 U | 0.318 U | 0.34 U | 0.319 U | 0.313 U |
| Tylosin | 0.663 U | 0.68 U | 0.635 U | 0.681 U | 0.638 U | 0.626 U |
| Virginiamycin M1 | 0.663 U | 0.68 U | 0.635 U | 0.681 U | 0.638 U | 0.626 U |
| 1,7-Dimethylxanthine | 6.63 U | 6.8 U | 6.35 U | **7.98** | 6.38 U | 6.26 U |

[U] Non-detect at reporting limit
[H] Concentration is estimated
[B] Analyte found in associated blank
[C] Detected in duplicate sample

Table 3.3-6. PPCP concentrations (ng/L) measured at Spring Run 1, Spring Run 3, and Spring Run 7 (Landa Lake) during Spring and Fall sampling events (2023). Samples with detectable concentrations denoted in bold.

| PPCP List Continued | Spring | | | Fall | | |
|---|---|---|---|---|---|---|
| | Spring Run 1 | Spring Run 3 | Spring Run 7 | Spring Run 1 | Spring Run 3 | Spring Run 7 |
| Alprazolam | 0.332 U | 0.34 U | 0.318 U | 0.34 U | 0.319 U | 0.313 U |
| Amitriptyline | 0.332 U | 0.34 U | 0.318 U | 0.34 U | 0.319 U | 0.313 U |
| Amlodipine | 1.11 U | 1.14 U | 1.07 U | 1.14 U | 1.07 U | 1.05 U |
| Benzoylecgonine | 0.166 U | 0.17 U | 0.159 U | **0.46** | 0.159 U | **0.384** |
| Benztropine | 0.774 U | 0.794 U | 0.741 U | 0.794 U | 0.744 U | 0.731 U |
| Betamethasone | 1.66 U | 1.7 U | 1.59 U | 1.7 U | 1.59 U | 1.57 U |
| Cocaine | 0.166 U | 0.17 U | 0.159 U | **1.33** | **0.25** | **3.16** |
| DEET | **3.98** B | **3.77** BC | **5.06** B | **3.04** B | **2.7** B | **9.18** B |
| Desmethyldiltiazem | 0.166 U | 0.17 U | 0.159 U | 0.17 U | 0.159 U | 0.157 U |
| Diazepam | 0.555 U | 0.569 U | 0.531 U | 0.57 U | 0.534 U | 0.524 U |
| Fluocinonide | 2.22 U | 2.28 U | 2.13 U | 2.28 U | 2.14 U | 2.1 U |
| Fluticasone propionate | 2.22 U | 2.28 U | 2.13 U | 2.28 U | 2.14 U | 2.1 U |
| Hydrocortisone | 6.63 U | 6.8 U | 6.35 U | **40.8** | 6.38 U | **6.48** |
| 10-hydroxy-amitriptyline | 0.166 U | 0.17 U | 0.159 U | 0.17 U | 0.159 U | 0.157 U |
| Meprobamate | 1.66 U | 1.7 U | 1.59 U | 1.7 U | 1.59 U | 1.57 U |
| Methylprednisolone | 4.42 U | 4.53 U | 4.23 U | 4.54 U | 4.25 U | 4.17 U |
| Metoprolol | 0.555 U | 0.569 U | 0.531 U | 0.57 U | 0.534 U | 0.524 U |
| Norfluoxetine | 0.555 U | 0.569 U | 0.531 U | 0.57 U | 0.534 U | 0.524 U |
| Norverapamil | 0.166 U | 0.17 U | 0.159 U | 0.17 U | 0.159 U | 0.157 U |
| Paroxetine | 1.11 U | 1.14 U | 1.07 U | 1.14 U | 1.07 U | 1.05 U |
| Prednisolone | 4.42 U | 4.53 U | 4.23 U | 4.54 U | 4.25 U | 4.17 U |
| Prednisone | 6.63 U | 6.8 U | 6.35 U | 6.81 U | 6.38 U | 6.26 U |
| Promethazine | 0.332 U | 0.34 U | 0.318 U | 0.34 U | 0.319 U | 0.313 U |
| Propoxyphene | 0.332 U | 0.34 U | 0.318 U | 0.34 U | 0.319 U | 0.313 U |
| Propranolol | 0.332 U | 0.34 U | 0.318 U | 0.34 U | 0.319 U | 0.313 U |
| Sertraline | 0.332 U | 0.34 U | 0.318 U | 0.34 U | 0.319 U | 0.313 U |
| Simvastatin | 2.22 U | 2.28 U | 2.13 U | 2.28 U | 2.14 U | 2.1 U |
| Theophylline | 6.63 U | 6.8 U | 6.35 U | **14.9** R | 6.38 U | 6.26 U |
| Trenbolone | 2.22 U | 2.28 U | 2.13 U | 2.28 U | 2.14 U | 2.1 U |
| Trenbolone acetate | 0.332 U | 0.34 U | 0.318 U | 0.34 U | 0.319 U | 0.313 U |
| Valsartan | 4.42 U | 4.53 U | 4.23 U | 4.54 U | 4.25 U | 4.17 U |
| Verapamil | 0.166 U | 0.17 U | 0.159 U | 0.17 U | 0.159 U | 0.157 U |

U Non-detect at reporting limit
H Concentration is estimated

Table 3.3-7. PPCP concentrations (ng/L) measured at Spring Run3 (Landa Lake, New Braunfels) during January, June, and July sampling events (2023). Samples with detectable concentrations denoted in bold.

| PPCP List | January | | June | | July | |
|---|---|---|---|---|---|---|
| Acetaminophen | 3.24 | U | 3.64 | U | 3.27 | U |
| Azithromycin | 1.62 | U | 1.82 | U | 1.63 | U |
| Caffeine | **18.7** | | 7.27 | U | **7.44** | |
| Carbadox | 0.647 | U | 0.727 | U | 0.653 | U |
| Carbamazepine | 0.324 | U | 0.364 | U | 0.327 | U |
| Cefotaxime | 6.41 | U | 7.2 | U | 6.47 | U |
| Ciprofloxacin | 1.62 | U | 1.82 | U | 1.63 | U |
| Clarithromycin | 0.324 | U | 0.364 | U | 0.327 | U |
| Clinafloxacin | 2.16 | U | 2.42 | U | 2.18 | U |
| Cloxacillin | 3.24 | U H | 3.64 | U H | 3.27 | U H |
| Dehydronifedipine | 0.324 | U | 0.364 | U | 0.327 | U |
| Digoxigenin | 1.62 | U | 1.82 | U | 1.63 | U |
| Digoxin | 6.47 | U | 7.27 | U | 6.53 | U |
| Diltiazem | 0.162 | U | 0.182 | U | 0.163 | U |
| Diphenhydramine | 0.647 | U | 0.727 | U | 0.653 | U |
| Enrofloxacin | 0.647 | U | 0.727 | U | 0.653 | U |
| Erythromycin-H2O | 1.62 | U H | 1.82 | U H | 1.63 | U H |
| Flumequine | 0.324 | U | 0.364 | U | 0.327 | U |
| Fluoxetine | 0.162 | U | 0.182 | U | 0.163 | U |
| Lincomycin | 0.647 | U | 0.727 | U | 0.653 | U |
| Lomefloxacin | 0.647 | U | 0.727 | U | 0.653 | U |
| Miconazole | 0.324 | U | 0.364 | U | 0.327 | U |
| Norfloxacin | 2.16 | U | 2.42 | U | 2.18 | U |
| Norgestimate | 1.62 | U | 1.82 | U | 1.63 | U |
| Ofloxacin | 0.647 | U | 0.727 | U | 0.653 | U |
| Ormetoprim | 0.162 | U | 0.182 | U | 0.163 | U |
| Oxacillin | 1.62 | U H | 1.82 | U H | 1.63 | U H |
| Oxolinic Acid | 0.647 | U | 0.727 | U | 0.653 | U |
| Penicillin G | **4.12** | RBH | **3.64** | RBH | **4.28** | RH |
| Penicillin V | 1.62 | U | 1.82 | U | 1.63 | U |
| Roxithromycin | 0.162 | U | 0.182 | U | 0.163 | U |
| Sarafloxacin | 3.24 | U | 3.64 | U | 3.27 | U |
| Sulfachloropyridazine | 0.647 | U | 0.727 | U | 0.653 | U |
| Sulfadiazine | 0.647 | U | 0.727 | U | 0.653 | U |
| Sulfadimethoxine | 0.324 | U | 0.364 | U | 0.327 | U |
| Sulfamerazine | 0.647 | U | 0.727 | U | 0.653 | U |
| Sulfamethazine | 0.647 | U | 0.727 | U | 0.653 | U |
| Sulfamethizole | 0.647 | U | 0.727 | U | 0.752 | U |
| Sulfamethoxazole | 0.647 | U | 0.727 | U | 0.653 | U |
| Sulfanilamide | 6.47 | U | 7.27 | U | 6.53 | U |
| Sulfathiazole | 1.62 | U | 1.82 | U | 1.63 | U |
| Thiabendazole | 0.324 | U | 0.364 | U | 0.327 | U |
| Trimethoprim | 0.324 | U | 0.364 | U | 0.327 | U |
| Tylosin | 0.647 | U | 0.727 | U | 0.653 | U |
| Virginiamycin M1 | 0.647 | U | 0.727 | U | 0.653 | U |
| 1,7-Dimethylxanthine | **6.74** | | 7.27 | U | 6.53 | U |

[U] Non-detect at reporting limit
[R] Peak detected but did not meet quantification criteria, result reported is estimated maximum possible concentration
[H] Concentration is estimated

Table 3.3-8. PPCP concentrations (ng/L) measured at Spring Run3 (Landa Lake, New Braunfels) during January, June, and July sampling events (2023). Samples with detectable concentrations denoted in bold.

| PPCP List Continued | January | | June | | July | |
|---|---|---|---|---|---|---|
| Alprazolam | 0.324 | U | 0.364 | U | 0.327 | U |
| Amitriptyline | 0.324 | U | 0.364 | U | 0.327 | U |
| Amlodipine | 1.09 | U | 1.22 | U | 1.1 | U |
| Benzoylecgonine | 0.162 | U | 0.182 | U | 0.163 | U |
| Benztropine | 0.755 | U | 0.848 | U | 0.762 | U |
| Betamethasone | 1.62 | U | 1.82 | U | 1.63 | U |
| Cocaine | 0.162 | U | 0.182 | U | 0.163 | U |
| DEET | **3.33** | B | **4.17** | B | **3.03** | B |
| Desmethyldiltiazem | 0.162 | U | 0.182 | U | 0.163 | U |
| Diazepam | 0.542 | U | 0.608 | U | 0.547 | U |
| Fluocinonide | 2.17 | U | 2.44 | U | 2.19 | U |
| Fluticasone propionate | 2.17 | U | 2.44 | U | 2.19 | U |
| Hydrocortisone | 6.47 | U | 7.27 | U | 6.53 | U |
| 10-hydroxy-amitriptyline | 0.162 | U | 0.182 | U | 0.163 | U |
| Meprobamate | 1.62 | U | 1.82 | U | 1.63 | U |
| Methylprednisolone | 4.32 | U | 4.85 | U | 4.36 | U |
| Metoprolol | 0.542 | U | 0.608 | U | 0.547 | U |
| Norfluoxetine | 0.542 | U | 0.608 | U | 0.547 | U |
| Norverapamil | 0.162 | U | 0.182 | U | 0.163 | U |
| Paroxetine | 1.09 | U | 1.22 | U | 1.1 | U |
| Prednisolone | 4.32 | U | 4.85 | U | 4.36 | U |
| Prednisone | 6.47 | U | 7.27 | U | 6.53 | U |
| Promethazine | 0.324 | U | 0.364 | U | 0.327 | U |
| Propoxyphene | 0.324 | U | 0.364 | U | 0.327 | U |
| Propranolol | 0.324 | U | 0.364 | U | 0.327 | U |
| Sertraline | 0.324 | U | 0.364 | U | 0.327 | U |
| Simvastatin | 2.17 | U | 2.44 | U | 2.19 | U |
| Theophylline | **14.1** | | 7.27 | U | 6.53 | U |
| Trenbolone | 2.17 | U | 2.44 | U | 2.19 | U |
| Trenbolone acetate | 0.324 | U | 0.364 | U | 0.327 | U |
| Valsartan | 4.32 | U | 4.85 | U | 4.36 | U |
| Verapamil | 0.162 | U | 0.182 | U | 0.163 | U |

U Non-detect at reporting limit

R Peak detected but did not meet quantification criteria, result reported is estimated maximum possible concentration

H Concentration is estimated

# 3.4 Fish Tissue sampling

## 3.4.1 San Marcos

Table 3.4-1 denotes the PPCP results for fish tissue samples collected in 2023 in the San Marcos system sites. Only one PPCP was detected among fish tissue samples, Ciprofloxacin (i.e., antibiotic) was found in fish collected from the Upper San Marcos system.

Table 3.4-1 PPCP concentrations (ng/g) detected in fish tissue samples collected from the San Marcos system in May-June 2023. PPCPs detected are denoted in bold.

| PPCP List | Upper | | Lower | |
|---|---|---|---|---|
| Acetaminophen | 1.15 | U | 1.19 | U |
| Azithromycin | 0.577 | U | 0.595 | U |
| Caffeine | 2.31 | U | 2.38 | U |
| Carbadox | 0.231 | U | 0.238 | U |
| Carbamazepine | 0.115 | U | 0.119 | U |
| Cefotaxime | 2.28 | U | 2.36 | U |
| Ciprofloxacin | **0.663** | | 0.595 | U |
| Clarithromycin | 0.115 | U | 0.119 | U |
| Clinafloxacin | 0.768 | U | 0.793 | U |
| Cloxacillin | 1.15 | U H | 1.19 | U H |
| Dehydronifedipine | 0.115 | U | 0.119 | U |
| Digoxigenin | 0.577 | U | 0.595 | U |
| Digoxin | 2.31 | U | 2.38 | U |
| Diltiazem | 0.0577 | U | 0.0595 | U |
| Diphenhydramine | 0.231 | U | 0.238 | U |
| Enrofloxacin | 0.231 | U | 0.238 | U |
| Erythromycin-H2O | 0.577 | U H | 0.595 | U H |
| Flumequine | 0.115 | U | 0.119 | U |
| Fluoxetine | 0.0577 | U | 0.0595 | U |
| Lincomycin | 0.231 | U | 0.238 | U |
| Lomefloxacin | 0.231 | U | 0.238 | U |
| Miconazole | 0.115 | U | 0.119 | U |
| Norfloxacin | 0.768 | U | 0.793 | U |
| Norgestimate | 0.577 | U | 0.595 | U |
| Ofloxacin | 0.231 | U | 0.238 | U |
| Ormetoprim | 0.0577 | U | 0.0595 | U |
| Oxacillin | 0.577 | U H | 0.595 | U H |
| Oxolinic Acid | 0.231 | U | 0.238 | U |
| Penicillin G | 1.15 | U H | 1.19 | U H |
| Penicillin V | 0.577 | U | 0.595 | U |
| Roxithromycin | 0.0577 | U | 0.0595 | U |
| Sarafloxacin | 1.15 | U | 1.19 | U |
| Sulfachloropyridazine | 0.231 | U | 0.238 | U |
| Sulfadiazine | 0.231 | U | 0.238 | U |
| Sulfadimethoxine | 0.115 | U | 0.119 | U |
| Sulfamerazine | 0.231 | U | 0.238 | U |
| Sulfamethazine | 0.231 | U | 0.238 | U |
| Sulfamethizole | 0.363 | U | 0.306 | U |
| Sulfamethoxazole | 0.231 | U | 0.238 | U |
| Sulfanilamide | 2.31 | U | 2.38 | U |
| Sulfathiazole | 0.577 | U | 0.595 | U |
| Thiabendazole | 0.115 | U | 0.119 | U |
| Trimethoprim | 0.115 | U | 0.119 | U |
| Tylosin | 0.231 | U | 0.238 | U |
| Virginiamycin M1 | 0.231 | U | 0.238 | U |
| 1,7-Dimethylxanthine | 2.31 | U | 2.38 | U |

[U] Non-detect at reporting limit
[H] Concentration is estimated

## 3.4.2 **Comal**

Table 3.4-2 denotes the PPCP results for fish tissue samples collected in 2023 in the Comal system sites. Like the San Marcos, only one PPCP were detected among fish tissue samples, Penicillin G was found in fish collected in the Upper Comal system.

Table 3.4-2 PPCP concentrations (ng/g) detected in fish tissue samples collected from the Comal system in June 2023. PPCPs detected are denoted in bold.

| PPCP List | Upper | | Lower | |
|---|---|---|---|---|
| Acetaminophen | 1.17 | U | 1.15 | U |
| Azithromycin | 0.586 | U | 0.577 | U |
| Caffeine | 2.34 | U | 2.31 | U |
| Carbadox | 0.234 | U | 0.231 | U |
| Carbamazepine | 0.117 | U | 0.115 | U |
| Cefotaxime | 2.32 | U | 3.37 | U |
| Ciprofloxacin | 0.586 | U | 0.577 | U |
| Clarithromycin | 0.117 | U | 0.115 | U |
| Clinafloxacin | 0.78 | U | 0.768 | U |
| Cloxacillin | 1.17 | U H | 1.15 | U H |
| Dehydronifedipine | 0.117 | U | 0.115 | U |
| Digoxigenin | 0.586 | U | 0.577 | U |
| Digoxin | 2.34 | U | 2.31 | U |
| Diltiazem | 0.0586 | U | 0.0577 | U |
| Diphenhydramine | 0.234 | U | 0.231 | U |
| Enrofloxacin | 0.234 | U | 0.231 | U |
| Erythromycin-H2O | 0.586 | U H | 0.577 | U H |
| Flumequine | 0.117 | U | 0.115 | U |
| Fluoxetine | 0.0586 | U | 0.0577 | U |
| Lincomycin | 0.234 | U | 0.231 | U |
| Lomefloxacin | 0.234 | U | 0.231 | U |
| Miconazole | 0.117 | U | 0.115 | U |
| Norfloxacin | 0.78 | U | 0.768 | U |
| Norgestimate | 0.586 | U | 0.577 | U |
| Ofloxacin | 0.234 | U | 0.231 | U |
| Ormetoprim | 0.0586 | U | 0.0577 | U |
| Oxacillin | 0.586 | U H | 0.577 | U H |
| Oxolinic Acid | 0.234 | U | 0.231 | U |
| Penicillin G | **1.21** | H | 1.15 | U H |
| Penicillin V | 0.586 | U | 0.577 | U |
| Roxithromycin | 0.0586 | U | 0.0577 | U |
| Sarafloxacin | 1.17 | U | 1.15 | U |
| Sulfachloropyridazine | 0.234 | U | 0.231 | U |
| Sulfadiazine | 0.234 | U | 0.231 | U |
| Sulfadimethoxine | 0.117 | U | 0.115 | U |
| Sulfamerazine | 0.234 | U | 0.231 | U |
| Sulfamethazine | 0.234 | U | 0.231 | U |
| Sulfamethizole | 0.239 | U | 0.231 | U |
| Sulfamethoxazole | 0.234 | U | 0.231 | U |
| Sulfanilamide | 2.34 | U | 2.31 | U |
| Sulfathiazole | 0.586 | U | 0.58 | U |
| Thiabendazole | 0.117 | U | 0.12 | U |
| Trimethoprim | 0.117 | U | 0.12 | U |
| Tylosin | 0.234 | U | 0.23 | U |
| Virginiamycin M1 | 0.234 | U | 0.23 | U |
| 1,7-Dimethylxanthine | 2.34 | U | 2.31 | U |

[U] Non-detect at reporting limit
[H] Concentration is estimated

# 4 | References


Oppenheimer, J., A. Eaton, M. Badruzzaman, A. W. Haghani, and J. G. Jacangelo. 2011. Occurrence and suitability of sucralose as an indicator compound of wastewater loading to surface waters in urbanized regions. Water Research 45(13): 4019-4027.

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# Appendix A – Laboratory Quality Control Results

Table A-1. Sucralose concentrations (ng/L) for samples, DI blanks, lab blanks, and spiked matrices measured at Hotel Springs in Spring Lake (2023). Quality control spike recoveries (%) are reported to the right of each sample and samples with detectable concentrations are denoted in bold.

| Month | Sample (ng/L) | QC Spike Recovery (%) | Duplicate (ng/L) | QC Spike Recovery (%) | DI Blank (ng/L) | QC Spike Recovery (%) | Lab Blank (ng/L) | QC Spike Recovery (%) | Spiked Matrix (ng/L) | Spiked Recovery (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| January | **21.7** | 62.8 | **14.1** | 64.5 | NA | NA | 10.1[U] | 65.4 | 1.01 | 101 |
| February | **19.7** | 105.0 | NA | NA | NA | NA | 10.1[U] | 65.4 | 1.01 | 101 |
| March | **19.3** | 67.8 | NA | NA | 8.69[U] | 81.0 | 10.1[U] | 65.4 | 1.01 | 101 |
| April | **18.6** | 68.9 | NA | NA | NA | NA | 10.1[U] | 65.4 | 1.01 | 101 |
| May | **19.6** | 71.5 | NA | NA | NA | NA | 10.1[U] | 65.4 | 1.01 | 101 |
| June | **16.8** | 80.6 | NA | NA | NA | NA | 10.1[U] | 65.4 | 1.01 | 101 |
| July | **13.6** | 74.5 | NA | NA | NA | NA | 10.1[U] | 92.0 | 1.01 | 94.6 |
| August | **14.8** | 70.3 | NA | NA | NA | NA | 10.1[U] | 92.0 | 1.01 | 94.6 |
| September | **12.8** | 73.9 | NA | NA | 8.16[U] | 70.6 | 10.1[U] | 92.0 | 1.01 | 94.6 |
| October | **13.20** | 70.4 | NA | NA | NA | NA | 10.1[U] | 92.0 | 1.01 | 94.6 |
| November | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| December | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |

[U] Non-detect at reporting limit

Table A-2. Sucralose concentrations (ng/L) for samples, duplicate samples, DI blanks, lab blanks, and spiked matrices measured for Spring Run 3 in Landa Lake (2023). Quality control spike recoveries (%) are reported to the right of each sample and samples with detectable concentrations are denoted in bold.

| Month | Sample (ng/L) | QC Spike Recovery (%) | Duplicate (ng/L) | QC Spike Recovery (%) | DI Blank (ng/L) | QC Spike Recover y (%) | Lab Blank (ng/L) | QC Spike Recovery (%) | Spiked Matrix (ng/L) | QC Spiked Recovery (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| January | 8.19[U] | 66.0 | NA | NA | NA | NA | 10.1[U] | 65.4 | 1.01 | 101 |
| February | 9.11[U] | 82.1 | NA | NA | NA | NA | 10.1[U] | 65.4 | 1.01 | 101 |
| March | 7.84[U] | 91.9 | NA | NA | NA | NA | 10.1[U] | 65.4 | 1.01 | 101 |
| April | **9.65** | 69.2 | NA | NA | NA | NA | 10.1[U] | 65.4 | 1.01 | 101 |
| May | 7.93[U] | 107.0 | NA | NA | NA | NA | 10.1[U] | 65.4 | 1.01 | 101 |
| June | 8.92[U] | 71.8 | NA | NA | 8.46[U] | 66.6 | 10.1[U] | 65.4 | 1.01 | 101 |
| July | 8.74[U] | 105.0 | **34.4** | 67.3 | NA | NA | 10.1[U] | 92.0 | 1.01 | 94.6 |
| August | 8.64[U] | 78.7 | NA | NA | NA | NA | 10.1[U] | 92.0 | 1.01 | 94.6 |
| September | 9.06[U] | 80.1 | NA | NA | NA | NA | 10.1[U] | 92.0 | 1.01 | 94.6 |
| October | 8.31[U] | 83.9 | NA | NA | NA | NA | 10.1[U] | 92.0 | 1.01 | 94.6 |
| November | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| December | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |

[U] Non-detect at reporting limit

Table A-3. Nutrient concentrations (mg/L) reported for samples, duplicate samples, lab blanks, and field blanks, and the relative percent difference between sample and duplicate sample concentrations (%) at the San Marcos River upper and lower sites for Spring 2023. Samples with detectable concentrations denoted in bold.

| Nutrients | Upper | Upper Duplicates | Relative Percent Difference | Laboratory Blank | Field Blank |
|---|---|---|---|---|---|
| Total Phosphorus | 0.01[U] | 0.01[U] | 0.00% | 0.01[U] | 0.01[U] |
| Orthophosphate as P | **0.01[JH]** | **0.006[JH]** | 50.00% | 0.004[UH] | 0.004[UH] |
| Total Organic Carbon | **1** | **0.8[J]** | 22.20% | 0.5[U] | 0.5[U] |
| Dissolved Inorganic Carbon | **64.6** | **64.5** | 0.15% | **0.51[J]** | **0.69[J]** |
| Dissolved Organic Carbon | **1.1** | **0.615[J]** | 56.56% | **0.76[J]** | **0.49[J]** |
| Kjeldahl Nitrogen | 0.09[U] | 0.09[U] | 0.00% | **0.33** | 0.09[U] |
| Nitrate as N | **1.26[H]** | **1.23[H]** | 2.41% | **0.06[JH]** | **0.06[JH]** |
| Ammonia | 0.035[U] | 0.035[U] | 0.00% | **0.72** | 0.035[U] |
| **Nutrients** | **Lower** | **Lower Duplicates** | **Relative Percent Difference** | **Laboratory Blank** | **Field Blank** |
| Total Phosphorus | 0.01[U] | NA | NA | 0.01[U] | 0.01[U] |
| Orthophosphate as P | 0.004[UH] | NA | NA | 0.004[UH] | 0.004[UH] |
| Total Organic Carbon | **0.89[J]** | NA | NA | 0.5[U] | 0.5[U] |
| Dissolved Inorganic Carbon | **62.7** | NA | NA | **0.51[J]** | **0.69[J]** |
| Dissolved Organic Carbon | **1.01** | NA | NA | **0.76[J]** | **0.49[J]** |
| Kjeldahl Nitrogen | 0.09[U] | NA | NA | **0.33** | 0.09[U] |
| Nitrate as N | **1.35[H]** | NA | NA | **0.06[JH]** | **0.06[JH]** |
| Ammonia | 0.035[U] | NA | NA | **0.72** | 0.035[U] |

[U] Non-detect

[H] Sample was prepped and analyzed past holding time

[J] Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.

Table A-4. Nutrient concentrations (mg/L) reported for samples, duplicate samples, lab blanks, and field blanks, and the relative percent difference between sample and duplicate sample concentrations (%) at the San Marcos upper and lower sites for Fall 2023. Samples with detectable concentrations denoted in bold.

| Nutrients | Upper | Upper Duplicates | Relative Percent Difference | Laboratory Blank | Field Blank |
|---|---|---|---|---|---|
| Total Phosphorus | **0.93** | NA | NA | 0.009[U] | **0.03** |
| Orthophosphate as P | 0.006[U] | NA | NA | 0.006[U] | 0.006[U] |
| Total Organic Carbon | 0.5[U] | NA | NA | 0.5[U] | 0.5[U] |
| Dissolved Inorganic Carbon | **64.9[F1]** | NA | NA | **2.21** | **2.26** |
| Dissolved Organic Carbon | **1.59** | NA | NA | **1.37** | **1.39** |
| Kjeldahl Nitrogen | **0.86** | NA | NA | **0.49** | **0.40** |
| Nitrate as N | **1.48** | NA | NA | **0.13** | **0.12** |
| Ammonia | 0.05[U] | NA | NA | 0.051[U] | 0.051[U] |
| **Nutrients** | **Lower** | **Lower Duplicates** | **Relative Percent Difference** | **Laboratory Blank** | **Field Blank** |
| Total Phosphorus | **0.04** | **0.03** | 28.57% | 0.009[U] | **0.03** |
| Orthophosphate as P | 0.03[U] | 0.03[U] | 0.00% | 0.006[U] | 0.006[U] |
| Total Organic Carbon | 0.5[U] | 0.5[U] | 0.00% | 0.5[U] | 0.5[U] |
| Dissolved Inorganic Carbon | **64.2** | **63.4** | 1.25% | **2.21** | **2.26** |
| Dissolved Organic Carbon | **1.55** | **1.7** | 9.23% | **1.37** | **1.39** |
| Kjeldahl Nitrogen | **0.44** | **0.84** | 62.50% | **0.49** | **0.40** |
| Nitrate as N | **1.53** | **1.54** | 0.65% | **0.13** | **0.12** |
| Ammonia | **0.08[JF1]** | **0.13[F1]** | 47.62% | 0.051[U] | 0.051[U] |

[U] Non-detect

[H] Sample was prepped and analyzed past holding time

[F1] MS and/or MSD recovery exceeds control limits

[J] Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.

Table A-5. Nutrient concentrations (mg/L) reported for samples, duplicate samples, lab blanks, and field blanks, and the relative percent difference between sample and duplicate sample concentrations (%) at the Comal upper and lower sites for Spring 2023. Samples with detectable concentrations denoted in bold.

| Nutrients | Upper | Upper Duplicates | Relative Percent Difference | Laboratory Blank | Field Blank |
|---|---|---|---|---|---|
| Total Phosphorus | 0.01[U] | 0.01[U] | 0.00% | 0.01[U] | 0.01[U] |
| Orthophosphate as P | 0.004[UH] | 0.004[UH] | 0.00% | 0.004[UH] | 0.004[UH] |
| Total Organic Carbon | **0.85**[J] | **0.82**[J] | 3.50% | 0.5[U] | 0.5[U] |
| Dissolved Inorganic Carbon | **58** | **57.6** | 0.60% | **0.51**[J] | **0.69**[J] |
| Dissolved Organic Carbon | **0.91**[J] | **0.79**[J] | 14.11% | **0.76**[J] | **0.49**[J] |
| Kjeldahl Nitrogen | 0.09[U] | **0.19**[J] | 71.43% | **0.33** | 0.09[U] |
| Nitrate as N | **1.83**[H] | **1.83**[H] | 0.00% | **0.06**[JH] | **0.06**[JH] |
| Ammonia | 0.035[U] | 0.035[UF1] | 0.00% | **0.72** | 0.035[U] |
| **Nutrients** | **Lower** | **Lower Duplicates** | **Relative Percent Difference** | **Laboratory Blank** | **Field Blank** |
| Total Phosphorus | 0.01[U] | NA | NA | 0.01[U] | 0.01[U] |
| Orthophosphate as P | 0.004[UH] | NA | NA | 0.004[UH] | 0.004[UH] |
| Total Organic Carbon | **0.82**[J] | NA | NA | 0.5[U] | 0.5[U] |
| Dissolved Inorganic Carbon | **57.6** | NA | NA | **0.51**[J] | **0.69**[J] |
| Dissolved Organic Carbon | **0.79**[J] | NA | NA | **0.76**[J] | **0.49**[J] |
| Kjeldahl Nitrogen | **0.19**[J] | NA | NA | **0.33** | 0.09[U] |
| Nitrate as N | **1.83**[H] | NA | NA | **0.06**[JH] | **0.06**[JH] |
| Ammonia | 0.035[UF1] | NA | NA | **0.72** | 0.035[U] |

[U] Non-detect

[H] Sample was prepped and analyzed past holding time

[F1] MS and/or MSD recovery exceeds control limits

[J] Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.

Table A-6. Nutrient concentrations (mg/L) reported for samples, duplicate samples, lab blanks, and field blanks, and the relative percent difference between sample and duplicate sample concentrations (%) at the Comal upper and lower sites for Fall 2023. Samples with detectable concentrations denoted in bold.

| Nutrients | Upper | Upper Duplicates | Relative Percent Difference | Laboratory Blank | Field Blank |
|---|---|---|---|---|---|
| Total Phosphorus | 0.009 UF1 | NA | NA | 0.009 U | **0.03** |
| Orthophosphate as P | 0.03 U | NA | NA | 0.006 U | 0.006 U |
| Total Organic Carbon | 0.5 U | NA | NA | 0.5 U | 0.5 U |
| Dissolved Inorganic Carbon | **58.8** | NA | NA | **2.21** | **2.26** |
| Dissolved Organic Carbon | **1.63** | NA | NA | **1.37** | **1.39** |
| Kjeldahl Nitrogen | **0.54** | NA | NA | **0.49** | **0.40** |
| Nitrate as N | **1.88** | NA | NA | **0.13** | **0.12** |
| Ammonia | **0.053** J | NA | NA | 0.051 U | 0.051 U |
| **Nutrients** | **Lower** | **Lower Duplicates** | **Relative Percent Difference** | **Laboratory Blank** | **Field Blank** |
| Total Phosphorus | 0.009 U | 0.009 U | 0.00% | 0.009 U | **0.03** |
| Orthophosphate as P | 0.006 U | 0.006 U | 0.00% | 0.006 U | 0.006 U |
| Total Organic Carbon | 0.5 UF1 | **0.67** J | 29.06% | 0.5 U | 0.5 U |
| Dissolved Inorganic Carbon | **58.2** | **59.1** | 1.53% | **2.21** | **2.26** |
| Dissolved Organic Carbon | **1.46** | **2.18** | 39.56% | **1.37** | **1.39** |
| Kjeldahl Nitrogen | **0.57** | **0.37** | 42.55% | **0.49** | **0.40** |
| Nitrate as N | **1.72** | **1.72** | 0.00% | **0.13** | **0.12** |
| Ammonia | **0.06** J | **0.06** J | 0.00% | 0.051 U | 0.051 U |

U Non-detect

F1 MS and/or MSD recovery exceeds control limits

J Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.

Table A-7. PPCP concentrations reported for samples, equipment blank, DI blank, and lab blank at the San Marcos groundwater sites (i.e., Hotel and Deep Hole springs) in Spring. Samples with detectable concentrations denoted in bold.

| PPCP List | Hotel spring | | Deep Hole | | DI Blank | | Lab Blank | |
|---|---|---|---|---|---|---|---|---|
| Acetaminophen | 3.08 | U | 3.15 | U | 3.29 | U | 3.00 | U |
| Azithromycin | 1.54 | U | 1.58 | U | 1.65 | U | 1.50 | U |
| Caffeine | 6.17 | U | 6.3 | U | 6.59 | U | 6.00 | U |
| Carbadox | 0.617 | U | 0.63 | U | 0.659 | U | 0.60 | U |
| Carbamazepine | 0.308 | U | 0.315 | U | 0.329 | U | 0.30 | U |
| Cefotaxime | 6.1 | U | 6.24 | U | 6.52 | U | 5.94 | U |
| Ciprofloxacin | 1.54 | U | 1.58 | U | 1.65 | U | 1.50 | U |
| Clarithromycin | 0.308 | U | 0.315 | U | 0.329 | U | 0.30 | U |
| Clinafloxacin | 2.05 | U | 2.1 | U | 2.19 | U | 2.00 | U |
| Cloxacillin | 3.08 | U H | 3.15 | U H | 3.29 | U H | 3.00 | U H |
| Dehydronifedipine | 0.308 | U | 0.315 | U | 0.329 | U | 0.30 | U |
| Digoxigenin | 1.54 | U | 1.58 | U | 1.65 | U | 1.50 | U |
| Digoxin | 6.17 | U | 6.3 | U | 6.59 | U | 6.00 | U |
| Diltiazem | 0.154 | U | 0.158 | U | 0.165 | U | 0.15 | U |
| Diphenhydramine | 0.617 | U | 0.63 | U | 0.659 | U | 0.60 | U |
| Enrofloxacin | 0.617 | U | 0.63 | U | 0.659 | U | 0.60 | U |
| Erythromycin-H2O | 1.54 | U H | 1.58 | U H | 1.65 | U H | 1.50 | U H |
| Flumequine | 0.308 | U | 0.315 | U | 0.329 | U | 0.30 | U |
| Fluoxetine | 0.154 | U | 0.158 | U | 0.165 | U | 0.15 | U |
| Lincomycin | 0.617 | U | 0.63 | U | 0.659 | U | 0.60 | U |
| Lomefloxacin | 0.617 | U | 0.63 | U | 0.659 | U | 0.60 | U |
| Miconazole | 0.308 | U | 0.315 | U | 0.329 | U | 0.30 | U |
| Norfloxacin | 2.05 | U | 2.1 | U | 2.19 | U | 2.00 | U |
| Norgestimate | 1.54 | U | 1.58 | U | 1.65 | U | 1.50 | U |
| Ofloxacin | 0.617 | U | 0.63 | U | 0.659 | U | 0.60 | U |
| Ormetoprim | 0.154 | U | 0.158 | U | 0.165 | U | 0.15 | U |
| Oxacillin | 1.54 | U H | 1.58 | U H | 1.65 | U H | 1.50 | U H |
| Oxolinic Acid | 0.617 | U | 0.63 | U | 0.659 | U | 0.60 | U |
| Penicillin G | **3.86** | RH | **11.9** | RH | **4.47** | RH | **4.16** | RH |
| Penicillin V | 1.54 | U | 1.58 | U | 1.65 | U | 1.50 | U |
| Roxithromycin | 0.154 | U | 0.158 | U | 0.165 | U | 0.15 | U |
| Sarafloxacin | 3.08 | U | 3.15 | U | 3.29 | U | 3.00 | U |
| Sulfachloropyridazine | 0.617 | U | 0.63 | U | 0.659 | U | 0.60 | U |
| Sulfadiazine | 0.617 | U | 0.63 | U | 0.659 | U | 0.60 | U |
| Sulfadimethoxine | 0.308 | U | 0.315 | U | 0.329 | U | 0.30 | U |
| Sulfamerazine | 0.617 | U | 0.63 | U | 0.659 | U | 0.60 | U |
| Sulfamethazine | 0.617 | U | 0.63 | U | 0.659 | U | 0.60 | U |
| Sulfamethizole | 0.617 | U | 0.63 | U | 0.659 | U | 0.60 | U |
| Sulfamethoxazole | 0.617 | U | 0.63 | U | 0.659 | U | 0.60 | U |
| Sulfanilamide | 6.17 | U | 6.3 | U | 6.59 | U | 6.00 | U |
| Sulfathiazole | 1.54 | U | 1.58 | U | 1.65 | U | 1.50 | U |
| Thiabendazole | 0.308 | U | 0.315 | U | 0.329 | U | 0.30 | U |
| Trimethoprim | 0.308 | U | 0.315 | U | 0.329 | U | 0.30 | U |
| Tylosin | 0.617 | U | 0.63 | U | 0.659 | U | 0.60 | U |
| Virginiamycin M1 | 0.617 | U | 0.663 | U | 0.659 | U | 0.60 | U |
| 1,7-Dimethylxanthine | 6.17 | U | 6.3 | U | 6.59 | U | 6.00 | U |

[U] Non-detect at reporting limit
[R] Peak detected but did not meet quantification criteria, result reported is estimated maximum possible concentration
[H] Concentration is estimated

Table A-8. PPCP concentrations reported for samples, equipment blank, DI blank, and Lab blank at the San Marcos groundwater sites (i.e., Hotel and Deep Hole springs) in Spring. Samples with detectable concentrations denoted in bold.

| PPCP List Continued | Hotel spring | | Deep Hole | | DI Blank | | Lab Blank | |
|---|---|---|---|---|---|---|---|---|
| Alprazolam | 0.308 | U | 0.315 | U | 0.329 | U | 0.30 | U |
| Amitriptyline | 0.308 | U | 0.315 | U | 0.329 | U | 0.30 | U |
| Amlodipine | 1.03 | U | 1.06 | U | 1.1 | U | 1.01 | U |
| Benzoylecgonine | 0.154 | U | 0.158 | U | 0.165 | U | 0.15 | U |
| Benztropine | 0.719 | U | 0.735 | U | 0.769 | U | 0.70 | U |
| Betamethasone | 1.54 | U | 1.58 | U | 1.65 | U | 1.50 | U |
| Cocaine | **0.164** | | 0.158 | U | 0.165 | U | 0.15 | U |
| DEET | **5.19** | | **9.44** | | **3.29** | | **3.30** | |
| Desmethyldiltiazem | 0.154 | U | 0.158 | U | 0.165 | U | 0.15 | U |
| Diazepam | 0.516 | U | 0.527 | U | 0.551 | U | 0.50 | U |
| Fluocinonide | 2.07 | U | 2.11 | U | 2.21 | U | 2.01 | U |
| Fluticasone propionate | 2.07 | U | 2.11 | U | 2.21 | U | 2.01 | U |
| Hydrocortisone | 6.17 | U | 6.3 | U | 6.59 | U | 6.00 | U |
| 10-hydroxy-amitriptyline | 0.154 | U | 0.158 | U | 0.165 | U | 0.15 | U |
| Meprobamate | 1.54 | U | 1.58 | U | 1.65 | U | 1.50 | U |
| Methylprednisolone | 4.11 | U | 4.2 | U | 4.39 | U | 4.00 | U |
| Metoprolol | 0.516 | U | 0.527 | U | 0.551 | U | 0.50 | U |
| Norfluoxetine | 0.516 | U | 0.527 | U | 0.551 | U | 0.50 | U |
| Norverapamil | 0.154 | U | 0.158 | U | 0.165 | U | 0.15 | U |
| Paroxetine | 1.03 | U | 1.06 | U | 1.1 | U | 1.01 | U |
| Prednisolone | 4.11 | U | 4.2 | U | 4.39 | U | 4.00 | U |
| Prednisone | 6.17 | U | 6.3 | U | 6.59 | U | 6.00 | U |
| Promethazine | 0.308 | U | 0.315 | U | 0.329 | U | 0.30 | U |
| Propoxyphene | 0.308 | U | 0.315 | U | 0.329 | U | 0.30 | U |
| Propranolol | 0.308 | U | 0.315 | U | 0.329 | U | 0.30 | U |
| Sertraline | 0.308 | U | 0.315 | U | 0.329 | U | 0.30 | U |
| Simvastatin | 2.07 | U | 2.11 | U | 2.21 | U | 2.01 | U |
| Theophylline | 6.17 | U | 6.3 | U | 6.59 | U | 6.00 | U |
| Trenbolone | 2.07 | U | 2.11 | U | 2.21 | U | 2.01 | U |
| Trenbolone acetate | 0.308 | U | 0.315 | U | 0.329 | U | 0.30 | U |
| Valsartan | 4.11 | U | 4.2 | U | 4.39 | U | 4.00 | U |
| Verapamil | 0.154 | U | 0.158 | U | 0.165 | U | 0.15 | U |

U Non-detect at reporting limit
H Concentration is estimated

Table A-9. PPCP concentrations reported for samples, DI blank, and lab blank at the San Marcos groundwater sites (i.e., Hotel and Deep Hole springs) in Fall. Samples with detectable concentrations denoted in bold.

| PPCP List | Hotel spring | Hotel spring Duplicate | Deep Hole | Equipment DI Blank | Lab Blank |
|---|---|---|---|---|---|
| Acetaminophen | 3.02 U | 3.35 U | 3.06 U | 3.29 U | 3.00 U |
| Azithromycin | 1.51 U | 1.68 U | 1.53 U | 1.65 U | 1.50 U |
| Caffeine | 6.04 U | 6.71 U | 6.11 U | **7.33** | 6.00 U |
| Carbadox | 0.604 U | 0.671 U | 0.611 U | 0.659 U | 0.60 U |
| Carbamazepine | 0.302 U | 0.335 U | 0.306 U | 0.329 U | 0.30 U |
| Cefotaxime | 5.98 U | 6.64 U | 6.05 U | 6.52 U | 5.94 U |
| Ciprofloxacin | 1.51 U | 1.68 U | 1.53 U | 1.65 U | 1.50 U |
| Clarithromycin | 0.302 U | 0.335 U | 0.306 U | 0.329 U | 0.30 U |
| Clinafloxacin | 2.01 U | 2.23 U | 2.04 U | 2.19 U | 2.00 U |
| Cloxacillin | 3.02 UH | 3.35 U H | 3.06 UH | **36.3** H | 3.00 U H |
| Dehydronifedipine | 0.302 U | 0.335 U | 0.306 U | 0.329 U | 0.30 U |
| Digoxigenin | 1.51 U | 1.68 U | 1.53 U | 1.65 U | 1.50 U |
| Digoxin | 6.04 U | 6.71 U | 6.11 U | 6.59 U | 6.00 U |
| Diltiazem | 0.151 U | 0.168 U | 0.153 U | 0.165 U | 0.15 U |
| Diphenhydramine | 0.604 U | 0.671 U | 0.611 U | 0.659 U | 0.60 U |
| Enrofloxacin | 0.604 U | 0.671 U | 0.611 U | 0.659 U | 0.60 U |
| Erythromycin-H2O | 1.51 U H | 1.68 U H | 1.53 U H | 1.65 U H | 1.50 U H |
| Flumequine | 0.302 U | 0.335 U | 0.306 U | 0.329 U | 0.30 U |
| Fluoxetine | 0.151 U | 0.168 U | 0.153 U | 0.165 U | 0.15 U |
| Lincomycin | 0.604 U | 0.671 U | 0.611 U | 0.659 U | 0.60 U |
| Lomefloxacin | 0.604 U | 0.671 U | 0.611 U | 0.659 U | 0.60 U |
| Miconazole | 0.302 U | 0.335 U | 0.306 U | 0.329 U | 0.30 U |
| Norfloxacin | 2.01 U | 2.23 U | 2.04 U | 2.19 U | 2.00 U |
| Norgestimate | 1.51 U | 1.68 U | 1.53 U | 1.65 U | 1.50 U |
| Ofloxacin | 0.604 U | 0.671 U | 0.611 U | 0.659 U | 0.60 U |
| Ormetoprim | 0.151 U | 0.168 U | 0.153 U | 0.165 U | 0.15 U |
| Oxacillin | 1.51 U H | 1.68 U H | 1.53 U H | 1.65 U H | 1.50 U H |
| Oxolinic Acid | 0.604 U | 0.671 U | 0.611 U | 0.659 U | 0.60 U |
| Penicillin G | 3.02 UH | **4.04** R H | **20.4** RH | **384** RH | 3.00 U H |
| Penicillin V | 1.51 U | 1.68 U | **17.3** R | **201** R | 1.50 U |
| Roxithromycin | 0.151 U | 0.168 U | 0.153 U | 0.219 U | 0.15 U |
| Sarafloxacin | 3.02 U | 3.35 U | 3.06 U | 3.29 U | 3.00 U |
| Sulfachloropyridazine | 0.604 U | 0.671 U | 0.611 U | 0.659 U | 0.60 U |
| Sulfadiazine | 0.604 U | 0.671 U | 0.611 U | 0.659 U | 0.60 U |
| Sulfadimethoxine | 0.302 U | 0.335 U | 0.306 U | 0.329 U | 0.30 U |
| Sulfamerazine | 0.604 U | 0.671 U | 0.611 U | 0.659 U | 0.60 U |
| Sulfamethazine | 0.604 U | 0.671 U | 0.611 U | 0.659 U | 0.60 U |
| Sulfamethizole | 0.604 U | 0.671 U | 0.611 U | 0.659 U | 0.60 U |
| Sulfamethoxazole | 0.604 U | 0.671 U | 0.611 U | 0.659 U | 0.60 U |
| Sulfanilamide | 6.04 U | 6.71 U | 6.11 U | 6.59 U | 6.00 U |
| Sulfathiazole | 1.51 U | 1.68 U | 1.53 U | 1.65 U | 1.50 U |
| Thiabendazole | 0.302 U | 0.335 U | 0.306 U | 0.329 U | 0.30 U |
| Trimethoprim | 0.302 U | 0.335 U | 0.306 U | 0.329 U | 0.30 U |
| Tylosin | 0.604 U | 0.671 U | 0.611 U | 0.659 U | 0.60 U |
| Virginiamycin M1 | 0.604 U | 0.671 U | 0.798 U | 0.95 U | 0.60 U |
| 1,7-Dimethylxanthine | 6.04 U | 6.71 U | 6.11 U | 6.59 U | 6.00 U |

[U] Non-detect at reporting limit
[R] Peak detected but did not meet quantification criteria, result reported is estimated maximum possible concentration
[H] Concentration is estimated

Table A-10. PPCP concentrations reported for samples, DI blank, and lab blank at the San Marcos groundwater sites (i.e., Hotel and Deep Hole springs) in Fall. Samples with detectable concentrations denoted in bold.

| PPCP List Continued | Hotel spring | | Hotel spring Duplicate | | Deep Hole | | Equipment DI Blank | | Lab Blank | |
|---|---|---|---|---|---|---|---|---|---|---|
| Alprazolam | 0.302 | U | 0.335 | U | 0.306 | U | 0.329 | U | 0.30 | U |
| Amitriptyline | 0.302 | U | 0.335 | U | 0.306 | U | 0.329 | U | 0.30 | U |
| Amlodipine | 1.01 | U | 1.12 | U | 1.03 | U | 1.1 | U | 1.01 | U |
| Benzoylecgonine | 0.151 | U | 0.168 | U | 0.153 | U | 0.165 | U | 0.15 | U |
| Benztropine | 0.705 | U | 0.783 | U | 0.713 | U | 0.769 | U | 0.70 | U |
| Betamethasone | 1.51 | U | 1.68 | U | 1.53 | U | 1.65 | U | 1.50 | U |
| Cocaine | 0.151 | U | **0.479** | | **0.569** | | **0.618** | | 0.15 | U |
| DEET | **9.00** | | **3.56** | | **7.36** | | **50.1** | | **3.53** | |
| Desmethyldiltiazem | 0.151 | U | 0.168 | U | 0.153 | U | 0.165 | U | 0.15 | U |
| Diazepam | 0.506 | U | 0.561 | U | 0.512 | U | 0.551 | U | 0.50 | U |
| Fluocinonide | 2.02 | U | 2.25 | U | 2.05 | U | 2.21 | U | 2.01 | U |
| Fluticasone propionate | 2.02 | U | 2.25 | U | 2.05 | U | 2.21 | U | 2.01 | U |
| Hydrocortisone | 6.04 | U | 6.71 | U | 6.11 | U | 6.59 | U | 6.00 | U |
| 10-hydroxy-amitriptyline | 0.151 | U | 0.168 | U | 0.153 | U | 0.165 | U | 0.15 | U |
| Meprobamate | 1.51 | U | 1.68 | U | 1.53 | U | 1.65 | U | 1.50 | U |
| Methylprednisolone | 4.03 | U | 4.47 | U | 4.08 | U | 4.39 | U | 4.00 | U |
| Metoprolol | 0.506 | U | 0.561 | U | 0.512 | U | 0.551 | U | 0.50 | U |
| Norfluoxetine | 0.506 | U | 0.561 | U | 0.512 | U | 0.551 | U | 0.50 | U |
| Norverapamil | 0.151 | U | 0.168 | U | 0.153 | U | 0.165 | U | 0.15 | U |
| Paroxetine | 1.01 | U | 1.12 | U | 1.03 | U | 1.1 | U | 1.01 | U |
| Prednisolone | 4.03 | U | 4.47 | U | 4.08 | U | 4.39 | U | 4.00 | U |
| Prednisone | 6.04 | U | 6.71 | U | 6.11 | U | 6.59 | U | 6.00 | U |
| Promethazine | 0.302 | U | 0.335 | U | 0.306 | U | 0.329 | U | 0.30 | U |
| Propoxyphene | 0.302 | U | 0.335 | U | 0.306 | U | 0.329 | U | 0.30 | U |
| Propranolol | 0.302 | U | 0.335 | U | 0.306 | U | 0.329 | U | 0.30 | U |
| Sertraline | 0.302 | U | 0.335 | U | 0.306 | U | 0.329 | U | 0.30 | U |
| Simvastatin | 2.02 | U | 2.25 | U | 2.05 | U | 2.21 | U | 2.01 | U |
| Theophylline | 6.04 | U | 6.71 | U | 6.11 | U | 6.59 | U | 6.00 | U |
| Trenbolone | 2.02 | U | 2.25 | U | 2.05 | U | 2.21 | U | 2.01 | U |
| Trenbolone acetate | 0.302 | U | 0.335 | U | 0.306 | U | 0.329 | U | 0.30 | U |
| Valsartan | 4.03 | U | 4.47 | U | 4.08 | U | 4.39 | U | 4.00 | U |
| Verapamil | 0.151 | U | 0.168 | U | 0.153 | U | 0.165 | U | 0.15 | U |

[U] Non-detect at reporting limit
[H] Concentration is estimated

Table A-11. PPCP concentrations reported for samples, equipment blank, DI blank, and lab blank at the Comal groundwater sites (i.e., Spring run 1, 3 and 7) in Spring. Samples with detectable concentrations denoted in bold.

| PPCP List | Spring Run 1 | | Spring Run 3 | | Spring Run 3 Duplicate | | Spring Run 7 | | DI Blank | | Lab Blank | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Acetaminophen | 3.32 | U | 3.4 | U | 3.47 | U | 3.18 | U | 3.29 | U | 3.00 | U |
| Azithromycin | 1.66 | U | 1.7 | U | 1.74 | U | 1.59 | U | 1.65 | U | 1.50 | U |
| Caffeine | 6.63 | U | 6.8 | U | 6.94 | U | 6.35 | U | 6.59 | U | 6.00 | U |
| Carbadox | 0.663 | U | 0.68 | U | 0.694 | U | 0.635 | U | 0.659 | U | 0.60 | U |
| Carbamazepine | 0.332 | U | 0.34 | U | 0.347 | U | 0.318 | U | 0.329 | U | 0.30 | U |
| Cefotaxime | 6.56 | U | 6.73 | U | 6.87 | U | 6.29 | U | 6.52 | U | 5.94 | U |
| Ciprofloxacin | 1.66 | U | 1.7 | U | 1.74 | U | 1.59 | U | 1.65 | U | 1.50 | U |
| Clarithromycin | 0.332 | U | 0.34 | U | 0.347 | U | 0.318 | U | 0.329 | U | 0.30 | U |
| Clinafloxacin | 2.21 | U | 2.27 | U | 2.31 | U | 2.12 | U | 2.19 | U | 2.00 | U |
| Cloxacillin | 3.32 | U H | 3.4 | U H | 3.47 | U H | 3.18 | U H | 3.29 | U H | 3.00 | U H |
| Dehydronifedipine | 0.332 | U | 0.34 | U | 0.347 | U | 0.318 | U | 0.329 | U | 0.30 | U |
| Digoxigenin | 1.66 | U | 1.7 | U | 1.74 | U | 1.59 | U | 1.65 | U | 1.50 | U |
| Digoxin | 6.63 | U | 6.8 | U | 6.94 | U | 6.35 | U | 6.59 | U | 6.00 | U |
| Diltiazem | 0.166 | U | 0.17 | U | 0.174 | U | 0.159 | U | 0.165 | U | 0.15 | U |
| Diphenhydramine | 0.663 | U | 0.68 | U | 0.694 | U | 0.635 | U | 0.659 | U | 0.60 | U |
| Enrofloxacin | 0.663 | U | 0.68 | U | 0.694 | U | 0.635 | U | 0.659 | U | 0.60 | U |
| Erythromycin-H2O | 1.66 | U H | 1.7 | U H | 1.74 | U H | 1.59 | U H | 1.65 | U H | 1.50 | U H |
| Flumequine | 0.332 | U | 0.34 | U | 0.347 | U | 0.318 | U | 0.329 | U | 0.30 | U |
| Fluoxetine | 0.166 | U | 0.17 | U | 0.174 | U | 0.159 | U | 0.165 | U | 0.15 | U |
| Lincomycin | 0.663 | U | 0.68 | U | 0.694 | U | 0.635 | U | 0.659 | U | 0.60 | U |
| Lomefloxacin | 0.663 | U | 0.68 | U | 0.694 | U | 0.635 | U | 0.659 | U | 0.60 | U |
| Miconazole | 0.332 | U | 0.34 | U | 0.347 | U | 0.318 | U | 0.329 | U | 0.30 | U |
| Norfloxacin | 2.21 | U | 2.27 | U | 2.31 | U | 2.12 | U | 2.19 | U | 2.00 | U |
| Norgestimate | 1.66 | U | 1.7 | U | 1.74 | U | 1.59 | U | 1.65 | U | 1.50 | U |
| Ofloxacin | 0.663 | U | 0.68 | U | 0.694 | U | 0.635 | U | 0.659 | U | 0.60 | U |
| Ormetoprim | 0.166 | U | 0.17 | U | 0.174 | U | 0.159 | U | 0.165 | U | 0.15 | U |
| Oxacillin | 1.66 | U H | 1.7 | U H | 1.74 | U H | 1.59 | U H | 1.65 | U H | 1.50 | U H |
| Oxolinic Acid | 0.663 | U | 0.68 | U | 0.694 | U | 0.635 | U | 0.659 | U | 0.60 | U |
| Penicillin G | **4.65** | RH | **3.84** | RH | **3.58** | RH | **4.09** | RH | **4.47** | RH | **4.16** | RH |
| Penicillin V | 1.66 | U | 1.7 | U | 1.74 | U | 1.59 | U | 1.65 | U | 1.50 | U |
| Roxithromycin | 0.166 | U | 0.17 | U | 0.174 | U | 0.159 | U | 0.165 | U | 0.15 | U |
| Sarafloxacin | 3.32 | U | 3.4 | U | 3.47 | U | 3.18 | U | 3.29 | U | 3.00 | U |
| Sulfachloropyridazine | 0.663 | U | 0.68 | U | 0.694 | U | 0.635 | U | 0.659 | U | 0.60 | U |
| Sulfadiazine | 0.663 | U | 0.68 | U | 0.694 | U | 0.635 | U | 0.659 | U | 0.60 | U |
| Sulfadimethoxine | 0.332 | U | 0.34 | U | 0.347 | U | 0.318 | U | 0.329 | U | 0.30 | U |
| Sulfamerazine | 0.663 | U | 0.68 | U | 0.694 | U | 0.635 | U | 0.659 | U | 0.60 | U |
| Sulfamethazine | 0.663 | U | 0.68 | U | 0.694 | U | 0.635 | U | 0.659 | U | 0.60 | U |
| Sulfamethizole | 0.663 | U | 0.68 | U | 0.694 | U | 0.635 | U | 0.659 | U | 0.60 | U |
| Sulfamethoxazole | 0.663 | U | 0.68 | U | 0.694 | U | 0.635 | U | 0.659 | U | 0.60 | U |
| Sulfanilamide | 6.63 | U | 6.8 | U | 6.94 | U | 6.35 | U | 6.59 | U | 6.00 | U |
| Sulfathiazole | 1.66 | U | 1.7 | U | 1.74 | U | 1.59 | U | 1.65 | U | 1.50 | U |
| Thiabendazole | 0.332 | U | 0.34 | U | 0.347 | U | 0.318 | U | 0.329 | U | 0.30 | U |
| Trimethoprim | 0.332 | U | 0.34 | U | 0.347 | U | 0.318 | U | 0.329 | U | 0.30 | U |
| Tylosin | 0.663 | U | 0.68 | U | 0.694 | U | 0.635 | U | 0.659 | U | 0.60 | U |
| Virginiamycin M1 | 0.663 | U | 0.68 | U | 0.694 | U | 0.635 | U | 0.659 | U | 0.60 | U |
| 1,7-Dimethylxanthine | 6.63 | U | 6.8 | U | 6.94 | U | 6.35 | U | 6.59 | U | 6.00 | U |

[U] Non-detect at reporting limit
[R] Peak detected but did not meet quantification criteria, result reported is estimated maximum possible concentration
[H] Concentration is estimated

Table A-12. PPCP concentrations reported for samples, equipment blank, DI blank, and lab blank at the Comal groundwater sites (i.e., Spring run 1, 3 and 7) in Spring. Samples with detectable concentrations denoted in bold.

| PPCP List Continued | Spring Run 1 | Spring Run 3 | Spring Run 3 Duplicate | Spring Run 7 | DI Blank | Lab Blank |
|---|---|---|---|---|---|---|
| Alprazolam | 0.332 U | 0.34 U | 0.347 U | 0.318 U | 0.329 U | 0.30 U |
| Amitriptyline | 0.332 U | 0.34 U | 0.347 U | 0.318 U | 0.329 U | 0.30 U |
| Amlodipine | 1.11 U | 1.14 U | 1.16 U | 1.07 U | 1.1 U | 1.01 U |
| Benzoylecgonine | 0.166 U | 0.17 U | 0.174 U | 0.159 U | 0.165 U | 0.15 U |
| Benztropine | 0.774 U | 0.794 U | 0.81 U | 0.741 U | 0.769 U | 0.70 U |
| Betamethasone | 1.66 U | 1.7 U | 1.74 U | 1.59 U | 1.65 U | 1.50 U |
| Cocaine | 0.166 U | 0.17 U | 0.174 U | 0.159 U | 0.165 U | 0.15 U |
| DEET | **3.98** | **3.77** | **4.65** | **5.06** | **3.29** | **3.30** |
| Desmethyldiltiazem | 0.166 U | 0.17 U | 0.174 U | 0.159 U | 0.165 U | 0.15 U |
| Diazepam | 0.555 U | 0.569 U | 0.581 U | 0.531 U | 0.551 U | 0.50 U |
| Fluocinonide | 2.22 U | 2.28 U | 2.33 U | 2.13 U | 2.21 U | 2.01 U |
| Fluticasone propionate | 2.22 U | 2.28 U | 2.33 U | 2.13 U | 2.21 U | 2.01 U |
| Hydrocortisone | 6.63 U | 6.8 U | 6.94 U | 6.35 U | 6.59 U | 6.00 U |
| 10-hydroxy-amitriptyline | 0.166 U | 0.17 U | 0.174 U | 0.159 U | 0.165 U | 0.15 U |
| Meprobamate | 1.66 U | 1.7 U | 1.74 U | 1.59 U | 1.65 U | 1.50 U |
| Methylprednisolone | 4.42 U | 4.53 U | 4.63 U | 4.23 U | 4.39 U | 4.00 U |
| Metoprolol | 0.555 U | 0.569 U | 0.581 U | 0.531 U | 0.551 U | 0.50 U |
| Norfluoxetine | 0.555 U | 0.569 U | 0.581 U | 0.531 U | 0.551 U | 0.50 U |
| Norverapamil | 0.166 U | 0.17 U | 0.174 U | 0.159 U | 0.165 U | 0.15 U |
| Paroxetine | 1.11 U | 1.14 U | 1.16 U | 1.07 U | 1.1 U | 1.01 U |
| Prednisolone | 4.42 U | 4.53 U | 4.63 U | 4.23 U | 4.39 U | 4.00 U |
| Prednisone | 6.63 U | 6.8 U | 6.94 U | 6.35 U | 6.59 U | 6.00 U |
| Promethazine | 0.332 U | 0.34 U | 0.347 U | 0.318 U | 0.329 U | 0.30 U |
| Propoxyphene | 0.332 U | 0.34 U | 0.347 U | 0.318 U | 0.329 U | 0.30 U |
| Propranolol | 0.332 U | 0.34 U | 0.347 U | 0.318 U | 0.329 U | 0.30 U |
| Sertraline | 0.332 U | 0.34 U | 0.347 U | 0.318 U | 0.329 U | 0.30 U |
| Simvastatin | 2.22 U | 2.28 U | 2.33 U | 2.13 U | 2.21 U | 2.01 U |
| Theophylline | 6.63 U | 6.8 U | 6.94 U | 6.35 U | 6.59 U | 6.00 U |
| Trenbolone | 2.22 U | 2.28 U | 2.33 U | 2.13 U | 2.21 U | 2.01 U |
| Trenbolone acetate | 0.332 U | 0.34 U | 0.347 U | 0.318 U | 0.329 U | 0.30 U |
| Valsartan | 4.42 U | 4.53 U | 4.63 U | 4.23 U | 4.39 U | 4.00 U |
| Verapamil | 0.166 U | 0.17 U | 0.174 U | 0.159 U | 0.165 U | 0.15 U |

U Non-detect at reporting limit

H Concentration is estimated

Table A-13. PPCP concentrations reported for samples, DI blank, and lab blank at the Comal groundwater sites (i.e., Spring run 1, 3 and 7) in Fall. Samples with detectable concentrations denoted in bold.

| PPCP List | Spring Run 1 | Spring Run 3 | Spring Run 7 | Lab Blank |
|---|---|---|---|---|
| Acetaminophen | **7.56** | 3.19 [U] | 3.13 [U] | 3.00 [U] |
| Azithromycin | 1.7 [U] | 1.59 [U] | 1.57 [U] | 1.50 [U] |
| Caffeine | **21.1** | 6.38 [U] | 6.26 [U] | 6.00 [U] |
| Carbadox | 0.681 [U] | 0.638 [U] | 0.626 [U] | 0.60 [U] |
| Carbamazepine | 0.34 [U] | 0.319 [U] | 0.313 [U] | 0.30 [U] |
| Cefotaxime | 6.74 [U] | 6.31 [U] | 6.2 [U] | 5.94 [U] |
| Ciprofloxacin | 1.7 [U] | 1.59 [U] | 1.57 [U] | 1.50 [U] |
| Clarithromycin | 0.34 [U] | 0.319 [U] | 0.313 [U] | 0.30 [U] |
| Clinafloxacin | 2.27 [U] | 2.12 [U] | 2.09 [U] | 2.00 [U] |
| Cloxacillin | 3.4 [U H] | 3.19 [U H] | 3.13 [U H] | 3.00 [U H] |
| Dehydronifedipine | 0.34 [U] | 0.319 [U] | 0.313 [U] | 0.30 [U] |
| Digoxigenin | 1.7 [U] | 1.59 [U] | 1.57 [U] | 1.50 [U] |
| Digoxin | 6.81 [U] | 6.38 [U] | 6.26 [U] | 6.00 [U] |
| Diltiazem | 0.17 [U] | 0.159 [U] | 0.157 [U] | 0.15 [U] |
| Diphenhydramine | 0.681 [U] | 0.638 [U] | 0.626 [U] | 0.60 [U] |
| Enrofloxacin | 0.681 [U] | 0.638 [U] | 0.626 [U] | 0.60 [U] |
| Erythromycin-H2O | 1.7 [U H] | 1.59 [U H] | 1.57 [U H] | 1.50 [U H] |
| Flumequine | 0.34 [U] | 0.319 [U] | 0.313 [U] | 0.30 [U] |
| Fluoxetine | 0.17 [U] | 0.159 [U] | 0.157 [U] | 0.15 [U] |
| Lincomycin | 0.681 [U] | 0.638 [U] | 0.626 [U] | 0.60 [U] |
| Lomefloxacin | 0.681 [U] | 0.638 [U] | 0.626 [U] | 0.60 [U] |
| Miconazole | 0.34 [U] | 0.319 [U] | 0.313 [U] | 0.30 [U] |
| Norfloxacin | 2.27 [U] | 2.12 [U] | 2.09 [U] | 2.00 [U] |
| Norgestimate | 1.7 [U] | 1.59 [U] | 1.57 [U] | 1.50 [U] |
| Ofloxacin | 0.681 [U] | 0.638 [U] | 0.626 [U] | 0.60 [U] |
| Ormetoprim | 0.17 [U] | 0.159 [U] | 0.157 [U] | 0.15 [U] |
| Oxacillin | 1.7 [U H] | 1.59 [U H] | 1.57 [U H] | 1.50 [U H] |
| Oxolinic Acid | 0.681 [U] | 0.638 [U] | 0.626 [U] | 0.60 [U] |
| Penicillin G | 3.4 [U H] | 3.19 [U H] | 3.13 [U H] | 3.00 [U H] |
| Penicillin V | 1.7 [U] | 1.59 [U] | 1.57 [U] | 1.50 [U] |
| Roxithromycin | 0.17 [U] | 0.159 [U] | 0.157 [U] | 0.15 [U] |
| Sarafloxacin | 3.4 [U] | 3.19 [U] | 3.13 [U] | 3.00 [U] |
| Sulfachloropyridazine | 0.681 [U] | 0.638 [U] | 0.626 [U] | 0.60 [U] |
| Sulfadiazine | 0.681 [U] | 0.638 [U] | 0.626 [U] | 0.60 [U] |
| Sulfadimethoxine | 0.34 [U] | 0.319 [U] | 0.313 [U] | 0.30 [U] |
| Sulfamerazine | 0.681 [U] | 0.638 [U] | 0.626 [U] | 0.60 [U] |
| Sulfamethazine | 0.681 [U] | 0.638 [U] | 0.626 [U] | 0.60 [U] |
| Sulfamethizole | 0.745 [U] | 0.638 [U] | **0.818** | 0.60 [U] |
| Sulfamethoxazole | 0.681 [U] | 0.638 [U] | **0.667** | 0.60 [U] |
| Sulfanilamide | 6.81 [U] | 6.38 [U] | 6.26 [U] | 6.00 [U] |
| Sulfathiazole | 1.7 [U] | 1.59 [U] | 1.57 [U] | 1.50 [U] |
| Thiabendazole | 0.34 [U] | 0.319 [U] | 0.313 [U] | 0.30 [U] |
| Trimethoprim | 0.34 [U] | 0.319 [U] | 0.313 [U] | 0.30 [U] |
| Tylosin | 0.681 [U] | 0.638 [U] | 0.626 [U] | 0.60 [U] |
| Virginiamycin M1 | 0.681 [U] | 0.638 [U] | 0.626 [U] | 0.60 [U] |
| 1,7-Dimethylxanthine | **7.98** | 6.38 [U] | 6.26 [U] | 6.00 [U] |

[U] Non-detect at reporting limit
[H] Concentration is estimated

Table A-14. PPCP concentrations reported for samples, DI blank, and lab blank at the Comal groundwater sites (i.e., Spring run 1, 3 and 7) in Fall. Samples with detectable concentrations denoted in bold.

| PPCP List | Spring Run 1 | | Spring Run 3 | | Spring Run 7 | | Lab Blank | |
|---|---|---|---|---|---|---|---|---|
| Alprazolam | **0.34** | U | 0.319 | U | 0.313 | U | 0.30 | U |
| Amitriptyline | 0.34 | U | 0.319 | U | 0.313 | U | 0.30 | U |
| Amlodipine | **1.14** | U | 1.07 | U | 1.05 | U | 1.01 | U |
| Benzoylecgonine | **0.46** | | 0.159 | U | **0.384** | | 0.15 | U |
| Benztropine | 0.794 | U | 0.744 | U | 0.731 | U | 0.70 | U |
| Betamethasone | 1.7 | U | 1.59 | U | 1.57 | U | 1.50 | U |
| Cocaine | **1.33** | | **0.25** | | **3.16** | | 0.15 | U |
| DEET | **3.04** | | **2.7** | | **9.18** | | **3.53** | |
| Desmethyldiltiazem | 0.17 | U | 0.159 | U | 0.157 | U | 0.15 | U |
| Diazepam | 0.57 | U | 0.534 | U | 0.524 | U | 0.50 | U |
| Fluocinonide | 2.28 | U | 2.14 | U | 2.1 | U | 2.01 | U |
| Fluticasone propionate | 2.28 | U | 2.14 | U | 2.1 | U | 2.01 | U |
| Hydrocortisone | **40.8** | | 6.38 | U | **6.48** | | 6.00 | U |
| 10-hydroxy-amitriptyline | 0.17 | U | 0.159 | U | 0.157 | U | 0.15 | U |
| Meprobamate | 1.7 | U | 1.59 | U | 1.57 | U | 1.50 | U |
| Methylprednisolone | 4.54 | U | 4.25 | U | 4.17 | U | 4.00 | U |
| Metoprolol | 0.57 | U | 0.534 | U | 0.524 | U | 0.50 | U |
| Norfluoxetine | 0.57 | U | 0.534 | U | 0.524 | U | 0.50 | U |
| Norverapamil | 0.17 | U | 0.159 | U | 0.157 | U | 0.15 | U |
| Paroxetine | 1.14 | U | 1.07 | U | 1.05 | U | 1.01 | U |
| Prednisolone | 4.54 | U | 4.25 | U | 4.17 | U | 4.00 | U |
| Prednisone | 6.81 | U | 6.38 | U | 6.26 | U | 6.00 | U |
| Promethazine | 0.34 | U | 0.319 | U | 0.313 | U | 0.30 | U |
| Propoxyphene | 0.34 | U | 0.319 | U | 0.313 | U | 0.30 | U |
| Propranolol | 0.34 | U | 0.319 | U | 0.313 | U | 0.30 | U |
| Sertraline | 0.34 | U | 0.319 | U | 0.313 | U | 0.30 | U |
| Simvastatin | 2.28 | U | 2.14 | U | 2.1 | U | 2.01 | U |
| Theophylline | **14.9** | R | 6.38 | U | 6.26 | U | 6.00 | U |
| Trenbolone | 2.28 | U | 2.14 | U | 2.1 | U | 2.01 | U |
| Trenbolone acetate | 0.34 | U | 0.319 | U | 0.313 | U | 0.30 | U |
| Valsartan | 4.54 | U | 4.25 | U | 4.17 | U | 4.00 | U |
| Verapamil | 0.17 | U | 0.159 | U | 0.157 | U | 0.15 | U |

U Non-detect at reporting limit

R Peak detected but did not meet quantification criteria, result reported is estimated maximum possible concentration

H Concentration is estimated

# Appendix G2 | **Comal Springs Biological Monitoring Report**

**HABITAT CONSERVATION PLAN**

# BIOLOGICAL MONITORING PROGRAM

## Comal Springs/River Aquatic Ecosystem

**ANNUAL REPORT**

**December 2023**

**Prepared for:**

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# EXECUTIVE SUMMARY

The Edwards Aquifer Habitat Conservation Plan (EAHCP) Biological Monitoring Program continued to track biota and habitat conditions of the Comal Springs/River ecosystem in 2023 through a series of routine and Critical Period monitoring activities outlined in this report. Monitoring in the Comal system consisted of routine surveys specific to EAHCP Covered Species: Fountain Darter (*Etheostoma fonticola*), Comal Springs Salamander (*Eurycea* sp.), and multiple Comal Springs invertebrates. Community-level monitoring data were also collected on aquatic vegetation, fish, and benthic macroinvertebrates. In addition to routine monitoring, springflows dropped to the lowest levels observed since the start of biological monitoring in 2000, triggering multiple Critical Period and species-specific low-flow sampling events. Results from 2023 biological monitoring provided valuable data to further assess spatiotemporal trends of aquatic biota in the Comal Springs/River ecosystem, as well as a unique opportunity to better understand ecological responses under extreme low flow scenarios.

In 2023, central Texas experienced a continuation of low precipitation and higher ambient temperatures observed in 2022. Exceptional drought conditions occurred throughout central Texas from January through August, impacting large portions of the Hill Country over the Edwards Aquifer Contributing Zone. As a result, discharge in the Comal Springs/River System was below median historical conditions for the entire year, continuing the decreased trend observed in 2022 and resulting in the lowest flow conditions documented over the course of the 23 year biological monitoring program. When compared to previous drought years, median and minimum daily mean discharge were lower in 2023 (121 and 55 cfs, respectively) than the previous monitoring program low observed in 2014 (135 and 65 cfs, respectively), and were considerably lower than other drought years in 2009, 2011, and 2013. Monthly median discharges were below the long-term 10$^{th}$ percentiles throughout the year, except for the months of May and June when they were slightly above 10$^{th}$ percentile levels. Flows dropped below 100 cfs in July, resulting in additional Critical Period sampling activities. Total system discharge dropped to a minimum mean daily flow of 55 cfs by August, triggering multiple habitat evaluations, discharge and flow partitioning measurements, and species-specific triggers (i.e., Comal Springs Salamander, Comal Springs Riffle Beetle). Although flows increased slightly in September and October, total system discharge remained below 10$^{th}$ percentile levels throughout fall 2023.

The most conspicuous impact of low summer water levels was desiccation of spring and spring run habitats. Spring Run 1, Spring Run 2, and Spring Island Spring runs were completely desiccated for extended periods in summer 2023, resulting in obvious impacts to surface habitat for salamanders and spring-associated invertebrates. As a result of Critical Period and species-specific triggers, a total of 13 salamander monitoring events were conducted in 2023 as flows declined. In drying spring runs, salamander monitoring effort was correspondingly decreased as wetted habitat declined. Although overall counts were down compared to previous years, confidence intervals overlapped with historical data, and salamanders were documented in all monitored spring runs up until surface habitats went dry. *Eurycea* salamanders are known to use subsurface habitats and genomics data suggests that migration events are occurring between various spring locations within the Edwards Aquifer region (Devitt et al. 2019). Given their ability to occupy subsurface habitats and previous monitoring data showing recolonization after spring run desiccation events (e.g., 2014), it is assumed that salamanders will recolonize these areas as surface flow returns. However, additional monitoring is needed to confirm this as well as to evaluate recolonization rates and population responses.

Similar to salamanders, abundance estimates for *Stygobromus* sp. from spring drift-net sampling and Comal Springs Riffle Beetle from cotton-lure surveys were both down compared to historical data. Although drift-net counts of *Stygobromus* sp. are standardized per cubic meter of water, lower spring discharge may decrease the number of these organisms dislodged from near-spring environments. Across sites and seasons, a temporal decline in the number of Comal Springs Riffle Beetles observed per lure is noted when comparing 2023 data to 5-year and long-term datasets. In particular, abundance estimates have been low since fall 2021 suggesting population abundance was potentially impacted by low springflows observed the past two years. However, like the *Eurycea* salamanders described above, Comal Springs Riffle Beetles are capable of using sub-surface habitats. Therefore, reduced abundance on cotton lures set near spring surface habitats may not reflect a true population-level decline. A low-flow habitat utilization investigation conducted by BIO-WEST researchers as part of the species-specific triggered monitoring in fall 2023 suggests that Comal Springs Riffle Beetles follow water levels sub-surface when spring surface habitats dry up. Additional EAHCP research is currently being conducted to better understand Comal Springs Riffle Beetle population dynamics and its relationship to surface and subsurface habitat utilization.

In addition to impacts on spring orifices and spring runs, the influence of extremely low spring flows was also evident on abiotic habitat and aquatic vegetation conditions in areas further from springs and resulted in reach specific changes to Fountain Darter population metrics. In downstream riverine reaches, water temperature exceeded laboratory-estimated thresholds for maximum optimal Fountain Darter egg and larval production more commonly and for longer durations than during typical flow conditions. However, patterns in Fountain Darter population metrics didn't correspond well with patterns in water temperature threshold exceedance. For example, fall 2023 Fountain Darter densities declined in Landa Lake (where summer temperatures were consistently below thresholds) but increased abruptly in New Channel (where summer temperature exceedances were common). This suggests that lab-derived temperature thresholds for maximum optimal egg and larval production may not be as key as other environmental variables in predicting patterns in wild Fountain Darter population response.

Although a variety of abiotic and biotic factors are likely influential on Fountain Darter population abundance, habitat suitability driven by patterns in aquatic vegetation coverage appears to be the most important factor in predicting observed patterns. Indeed, reduced flows in 2023 led to reductions in the abundance of bryophytes in the Upper Spring Run and Landa Lake reaches, drove down the Overall Habitat Suitability Index (OHSI) in these areas, and resulted in subsequent declines in Fountain Darter population metrics. In Upper Spring Run, reductions in bryophytes led to low Fountain Darter densities throughout 2022 and 2023. In Landa Lake, impacts to Fountain Darter density were not readily apparent until fall 2023. In this event, although limited amounts of bryophytes were present within the lake, they were in areas too deep for drop-net sampling. Therefore, bryophytes were not sampled via drop-net in this reach in fall 2023. Importantly, Fountain Darters were observed in similar numbers to previous years in these deeper areas via visual surveys in fall 2023, highlighting the importance of multiple sampling techniques. However, since bryophytes typically show the highest densities among vegetation taxa via drop-net sampling, this resulted in a low overall density estimate in Landa Lake in fall 2023. In contrast to Landa Lake, Upper New Channel reach exhibited rather high but variable vegetation composition and OHSI in 2023. High amounts of vegetation coverage in spring and fall 2023 were supported by a lack of recent high flow events within the Dry Comal Creek watershed. Although vegetation coverage was impacted by recreation in summer 2023, it quickly rebounded to the highest levels observed in Upper New Channel in the past five years in fall 2023, and Fountain Darter population densities responded. Lastly, in contrast to patterns observed at Landa Lake and Upper Spring Run, the post-restoration vegetation community within the Old Channel has maintained consistently high amounts of bryophytes over the past five years despite low-flow conditions, and Fountain Darter drop-net densities have remained near or above the long-term median in this reach for eleven of the twelve sampling events over this time period.

At a community scale, fish and macroinvertebrate community-level responses to low flows were not as evident as those within Covered Species populations. In general, no long-term temporal trends in overall or spring-associated fish diversity, richness, and relative density are evident from fish community monitoring data. Macroinvertebrate Index of Biotic Integrity (IBI) scores did show slight declines at some riverine reaches (Old Channel and Other Place) suggesting that low flows may have led to habitat homogenization and reduction in abundance of fluvial specialists in these areas. However, besides these minor deviations, fish and macroinvertebrate community data were generally comparable to historical data.

Overall, 2023 biological monitoring provided insights into the current condition of the EAHCP Covered Species in the Comal Springs/River System, as well as flow-ecology relationships related to the broader aquatic community. Spring discharge in 2023 was the lowest observed since initiation of biological monitoring in 2000. As a result, acute impacts to Covered Species habitats and resulting responses of population metrics were noted. Despite the extreme conditions observed, all Covered Species are still present at multiple habitats within the system and are expected to persist and rebound once more typical flow conditions return. Subsequent monitoring will be critical to assess the ultimate response of species populations to these unique, and at present, continuing stressors.

# INTRODUCTION

The Edwards Aquifer Habitat Conservation Plan (EAHCP) is intended to provide assurance of suitable habitat for threatened and endangered species (i.e., Covered Species) (Table 1) in both the San Marcos and Comal Springs. Established in 2012, the EAHCP supports the issuance of an Incidental Take Permit that allows the "incidental take" of Covered Species from otherwise lawful activities in the Comal Springs system. Section 6.3.1 of the HCP established a continuation of biological monitoring in the Comal Springs/River. This biological monitoring program was first established in 2000 (formerly known as the Edwards Aquifer Authority [EAA] Variable Flow Study), and its original purpose was to evaluate the effects of variable flow on the biological resources of the Comal Springs/River, with an emphasis on threatened and endangered species. However, the utility of the HCP biological monitoring program has surpassed its initial purpose (EAHCP 2012). The biological data collected since the implementation of this monitoring program (BIO-WEST 2001–2023) now serves as the cornerstone for several underlying sections in the HCP, which include the following: (1) long-term biological goals (LTBGs) and management objectives (Section 4.1); (2) determination of potential impacts to Covered Species, "incidental take" assessment, and Environmental Impact Statement alternatives (Section 4.2); and (3) establishment of core adaptive-management activities for triggered monitoring and adaptive-management response actions (Section 6.4.3). Additionally, biological monitoring program data, in conjunction with other available information, are essential to adaptive management as the EAHCP proceeds. Current and future data collection will help assess the effectiveness and efficiency of certain EAHCP mitigation and restoration activities conducted in the Comal Springs/River and calculate the EAHCP habitat baseline and net disturbance determination and annual "incidental take" estimate (EAHCP 2012).

**Table 1. Covered Species sampled for under the Edwards Aquifer Habitat Conservation Plan in the Comal spring and river ecosystems.**

| SCIENTIFIC NAME | COMMON NAME | ESA STATUS |
|---|---|---|
| **Insects** | | |
| *Haideoporus texanus* | Edwards Aquifer Diving Beetle | Petitioned |
| *Heterelmis comalensis* | Comal Springs Riffle Beetle | Endangered |
| *Stygoparnus comalensis* | Comal Springs Dryopid Beetle | Endangered |
| **Crustaceans** | | |
| *Lirceolus smithii* | Texas Troglobitic Water Slater | N/A |
| *Stygobromus pecki* | Peck's Cave Amphipod | Endangered |
| **Amphibians** | | |
| *Eurycea* sp. | Comal Springs Salamander | N/A |
| **Fish** | | |
| *Etheostoma fonticola* | Fountain Darter | Endangered |

This report provides the methodology and results for biological monitoring activities conducted in 2023 within the Comal Spring/River ecosystem. In addition to routine monitoring, Critical Period and species-specific low-flow sampling were triggered. The results include summaries of current physiochemical conditions, as well as current conditions of floral and faunal communities, encompassing routine and low-flow sampling. For all aquatic organisms, historic observations (BIO-WEST 2001–2023a) are also used to provide context to current conditions.

# METHODS

## Study Location

The Comal Springs System is the largest spring complex in Texas. It encompasses an extensive headsprings system and the Comal River (New Braunfels, Comal County, Texas), and is fed by the Edwards Aquifer (Brune 2002). Dam construction and channelization during the late-1800s modified headspring habitats (Odgen et al. 1986; Crowe and Sharpe 1997) and drainage patterns of the river (Ottmers 1987). Impoundment of Comal Springs resulted in the formation of Landa Lake (Linam et al. 1993), which is fed by four spring runs of variable size (Ogden et al. 1986; Crowe and Sharpe 1997). From the headwaters, the river flows about 5 kilometers (km) before its confluence with the Guadalupe River. The majority of water that exits Landa Lake flows through the "New Channel", an engineered diversion that was originally created to act as a cooling system for a power generation plant. Remaining flows are diverted to the original river channel, known as the "Old Channel," that rejoins the New Channel about 2.5 km downstream (Ottmers 1987).

The watershed is dominated by urban landcover and is subjected to recreational use. Spring inputs from the Edwards Aquifer provide stable physiochemical conditions, and springflow conditions are dictated by aquifer recharge and human water use (Sung and Li 2010). In the 1950s, Comal Springs temporarily ceased flowing (Schneck and Whiteside 1976; Brune 2002). Despite this, the Comal Springs System maintains diverse assemblages of floral and faunal communities (Bowles and Arsuffi 1993; Crowe and Sharpe 1997) and includes multiple endemic aquatic organisms, such as Comal Springs Riffle Beetle (*Heterelmis comalensis*), Peck's Cave Amphipod (*Stygobromus pecki*), Comal Springs Salamander (*Eurycea* sp.), and Fountain Darter (*Etheostoma fonticola*).

## Sampling Strategy

Based on the long-term biological goals (LTBGs) and management objectives outlined in the HCP, study areas were established to conduct long-term monitoring and quantify population trends of the Covered Species (EAHCP 2012). The sampling locations selected are designed to cover the entire extent of Covered Species habitats, but they also allow for holistic ecological interpretation while maximizing resources (Figures 1–3).

Comprehensive sampling within the established study area varies temporally and spatially among Covered Species. The current sampling strategy includes five spatial resolutions:

1. System-wide sampling
    a. Aquatic vegetation mapping: 5-year intervals (winter)
2. Select longitudinal locations
    a. Water temperature monitoring: year-round at permanent monitoring stations
    b. Discharge measurements: 2 events/year (spring, fall)
3. Reach sampling
    a. Aquatic vegetation mapping: 2 events/year (spring, fall)
    b. Fountain Darter drop-net sampling: 2 events/year (spring, fall)
    c. Fountain Darter random-station dip-net surveys: 3 events/year (spring, summer, fall)

4. Springs Sampling
    a. Endangered Comal invertebrate sampling: 2 events/year (spring, fall)
    b. Comal Salamander surveys: 2 events/year (spring, fall)
    c. Fountain Darter visual surveys: 2 events/year (spring, fall)
5. River section/segment
    a. Fountain Darter timed dip-net surveys: 3 events/year (spring, summer, fall)
    b. Fish community sampling: 2 events/year (spring, fall)
    c. Macroinvertebrate community sampling: 2 events/year (spring, fall)

In addition to annual comprehensive sampling outlined above, low-flow sampling may also be conducted, but is dependent on HCP flow triggers, which include Critical Period Low-Flow Sampling and species-specific sampling (EAHCP 2012). In April 2023, river discharge was less than 150 cfs, so the spring 2023 comprehensive monitoring effort doubled as the 150 cfs full Critical Period low-flow event. Discharge decreased below 100 cfs in July, which resulted in another Critical Period low-flow full sampling event and subsequent low-flow habitat evaluations. In addition, species-specific triggers were met from July to October for Comal Springs Salamander and Comal Springs Riffle Beetle (Appendix A). Species-specific triggers were also met from January to October (n = 3) for the Fountain Darter. Critical Period water grab sampling and habitat assessment results are presented in Appendix B.

The remaining methods sections provide brief descriptions of the procedures utilized for comprehensive sampling efforts, which includes details on all Critical Period and species-specific sampling efforts. A more-detailed description of the gear types used, methodologies employed, and specific GPS coordinates can be found in the Standard Operating Procedures Manual for the HCP biological monitoring program for the Comal Springs/River ecosystem (EAA 2017).

# Comal River Discharge and Springflow

River hydrology in 2023 was assessed using US Geological Survey (USGS) stream gage data from January 1 to October 31. Mean daily discharge expressed in cubic feet per second (cfs) was acquired from USGS gage #08169000, which represents cumulative river discharge that encompasses springflow and local runoff contributions. It should be noted that some of these data are provisional and are subject to revision at a later date (USGS 2023). The annual distribution of mean daily discharge was compared for the past 5-years using boxplots. The distribution of 2023 mean daily discharge was summarized by month using boxplots. Monthly discharge levels were compared with long-term (1928–present) 10th, 50th (i.e., median), and 90th percentiles.

Discharge was also measured in spring and fall at five cross-section stations (Upper Spring Run, Spring Run 1, Spring Run 2, Spring Run 3, Old Channel) using a flowmeter and adjustable wading rod, with the exceptions of measurements at Spring Run 1 and Spring Run 2 in the fall due to dry conditions. Additional discharge measurements were conducted during Critical Period and species-specific events triggered in July (n = 2), August (n = 4), September (n = 4), and October (n = 2). Additionally, discharge was measured at four M9 stations (Spring Island Upper Far, Spring Island Lower Near, Spring Island Lower Far, Landa Lake Cable) by EAA personnel using a SonTek RiverSurveyor Acoustic Doppler Profiler (Figure 3).

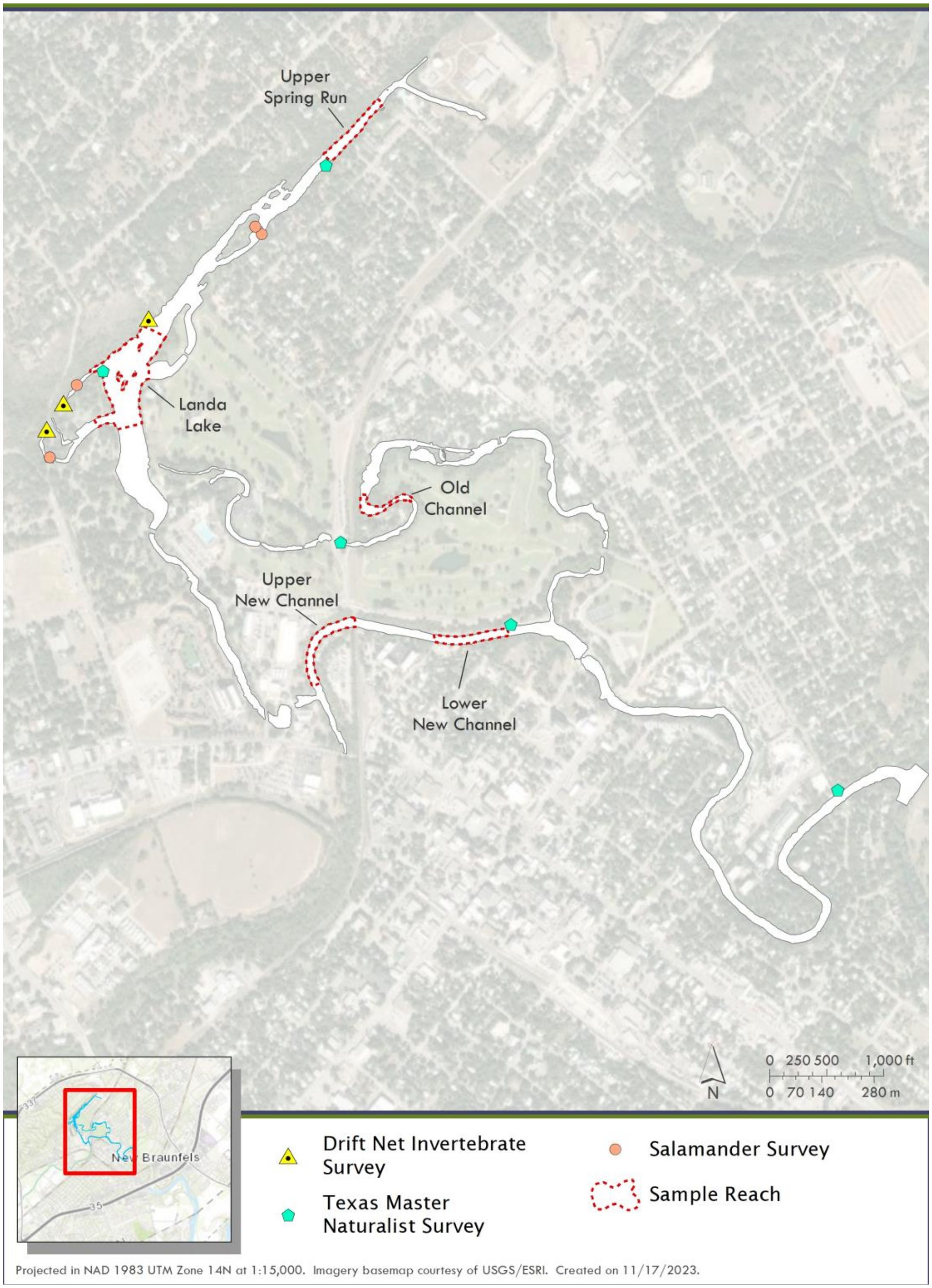


**Figure 1.** **Locations of drift-net invertebrate, Comal Springs Salamander, Texas Master Naturalist, and biomonitoring (includes aquatic vegetation mapping, drop-net sampling, presence/absence dip-net sampling, and macroinvertebrate community sampling) sample areas within the Comal Spring/River study area.**

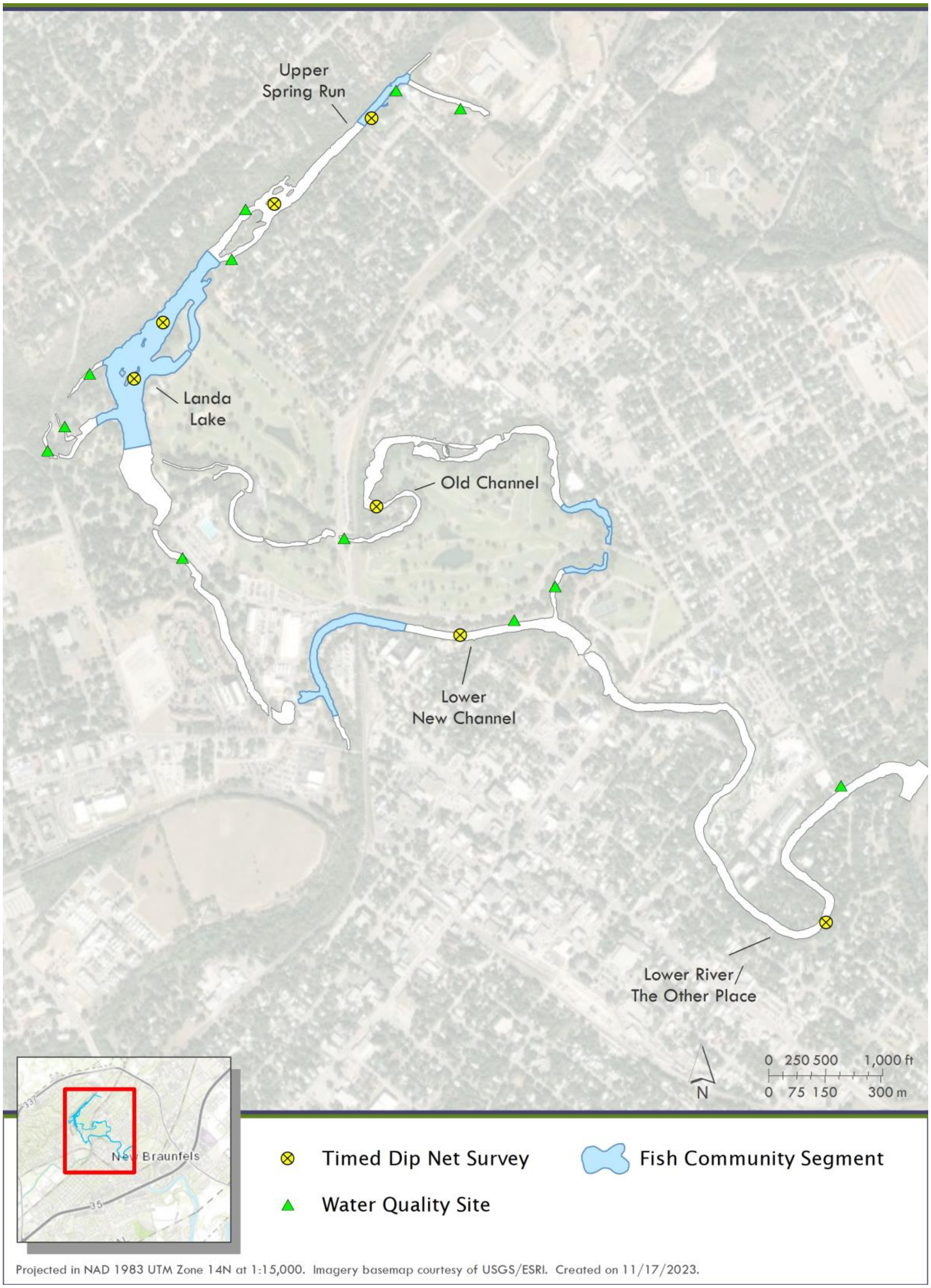


**Figure 2.** **Locations of fish community, water quality, and Fountain Darter timed dip-net surveys within the Comal Springs/River study area.**

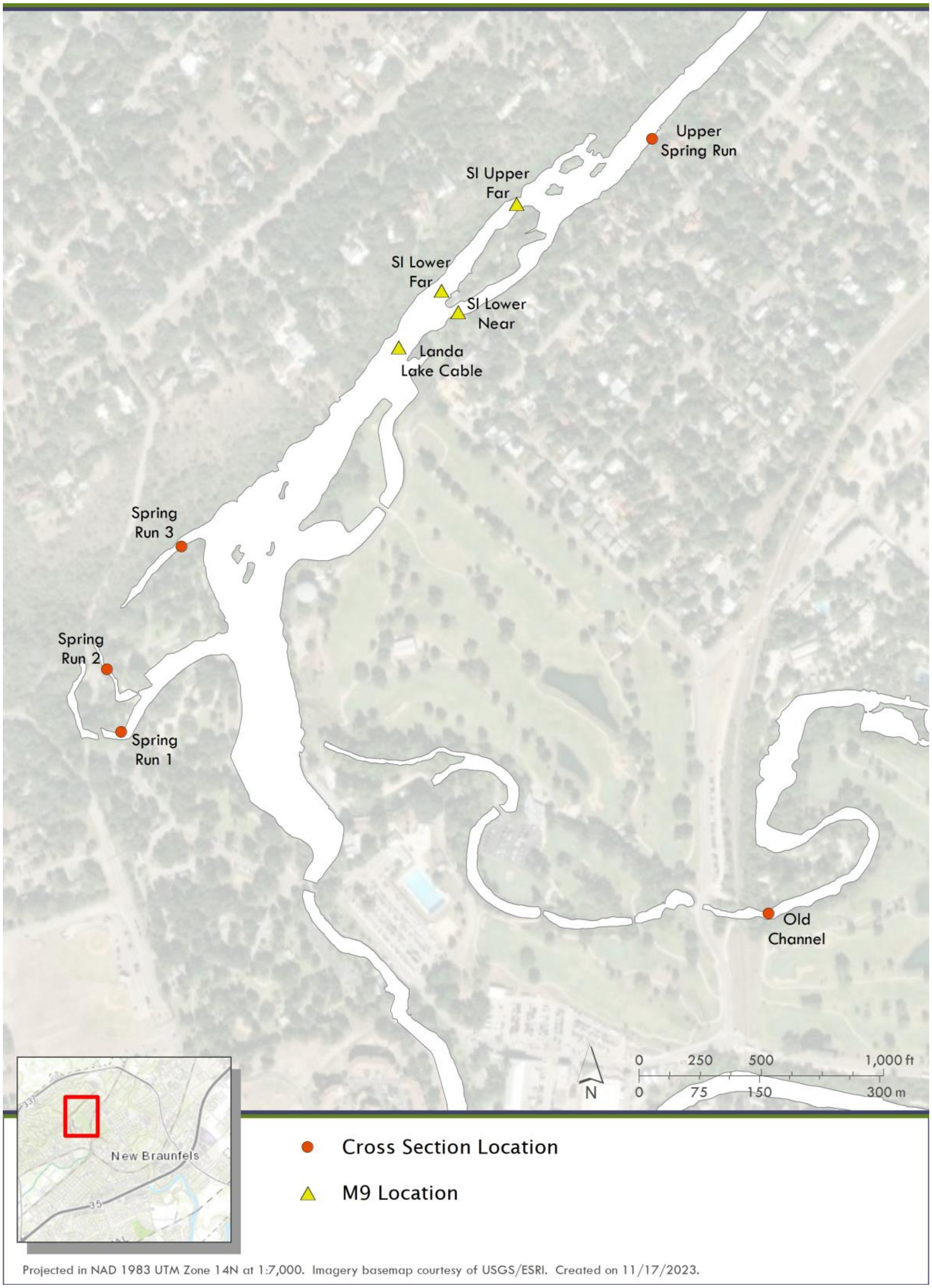


**Figure 3. Cross-section and M9 discharge collection locations in the Comal Springs/River study area.**

To quantify the contribution of each station to total system discharge, percent total discharge ([discharge(station *x*)/cumulative river discharge]*100) was calculated. Cumulative river discharge was based on the mean daily discharge value on the day of each measurement. Discharge and percent total discharge were summarized for spring and fall measurements, which were compared to 5-year and long-term (cross-section stations: 2003–present; M9 stations: 2014–present) averages ±95% confidence intervals using bar graphs. Results for cross-section stations are presented in the main body of the report and results for M9 stations can be found in Appendix E.

## Water Temperature

Spatiotemporal trends in water temperature were assessed using temperature data loggers (HOBO Tidbit v2 Temp Loggers) at the 13 permanent monitoring stations established in 2000. Data loggers recorded water temperature every 10 minutes and were downloaded at regular intervals. Prior to analysis, data processing was conducted to locate potential data logger errors per station by comparing time-series for the current year with previous years. Timeframes displaying temperatures that deviated substantially from historical data and did not exhibit ecologically rational trends (e.g., discontinuities, ascending drift) were considered unreliable and omitted from the dataset. For analysis, the distribution of water temperatures for the current year was assessed among stations based on 4-hour intervals and summarized using boxplots. Water temperatures were also compared with maximum optimal temperature requirements for Fountain Darter larval (≥25 °C) and egg (≥26 °C) production (McDonald et al. 2007). Further, 25 °C is also the designated threshold within the HCP Fountain Darter LTBGs study reaches (Upper Spring Run [Heidelberg], Landa Lake, New Channel, Old Channel) (EAHCP 2012). In the case of stations that surpassed either water temperature threshold during the year, the general timeframes in which those exceedances occurred are discussed in the text.

## Texas Master Naturalist Monitoring

Volunteers with the Texas Master Naturalist program continued their monitoring efforts in 2023 at select locations along the Comal system. Volunteers collected water quality and recreation data at the following five sites: (1) Houston Street site within the Upper Spring Run reach, (2) Gazebo site within the Landa Lake reach, (3) Elizabeth Avenue site upstream of the Old Channel reach, (4) New Channel site within the New Channel reach, and (5) the downstream-most Union Avenue site (Figure 1). Volunteer monitoring was performed on a weekly basis, with surveys conducted primarily on Friday afternoons between 1200 and 1500 hours. At each site, an Oakton Waterproof EcoTester pH 2 was used to measure pH, and a LaMotte Carbon Dioxide Test Kit was used to measure carbon dioxide ($CO_2$) concentrations in the water column. In addition to water-quality measurements, recreational-use data were collected at each site by counting the number of tubers, kayakers, anglers, etc., within the survey site at the time of sampling. Volunteers also took photographs at each site during each sampling event, and occasionally made additional notes on recreational use or the condition of the river. Results from this monitoring effort can be found in Appendix D.

# Aquatic Vegetation

## *Mapping*

The team used a sit-in kayak to complete aquatic vegetation mapping in each sample reach during the winter full system, spring, summer Critical Period, and fall monitoring events (Figure 1). A Trimble GPS unit and external Tempest antenna set on the bow of the kayak was used to collect high-accuracy (10–60 centimeter [cm]) geospatial data. A data dictionary with pre-determined attributes was loaded into the GPS unit for data collection in the field. Discrete patch dimensions and the type and density of vegetation were recorded from the kayak. In some instances, an accompanying free diver was used to provide additional detail and to verify surface observations. The discreteness of an individual vegetation patch was determined by the dominant species located within the patch compared to surrounding vegetation. Once a patch of vegetation was visually delineated, the kayak was maneuvered around the perimeter of the vegetation patch to collect geospatial data with the GPS unit, thus creating a vegetation polygon. Attributes assigned to each polygon included species type and percent cover of each of the four most-dominant species. The type of substrate (silt, sand, gravel, cobble, organic) was identified if substrate was a dominant feature within the patch. Rooted aquatic vegetation, floating aquatic vegetation, bryophytes, and algae were mapped as separate features. Only aquatic vegetation patches 1 meter (m) in diameter or larger were mapped as polygons.

## *Data Processing and Analysis*

During data processing, Microsoft pathfinder was used to correct spatial data and create shapefiles. Spatial data were projected using the Projected Coordinate System NAD 1983 Zone 14N. Post processing was conducted to clean polygon intersections, check for and correct errors, and calculate cover for individual discrete polygons as well as totals for all encountered aquatic plant species.

Vegetation types are described in the Results and Discussion section by genus. Vegetation community composition among taxa and grouped by native vs. invasive taxa are compared for the last five years using stacked bar graphs. Total surface area of aquatic vegetation, measured in square meters ($m^2$), is presented for each season using bar graphs and is compared with long-term averages (2001–present) from spring, fall, high-flow events, and low-flow events. High-flow and low-flow averages were calculated from Critical Period Events. These events are based on predetermined river discharge triggers (Appendix A), which result in additional mapping events to assess flow-related impacts to the vegetation community.

# Fountain Darter

## *Drop-Net Sampling*

Drop-net sampling was utilized to quantify Fountain Darter densities and evaluate habitat utilization during the spring, summer Critical Period, and fall monitoring events (Figure 1). Sample stations were selected using a random-stratified design. In each study reach, two sample stations per vegetation strata were randomly selected based on dominant aquatic vegetation (including open areas) mapped prior to sampling (see Aquatic Vegetation Mapping for details). At each sample station, all organisms were first trapped using a 2 $m^2$ drop-net. Organisms were then collected by sweeping a 1 $m^2$ dip net along the river bottom within the drop-net. If no fish were collected after the first 10 dip-net sweeps, the station was considered complete, and if fish were collected, an additional 5 sweeps were conducted. If Fountain Darters were collected on sweep 15, additional sweeps were conducted until no Fountain Darters were collected.

Most fishes collected were identified to species and enumerated. Two morphologically similar species, Western Mosquitofish (*Gambusia affinis*) and Largespring Gambusia (*Gambusia geiseri*), which are known to hybridize, were classified by genus (*Gambusia* sp.). Larval and juvenile fishes too small to confidently identify to species in the field were also classified by genus. All Fountain Darters and the first 25 individuals of other fish taxa were measured (total length expressed in millimeters [mm]).

Physiochemical habitat data were collected at each drop-net location. Water depth in feet (ft) and velocity in feet per second (ft/s) were collected at the upstream end of drop-net samples using a flowmeter and adjustable wading rod. Water-velocity measurements were collected at 15 cm above the river bottom to characterize flows that directly influence Fountain Darters. Mean-column velocity was measured at 60% of water depth at depths of less than three feet. At depths of three feet or greater, water velocities were measured at 20% and 80% of depth and averaged to estimate mean column velocity. Water quality was measured within each drop-net using a multiprobe, which included water temperature (degrees Celsius [°C]), pH, dissolved oxygen (milligrams per liter [mg/L], percent saturation), and specific conductance (microsiemens per centimeter [µs/cm]). Mid-column water quality was measured at water depths of less than three feet, whereas bottom and surface values were measured and averaged at depths of three feet or greater. Lastly, vegetation composition (%) was visually estimated and dominant substrate type was recorded within each drop-net sample.

### *Dip-Net Sampling*

Dip-net sampling was used to provide additional metrics for assessing Fountain Darter population trends and included qualitative timed surveys and random-station presence/absence surveys. All sampling was conducted using a 40x40-cm (1.6-mm-mesh) dip net, and surveys for both methods were conducted in winter, spring, summer, and fall. Summer sampling included one Critical Period event which was integrated into routine summer monitoring.

Timed dip-net sampling was conducted to examine patterns in Fountain Darter abundance and size structure along a more extensive longitudinal gradient compared to drop-net sampling. Surveys were conducted within established monitoring sites for a fixed amount of search effort (Upper Spring Run: 0.5 hour, Spring Island: 0.5 hour, Landa Lake: 1 hour, Old Channel: 1.0 hour, New Channel: 1.0 hour, Lower River: 1.0 hour) (Figure 2). In each study reach, a single surveyor used a dip net to collect Fountain Darters in a downstream to upstream fashion. Collection efforts mainly focused on suitable Fountain Darter habitat, specifically in areas with dense aquatic vegetation. Non-wadable habitats (>1.4 m) were not sampled. All Fountain Darters collected were enumerated, measured (mm), and returned to the river at point of collection.

Random-station presence/absence surveys were implemented to assess Fountain Darter occurrence. During each monitoring event, sampling stations were randomly selected within the vegetated area of each sample reach (Upper Spring Run: 5, Landa Lake: 20, Old Channel: 20, New Channel: 5) (Figure 1). At each random station, presence/absence was recorded during four independent dips. To avoid recapture, collected Fountain Darters were returned to the river in areas adjacent to the random station being sampled. Habitat variables recorded at each station included dominant aquatic vegetation, and presence/absence of bryophytes and algae.

## *Visual Surveys*

Visual surveys with the aid of SCUBA gear were conducted at Landa Lake in areas too deep for implementing the Fountain Darter sampling methods described above (Figure 1). Sampling occurred during the spring, summer Critical Period, and fall monitoring events. To standardize data relative to any potential diel patterns in behavior, observations were conducted in early afternoon during each sampling event. A specially designed grid (7.8 $m^2$) was used to quantify the number of Fountain Darters using these deeper habitats. During each survey, all Fountain Darters within the grid were counted and the percentage of bryophyte coverage within the grid was recorded. Results of visual surveys are presented in Appendix E.

## *Data Analysis*

Key demographic parameters used to evaluate Fountain Darter observations included population performance, size structure, and recruitment. Population performance was assessed using drop-net, timed dip-net, and random dip-net data. Counts of darters per drop-net sample were standardized as density (darters/$m^2$). Timed dip-net total darter counts per study reach were standardized as catch-per-unit-effort (CPUE; darters/person-hour [p-h]) for each sampling event. Random dip-net occurrence per station was based on whether or not a Fountain Darter was observed during any of the four dips and percent occurrence was calculated per sampling event at each reach as: (sum[darter presence]/sum[random stations])*100. Fountain Darter density, CPUE, and percent occurrence were compared among seasons using boxplots. In addition, most seasonal observations were compared to observations from the past five years and long-term observations (2001–present). Lastly, temporal trends in Fountain Darter density were assessed per sampling event for each study reach for the past five years using boxplots and compared to their respective long-term (2001–present) medians and quartiles (25th and 75th percentile).

Size structure and recruitment were assessed among seasons. Fall and spring were assessed by combining drop-net and timed dip-net data, and summer was assessed only using timed dip-net data. Boxplots coupled with violin plots were used to display the distribution of darter lengths per sampling event during each season for the past five years. Boxplots show basic length-distribution statistics (i.e., median, quartiles, range) and violin plots visually display the full distribution of lengths relative to each sampling event using kernel probability density estimation (Hintze and Nelson 1998). Recruitment was quantified as the percent of darters ≤20 mm during each sampling event. Based on a linear model built by Brandt et al. (1993) that looked at age-length relationships of laboratory-reared Fountain Darters, individuals of this size are likely less than 3 months old and not sexually mature (Brandt et al. 1993; Schenck and Whiteside 1976). Percent recruitment ±95% confidence intervals (i.e., beta distribution quantiles; McDonald 2014) were shown for the past five years by season and compared to their respective long-term averages.

Habitat use was assessed based on population performance and size structure among vegetation strata using drop-net and random station dip-net observations. Fountain Darter density by vegetation taxa was compared based on current, five-year, and long-term (2001–present) observations using boxplots. Proportion of occurrence was also calculated among vegetation types sampled during random-station dip-netting for the current year. Lastly, boxplots coupled with violin plots were used to display the distribution of darter lengths by vegetation taxa using drop-net data to examine habitat use among size classes for the current year.

Habitat suitability was quantified to examine reach-level changes in habitat quality for Fountain Darters through time. First, Habitat Suitability Criteria (HSC) ranging from 0 (unsuitable habitat) to 1 (most suitable habitat) were built based on occurrence data for all vegetation types (including open habitat) that have been sampled using logistic regression (Manly et al. 1993). Resulting HSC were then multiplied by the areal coverage of each vegetation strata mapped during a biomonitoring event, and results were summed across vegetation strata to calculate a weighted usable area for each reach. To make data comparable between reaches of different sizes, the total weighted usable area of each reach was then divided by the total area of the reach, resulting in an Overall Habitat Suitability Index (OHSI) for each reach during each sampling event. Following this method, temporal trends of Fountain Darter OHSI ±95% CI were calculated per sampling event for each study reach (Upper Spring Run, Landa Lake, Old Channel, Upper New Channel, Lower New Channel) for the past five years. Long-term (2003–present) OHSI and 95% CI averages were also calculated to provide historical context to recent OHSI observations. Specific details on the analytical framework used for developing OHSI and evaluating its efficacy as a Fountain Darter habitat index, including methods to build HSC, can be found in Appendix H.

# Fish Community

## *Mesohabitat, Microhabitat, and Seine Sampling*

Fish community sampling was conducted in the spring, summer Critical Period event, and fall to quantify fish assemblage composition/structure and to assess Fountain Darter population performance in river segments and habitats (e.g., deeper areas) not sampled during drop-net and timed dip-net surveys. The following four monitoring segments were sampled: Upper Spring Run, Landa Lake, Old Channel, and New Channel (Figure 2). Deeper habitats were sampled using visual transect surveys, and shallow habitats were sampled via seining.

A total of three mesohabitat transects were sampled at each segment during visual surveys. At each transect, four divers swam from bank-to-bank at approximately mid-column depth, enumerating all fishes observed and identifying them to species. After each mesohabitat transect was completed, microhabitat sampling was also conducted along four, 5-meter-long PVC pipe segments (micro-transect pipes) placed on the stream bottom, spaced evenly along the original transect. Divers started at the downstream end and swam up the pipe searching through the vegetation, if present, and substrate within approximately 1 m of the pipe. All fishes observed were identified to species and enumerated. For both surveys, any individuals that could not be identified to species were classified by genus. At each micro-transect pipe, total area surveyed ($m^2$), aquatic vegetation composition (%), and substrate composition (%) were recorded. Water depth (ft) and velocity (ft/s) data were collected in the middle of each micro-transect pipe using a portable flowmeter and adjustable wading rod. Water-velocity measurements were taken 15 cm from the bottom, mid-column, and at the surface. Standard water-quality parameters were also recorded once at each mesohabitat transect using a handheld water-quality sonde.

In shallow habitats, at least three seining transects were sampled within each monitoring segment (except for Landa Lake). At each of these, multiple seine hauls were pulled until the entire wadable area had been covered. After each seine haul, fish were identified, measured (mm), and enumerated. Total area surveyed ($m^2$) was visually estimated for each seining transect. Habitat data from each seine haul location included substrate and vegetation composition (%); water depth (ft); and velocity (ft/s) measured at 15 cm above the river bottom, at mid-column, and at the surface. Fish taxonomy herein follows the most recent guide published by the American Fisheries Society (AFS 2023).

### *Data Analysis*

To evaluate fish community results, all analyses were conducted using fishes identified to species; fishes identified to genus or family were excluded. Total counts of species from independent samples were first quantified as density (fish/$m^2$) to standardize abundance among the three gear types used.

Based on microhabitat sampling, temporal trends in Fountain Darter density were assessed per sampling event for each study reach for the past five years using boxplots and compared to their respective long-term (2014–present) medians and quartiles. Overall species richness and diversity using the Shannon's diversity index (Spellerberg and Fedor 2003) for each study segment was assessed for the past five years and plotted with bar graphs. Richness and relative density (%; [sum(species *x* density)/sum(all species density)]*100) of spring-associated fishes (Table 2) were also quantified and presented in the same manner as species richness and diversity.

**Table 2. Spring-associated fishes within the Comal Springs System based on Craig et al. (2016).**

| SCIENTIFIC NAME | COMMON NAME |
|---|---|
| *Dionda nigrotaeniata* | Guadalupe Roundnose Minnow |
| *Notropis amabilis* | Texas Shiner |
| *Astyanax argentatus* | Mexican Tetra |
| *Gambusia geiseri* | Largespring Gambusia |
| *Etheostoma fonticola* | Fountain Darter |
| *Etheostoma lepidum* | Greenthroat Darter |
| *Percina apristis* | Guadalupe Darter |
| *Percina carbonaria* | Texas Logperch |

## Comal Springs Salamander Surveys

In spring and fall, biologists performed timed visual surveys for Comal Springs Salamanders within the four following established sampling areas: Spring Run 1, Spring Run 3, Spring Island Spring Run, and Spring Island East Outfall (Figure 1). Eleven additional sampling events occurred during Critical Period and species-specific events triggered in July (n = 2), August (n =

4), September (n = 4), and October (n = 1). Timed surveys involved sampling from downstream to upstream within the extent of the sampling area. Biologists inspected under rocks within the top 5 cm of the substrate surface and within aquatic vegetation to quantify salamanders while moving upstream toward the main spring orifice. A dive mask and snorkel were utilized to view organisms, as depth permitted. Locations of all Comal Springs Salamander observations were recorded using pin flags. Following survey completion, and water depth (ft) and presence/absence of vegetation were noted to potentially serve as a baseline assessment of habitat parameters should the salamander population change significantly in subsequent sampling years. To account for any potential diel patterns in behavior, all surveys were initiated in the morning and completed by early afternoon.

Survey effort was previously fixed during routine sampling. Within Spring Run 1, a one-hour survey was conducted from the Landa Park Drive Bridge upstream to just below the head spring orifice. Spring Run 3 was surveyed for one hour from the pedestrian bridge closest to Landa Lake upstream to the second pedestrian bridge. Surveys in the Spring Island area were divided into the following two sections: (1) one 30-minute survey of Spring Island Run and (2) one 30-minute survey of the east outfall upwelling area on the east side of Spring Island near Edgewater Drive. Based on this, effort across all sites represents a total of 6 person-hours (p-h) under the established monitoring methodology. However, reduced habitat availability associated with low-flow conditions experienced in 2023 required modification in search times. Specifically, total survey effort at each site was adjusted relative to the percent of wetted habitats available for salamanders at a given sampling event. For example, if wetted habitats were reduced by 50% at Spring Run 1, a 50% reduction in survey time was implemented (i.e., 30 minutes).

## Data Analysis

Comal Springs Salamander counts and CPUE (salamanders/p-h) were used to assess seasonal and five-year trends, respectively. Data from all sampling events in 2023 were used for analysis despite varied search effort at each site. Since adjustments in search time were scalable, varied effort offset differences in total survey area, providing statistically valid comparisons in catch rates. Salamander counts were presented for each season using bar graphs and are compared with long-term (2001–present) spring, fall, high-flow event, and low-flow event averages. High-flow and low-flow event averages were calculated from Critical Period Events. These events are based on predetermined river discharge triggers (Appendix A), which result in additional survey events to assess flow-related impacts to the Comal Springs Salamander population. Temporal trends in salamander density were also assessed per sampling event for each sampling area for the past five years using bar graphs.

# Macroinvertebrates

## *Drift-net Sampling and Data Analysis*

Macroinvertebrate samples were collected via drift net at three sites in the Comal system. During each comprehensive sampling event, drift nets were placed over the major spring openings of Comal Spring Runs 1 and 3 and a moderate-sized spring upwelling (Spring 7) along the western shoreline of Landa Lake (Figure 1). Drift nets were anchored into the substrate directly over each spring opening, with the net faced perpendicular to the direction of flow. Net openings were circular with a 0.45-m diameter, and the mesh size was 100 micrometers (µm). The tail of the drift net was connected to a detachable, 0.28-m-long cylindrical bucket (200 µm mesh), which was removed at 6-hour intervals during sampling, after which cup contents were sorted and invertebrates removed in the field. The remaining bulk samples were preserved in ethanol and sorted later in the laboratory, where minute organisms that had been overlooked in the field were removed. All Comal Springs Riffle Beetles, Peck's Cave Amphipods, and Comal Springs Dryopid Beetles captured via drift net were returned to their spring of origin, with the exception of voucher organisms (fewer than 20 living specimens of each species identifiable in the field). All non-endangered invertebrates were preserved in 70% ethanol. Additionally, water-quality measurements (temperature, pH, conductivity, dissolved oxygen, and current velocity) were taken at each drift-net site using a water-quality meter and handheld flow meter.

The total numbers of endangered species at each site are presented in the results and a summary of total numbers for all taxa can be found in Appendix E. Temporal trends in *Stygobromus pecki* per cubic meter were assessed per sampling event for each sampling area over the past five years using boxplots and compared to their respective long-term (2003–present) medians and quartiles (25th and 75th percentile).

## *Comal Springs Riffle Beetle Sampling and Data Analysis*

Comal Springs Riffle Beetles were collected from three areas in the Comal River system during two routine sampling events in spring and fall. Three additional sampling events occurred during one Critical Period and two species-specific events triggered in July through October. Sampling followed the methods of the Cotton Lure standard operating procedure developed for the HCP (EAA 2017). This methodology consists of placing lures of 15x15 cm pieces of 60% cotton/40% polyester cloth into spring openings/upwellings in the Comal system, where they remain in situ for approximately 30 days. During this time, they become inoculated with local organic and inorganic matter, biofilms, and invertebrates, including Comal Springs Riffle Beetle. These lures were placed in sets of 10 in the following three areas: (1) Spring Run 3, (2) along the western shoreline of Landa Lake ("Western Shoreline"), and (3) near Spring Island. Due to declines in wetted habitats in the summer, alternate sampling methods were implemented during two low-flow sampling events to limit disturbance from over sampling. For the low-flow event from August 25$^{th}$ to September 11$^{th}$, sets of 3 lures were placed in the most suitable habitat available at each site and remained in situ for about 15 days. For the third low-flow sampling event from mid-September through mid-October, the low-flow study design was modified to assess Comal Springs Riffle Beetle habitat use. The details of this modified study are described in Appendix I. Lures lost, disturbed, or buried by sedimentation were not included in subsequent analyses.

Numbered tags placed on the banks of Spring Run 3 and Western Shoreline were utilized, when possible, to identify lure locations.

Most Comal Springs Riffle Beetles collected with cotton lures were identified, counted, and returned to their spring of origin during each sampling effort. Some beetles were retained by SMARC personnel for genetic analysis or incorporation into the refugia program. A dissecting scope with a maximum magnification of 90x was used to correctly identify riffle beetles in the field. The sampling crew also recorded counts of *Microcylloepus pusillus*, Comal Springs Dryopid Beetle, and Peck's Cave Amphipod collected on lures. These and any other spring invertebrates collected on the lures were also placed back into their spring of origin. Crews utilized a mask and snorkel to place and remove lures in areas with deeper water depths.

Adult Comal Springs Riffle Beetle relative abundance (beetles/lure) were compared among seasons for each area using boxplots. In addition, seasonal observations were compared to five-year and long-term observations (2004–present). Temporal trends in relative abundance were also assessed per sampling event for each area for the past five years using boxplots and compared to their respective long-term (2004–present) medians and quartiles (25th and 75th percentile). Data collected during the three low-flow sampling with alternate methods were omitted from all analyses. Due to lower replicates and set times, these data were not statistically comparable with the other events, and were instead summarized for each event separately, based on total adult Comal Springs Riffle Beetle counts per site.

## *Rapid Bioassessment Sampling and Data Analysis*

Rapid bioassessment protocols (RBPs) are tools for evaluating biotic integrity and overall habitat health based on the community of organisms present (Barbour et al. 1999). Macroinvertebrates are the most frequently used biological units for RBPs because they are ubiquitous, diverse, and there is an acceptable working knowledge of their taxonomy and life histories (Poff et al. 2006, Merritt et al. 2008).

BIO-WEST performed sampling and processing of freshwater benthic macroinvertebrates, following Texas RBP standards (TCEQ 2014). Macroinvertebrates were sampled with a D-frame kick net (500 µm mesh) by disturbing riffle or run habitat (consisting primarily of cobble-gravel substrate) for five minutes while moving in a zig-zag fashion upstream. Invertebrates were then haphazardly distributed in a tray and subsamples were taken by scooping out haphazard portions of material and placing them into a separate sorting tray.

All macroinvertebrates were picked from the tray before another subsample was taken. This process was continued until a minimum of 140 individuals were picked to represent a sample. If the entire sample did not contain 140 individuals, the process was repeated again until this minimum count was reached. Macroinvertebrates were collected in this fashion from Upper Spring Run, Landa Lake, Old Channel, New Channel, and the Lower River reaches (Figure 1). Picked samples were preserved in 70% isopropyl, returned to the laboratory, and identified to established taxonomic levels (TCEQ 2014), usually genus. Members of the family Chironomidae (non-biting midges) and class Oligochaeta (worms) were retained at those taxonomic levels. The 12 ecological metrics of the Texas RBP benthic index of biotic integrity (B-IBI) were calculated for each sample. Each metric represents a functional aspect of the macroinvertebrate community related to ecosystem health, and sample values are scored from 1 to 4 based on benchmarks set by reference streams for the state of Texas. The aggregate of all 12 metric scores for a sample represent the B-IBI score for the reach that sample was taken from. The B-IBI point-scores for each sample are compared to benchmark ranges and are described as having aquatic-life-uses of "Exceptional", "High", "Intermediate", or "Limited". In this way, point-scores were calculated and the aquatic-life-use for each sample reach was evaluated. Temporal trends in B-IBI scores were assessed per sampling event for each reach during the past five years using bar graphs.

# RESULTS and DISCUSSION

In 2023, central Texas experienced a continuation of low precipitation and higher ambient temperatures observed in 2022. Exceptional (as designated by the National Weather Service [NWS]) drought conditions occurred through central Texas from January through August, covering large portions of the Hill Country. Drought conditions eased slightly to the NWS extreme classification during fall. As described in the next section, total river discharge in the Comal System was below median historical conditions for the entire year, continuing the trend observed in 2022. Flows declined to levels which have not been observed since 2014. Median and minimum mean daily discharge were lower in 2023 (121 and 55 cfs, respectively) than 2014 (135 and 65 cfs, respectively) and were both lower than other low-flow years in 2009, 2011, and 2013 (195–255 and 111–159 cfs, respectively). Despite the sustained low-flow conditions experienced in 2023, the majority of water quality parameters measured during Critical Period sampling were within the range of historical observations (Appendix B, Table B1 and B2; Crowe and Sharp 1997). Nitrate concentrations were similar to historical data (0.77–1.76 mg/L; Crowe and Sharp 1997) at most stations in both spring (i.e., Spring Runs, Landa Lake) and riverine (i.e., lower Old Channel and New Channel) habitats, with the exception of Spring Run 3 (1.82 mg/L). However, observed nitrate concentration at Spring Run 3 was still well below toxic concentrations (Boyd 2015). See Appendix B for a complete summary of water quality data collected during Critical Period low-flow sampling along with the low-flow triggered habitat evaluation memorandums.

Comal River discharge fluctuated throughout the year but had an overall decreasing trend from spring through late summer. The highest monthly median discharge was 191 cfs in May and the lowest monthly median discharge was 67 cfs in August. The declining flows triggered three full system habitat evaluations as documented in Appendix B. Habitat quality for the Covered Species varied spatially during the evaluations at these three flow tiers. Fountain Darter habitat quality (i.e., aquatic vegetation) was maintained in Landa Lake and Old Channel while conditions at Upper Spring Run were degraded. By August, the majority of bryophytes in Landa Lake were gone and *Ludwigia* was starting to go emergent. However, Fountain Darters still occurred in a majority of random dip-net points. Despite harsh low-flow conditions, the Old Channel continued to maintain high quality Fountain Darter habitat as vegetation coverage increased and it was the only reach to retain bryophytes. Habitat for Comal Springs Salamander (i.e., Spring Runs) and invertebrates (i.e., Spring Runs and Landa Lake's western shoreline) were noticeably reduced as water levels decreased. Most notably, the entire Comal Springs Salamander survey areas at Spring Run 1 and the spring run on Spring Island were dry during these low-flow evaluations. By mid-August, lower than average discharge coupled with summertime conditions resulted in elevated water temperatures in Blieders Creek and locations further downstream from spring flow orifices.

In summary, total river discharge in the Comal System in 2023 was the lowest since the inception of biological monitoring in 2000. Based on past low-flow conditions observed in 2014, it remains important to keep tracking the system-wide Fountain Darter and surface-dwelling invertebrate habitat conditions as these lower-than average discharge levels continue to persist. The remaining sections of the Results and Discussion describe current trends in river discharge, water temperature, Covered Species populations, and select floral and faunal communities through the Comal Spring/River System during this low-flow year.

## River Discharge and Springflow

Over the last five years, annual medians of mean daily discharge in the Comal River decreased from 2019 (358 cfs) to 2023 (121 cfs). Maximum discharge was lowest in 2023 (263 cfs) and highest in 2021 (1,850 cfs). The maximum mean daily discharge of 1,850 cfs in 2021 was a $99^{th}$ percentile discharge magnitude and the only high flow pulse that exceeded 1,000 cfs during this time period. Minimum discharge was lowest in 2022 (89 cfs) and 2023 (55 cfs). Variation in discharge (i.e., interquartile range) was greatest in 2022 (132 cfs), compared to more stable flow conditions in 2020 (55 cfs), 2023 (56 cfs), and 2021 (27 cfs) (Figure 4A).

Monthly medians of mean daily discharge were comparable to or below their respective long-term 10th percentiles the entire year. Monthly median discharge decreased from January (127 cfs) to March (120 cfs) and increased from April (143 cfs) to May (191 cfs), which represented the highest flows across months. Following May, median discharge descended from June (164 cfs) to the annual minimum in August (67 cfs). Median monthly discharge then increased in September (72 cfs) and October (90 cfs). Median monthly discharge was only above long-term 10th percentiles in May (+11 cfs) and June (+20 cfs) and was below this threshold the remainder of the year (-22 cfs in July to -83 cfs in March). Flows varied little during most months with interquartile ranges frequently below 20 cfs. Variation in discharge was highest in May (interquartile = 52 cfs) and lowest from August to October (interquartile = 3–7 cfs) (Figure 5B).

Cross-section discharges in spring habitats were below historical means in 2023 and mostly decreased from spring to fall. Discharge fell to 0 cfs for all fall measurements at Upper Spring Run, Spring Run 1, and Spring Run 2, while Spring Run 3 discharge slightly increased from summer to fall. All stations in Comal Springs exhibited discharges below lower confidence interval boundaries in spring and fall. However, flow regulation at the Landa Lake culverts regulate discharge in the Old Channel and result in more consistent discharge patterns in the Old Channel than in spring run habitats. Since contribution from spring runs declined, percent total discharge increased within the Old Channel. Lastly, it is important to note that lower historical averages in summer versus spring and fall within the spring runs is a result of the fact that discharges in the summer are only measured when low-flow triggers are met (Figure 5).

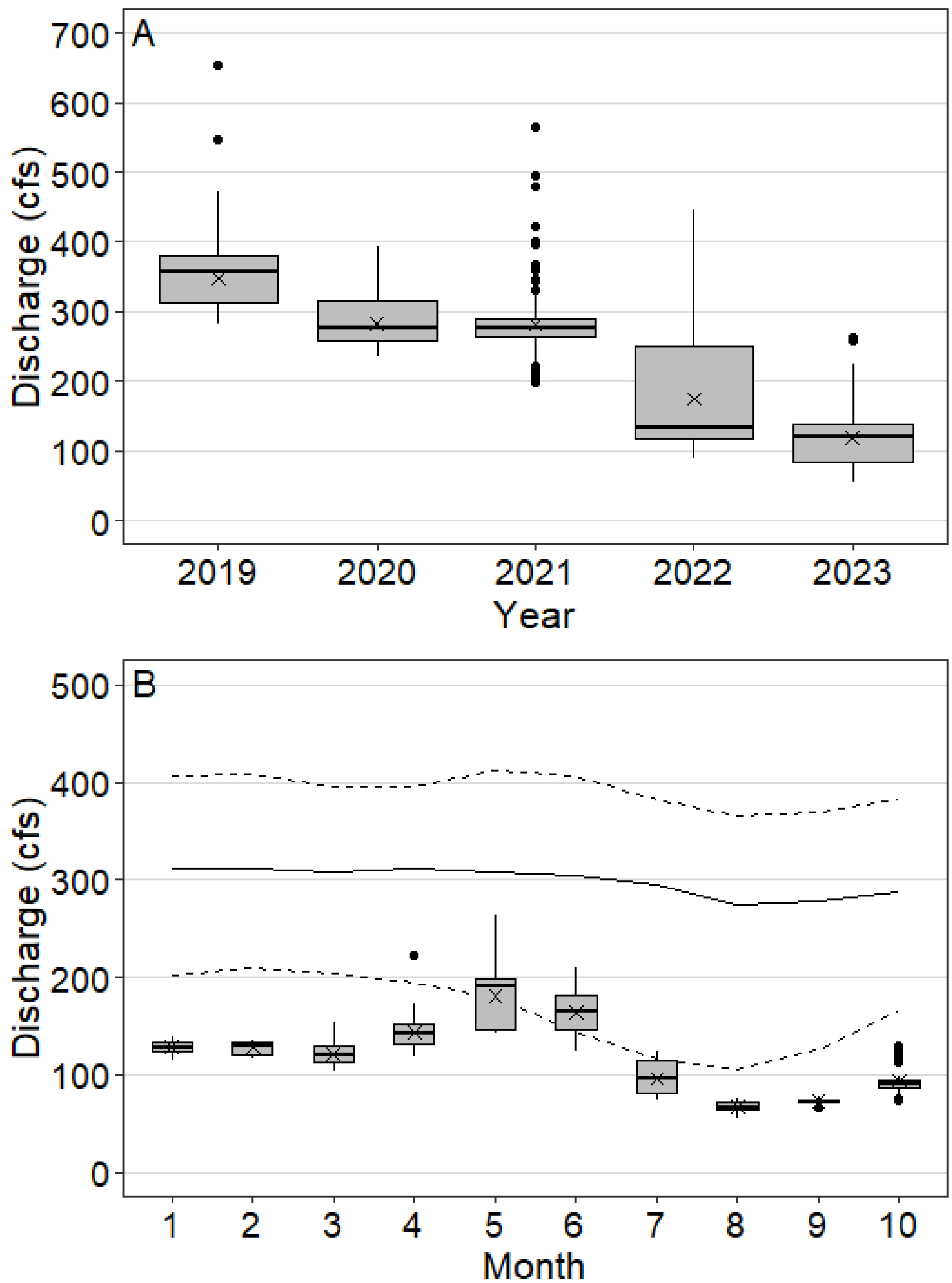


**Figure 4. Boxplots displaying Comal River mean daily discharge annually from 2019-2023 (A) and among months (January–October) in 2023 (B). Each month is compared to the 10th percentile (lower dashed line), median (solid line), and 90th percentile (upper dashed line) of their long-term (1956–2023) daily means. The thick horizontal line in each box is the median, x represents the mean, and the upper/lower bounds of each box represents the interquartile range. Whiskers represent minimum/maximum values up to 1.5 times the interquartile range, and outliers beyond this are designated with solid black circles. One outlier for year 2021 in panel A is not shown (1,850 cfs).**

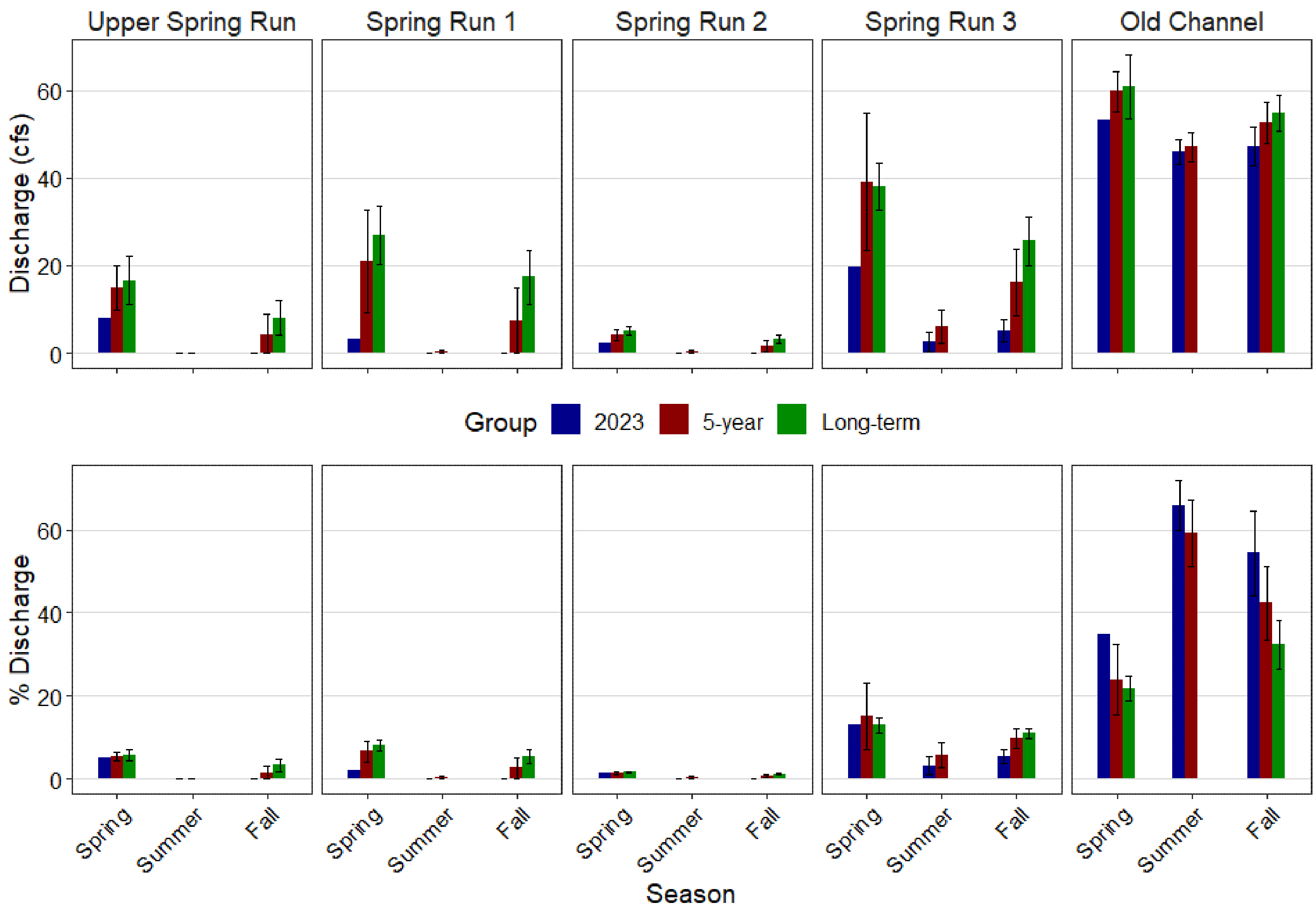


**Figure 5.** **Current (blue bars), five-year (2019–2023; red bars), and long-term (2003–2023; green bars) discharge and percent total discharge based on spring and fall cross-section measurements in the Comal Springs/River. Due to the heightened drought conditions during the summer season, Upper Spring Run, Spring Run 1, and Spring Run 2 experienced zero flow (Upper Spring Run) or dry conditions (Spring Runs 1 and 2). Five-year and long-term values are represented as means and error bars denote 95% confidence intervals.**

Routine spring sampling occurred in May, when daily discharge ranged from 142–261 cfs. Discharge during summer sampling in July ranged from 74–124 cfs. Flows below 100 cfs in July triggered Critical Period sampling, which in addition to routine summer sampling, included discharge measurements, fixed station photography, water quality grab sampling, aquatic vegetation mapping, Fountain Darter drop-netting and visual surveys, salamander surveys, fish community sampling, and Comal Springs Riffle Beetle surveys. Discharge decreased further in July, requiring full-system habitat assessments and species-specific sampling for Comal Springs Riffle Beetle and Comal Springs Salamander. In August, discharge declined to a low of 55 cfs, triggering increased species-specific sampling for Comal Springs Salamander and Comal Springs Riffle Beetle that continued through October. As mentioned previously, mean daily discharge during fall sampling in October was below the long-term 10th percentile, ranging from 111-128 cfs (Figure 5B).

# Water Temperature

Median water temperature during 2023 was similar among stations, varying about 1 °C and ranging from 23.4 °C at Spring Run 2 to 24.2 °C at Blieders Creek. Patterns in water temperature variability depended on station location within the system. Higher variation in water temperature (i.e., interquartile range) at Blieders Creek (6.6 °C) was unique compared to all other stations and directly related to this drainage receiving no springflow contributions. Spring runs and Landa Lake represented more stable environments within the Comal system and mostly varied by less than 1.0 °C. Variability was higher at Heidelberg (1.2 °C) and Booneville Far (1.2 °C), which was not surprising given that springflow was extremely low or zero near these stations through much of the year. Riverine stations were more variable than spring environments, exhibiting a longitudinal gradient, where variation (i.e., interquartile range) increased from Old Channel (1.7 °C) and New Channel Upstream (1.7 °C) to New Channel Downstream (2.5 °C) and Other Place (3.2 °C) (Figure 6). Longitudinal trends in 2023 met expectations based on previous years and are typical within spring-associated ecosystems, where water temperatures increase in magnitude and variation farther downstream from spring inputs (Groeger et al. 1997, Kollaus and Bonner 2012).

Fountain Darter maximum optimal egg or larvae production thresholds were not exceeded at six stations, which included spring run stations, Landa Lake stations, and Booneville Near. The remaining seven stations exceeded both egg and larvae thresholds at times. Total number of days water temperatures exceeded the Fountain Darter larval production threshold ranged from 49 to 140 days. Total days of exceedance was ~50 days at Blieders Creek and Heidelberg, 113 days at Booneville Far, and ~100–140 days at riverine stations. Across all stations, median total days of larval production exceedance per month generally increased from February (1 day) to June (29 days) and remained high in August (25 days) and September (28 days) before decreasing by October (5 days). In June, August, and September, total 4-hour measurements above this threshold per day was mostly 1–3 measurements and only consistently reached 4 per day at Heidelberg. Data was missing in July across most stations due to malfunctions in the data loggers.

Among stations where the Fountain Darter egg production threshold was exceeded, water temperatures exceeded the threshold from March to October and ranged from 33 to 116 days of exceedance per station. Total days of exceedance was 33 days at Booneville Far, ~70–90 days at

Heidelberg and riverine stations, and 116 days at Blieders Creek. Across all stations, median total days of egg production exceedance per month generally increased from March (0 days) to August (31 days) and decreased by October (2 days). In August, the daily number of 4-hour measurements above this threshold were about 2/day at Booneville Far and Old Channel, 3–4/day at New Channel stations and Blieders Creek, consistently reached 4/day at Heidelberg, and hit about 5/day at Other Place.

Among study reaches, the 26 °C optimal egg production threshold was not exceeded at Landa Lake from 2020-2023, but frequency of exceedance increased at some study reaches during the low-flow conditions of 2022 and 2023. For example, at the Heidelberg station (located within the Upper Spring Run study reach), the egg production threshold was not exceeded in 2020 or 2021 but was exceeded for four days in 2022 and 67 days in 2023. At New Channel Upstream, the egg production threshold was not exceeded in 2020 or 2021 but was exceeded for 44 days in 2022 and 74 days in 2023. At Old Channel, the egg production threshold was not exceeded in 2020 but was exceeded for five days in 2021, 75 days in 2022, and 89 days in 2023. However, despite water temperatures more commonly exceeding maximum optimal egg and larval production thresholds, direct negative effects of warmer temperatures on the Fountain Darter population was not observed in population monitoring data from 2023. Instead, habitat degradation from continued low-flow conditions more likely had an indirect negative effect on the population in select locations, due to decreased coverage of suitable vegetation taxa (see Fountain Darter sections for further discussion). That said, elevated water temperatures could potentially have nonlethal effects by decreasing fitness and leading to reductions in subsequent reproductive output.

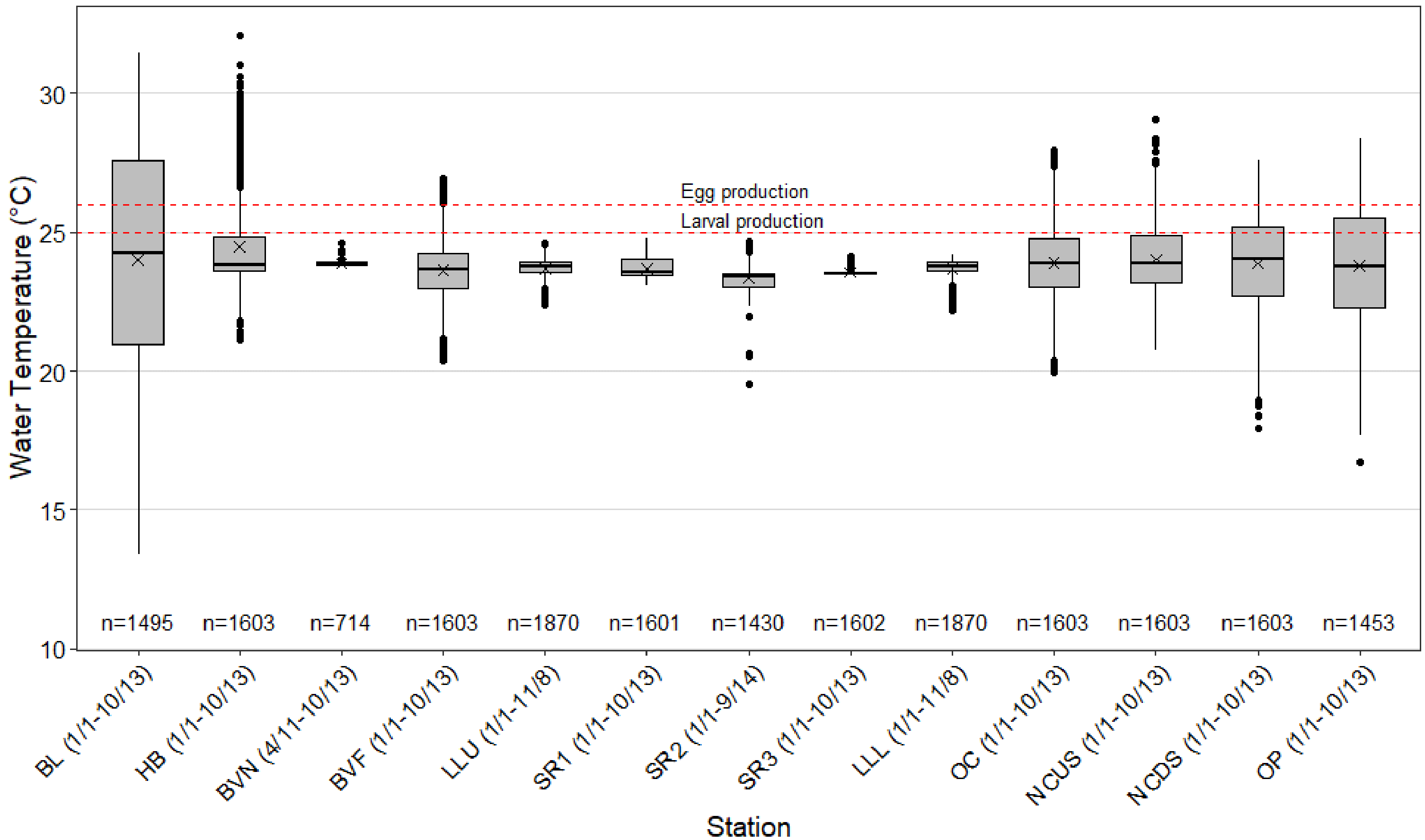


**Figure 6.** **Boxplots displaying 2023 water temperatures at logger stations (data collection timeframe [Month/Day]). Data are based on measurements collected at 4-hour increments. Stations include Blieders Creek (BL), Heidelberg (HB), Boonville Near (BVN), Boonville Far (BVF), Landa Lake Upper (LLU), Spring Run 1 (SR1), Spring Run 2 (SR2), Spring Run 3 (SR3), Landa Lake Lower (LLL), New Channel Upstream (NCUS), New Channel Downstream (NCDS), and Other Place (OP). The thick horizontal line in each box is the median, x represents the mean, and the upper/lower bounds of each box represents the interquartile range. Whiskers represent minimum/maximum values up to 1.5 times the interquartile range, and outliers beyond this are designated with solid black circles. The "n" values along the x-axis represent the number of individual temperature measurements in each category. The red dashed lines indicate maximum optimal temperatures for Fountain Darter larval (≥25 °C) and egg (≥26 °C) production (McDonald et al. 2007).**

# Aquatic Vegetation

## *HCP Benchmark Full System Mapping*

The HCP full system baseline vegetation mapping occurred in February to March 2023 and marks the third HCP benchmark mapping event since implementation of the EAHCP. Previous benchmark mapping events occurred in 2013 and 2018. In each event, aquatic vegetation was mapped from Blieders Creek at Klingemann Street to the Guadalupe River confluence. From 2013 to 2018, there was an increase in percent composition of native aquatic vegetation. Non-native *Hygrophila* decreased, whereas native species such as *Sagittaria*, *Cabomba*, and *Ludwigia* increased in relative percent composition (BIO-WEST 2018). In addition to natural variation in the system, changes were linked to HCP restoration activities through the removal of non-native species and planting of native species.

From 2018 to 2023, Comal River discharge generally decreased. In 2018, the Comal River system experienced flows near the historical median (~300 cfs), then flows generally declined from 2019 through 2023 (see Figure 4A). Changes in the aquatic vegetation community evident between 2018 and 2023 were likely influenced by a variety of factors including continued EAHCP restoration activities, reduced flows, and a few high flow pulses over this timeframe. The total vegetation coverage in 2018 (excluding bryophytes) was approximately 73,000 $m^2$, while the total vegetation coverage in 2023 exceeded 85,000 $m^2$ (Table 3). This increase was mostly attributed to the expansion of *Hygrophila* and *Sagittaria* (Figure 7). The expansion of *Hygrophila* occurred primarily in the Old Channel below the study reach and in the lower Comal River below San Antonio Street Bridge. The expansion of *Sagittaria* also contributed to the overall increase in vegetation coverage and occurred in Landa Lake and Upper Spring Run. Other native species with notable increases between years include *Justicia americana* and *Hydrocotyle verticillata.* The macroalgae *Chara* was also more abundant in the upper portions of the system, likely a response to decreased flows and velocity.

There were also notable decreases among some taxa between 2018 and 2023. Bryophyte coverage system-wide had the largest overall reduction of any species and decreased from 30,303 $m^2$ in 2018 to 9,385 $m^2$ in 2023. However, bryophytes are more sensitive to changes in flow conditions so comparisons over a five year span are difficult, especially during this low-flow year. *Vallisneria* decreased from 31,882 $m^2$ to 29,013 $m^2$ which was the most substantial drop among a single species of rooted vegetation. Declines in *Vallisneria* coverage were largely attributed to slower current velocities in Landa Lake caused by low flows. Overall, although restoration activities have removed non-native *Hygrophila* from the study reaches and replaced it with native vegetation, benchmark full system mapping shows that system-wide coverage of rooted aquatic vegetation (including non-natives) increases during periods of below average springflow. As previously noted, non-rooted taxa such as bryophytes are more heavily influenced by flow conditions.

**Table 3. A comparison of the notable changes in rooted aquatic vegetation assemblages observed in the 2013, 2018, and 2023 HCP Benchmark mapping events.**

| Taxa | 2013 Coverage ($m^2$) | 2018 Coverage ($m^2$) | 2023 Coverage ($m^2$) |
|---|---|---|---|
| *Cabomba* | 8,195 | 9,129 | 10,338 |
| *Hygrophila* | 26,612 | 13,796 | 22,424 |
| *Ludwigia* | 1,859 | 3,028 | 2,505 |
| *Nuphar* | 4,316 | 1,387 | 1,463 |
| *Sagittaria* | 7,330 | 10,061 | 14,186 |
| *Vallisneria* | 37,886 | 31,882 | 29,013 |
| Other species | 3,535 | 4,117 | 5,497 |
| **Total coverage** | **89,733** | **73,400** | **85,426** |

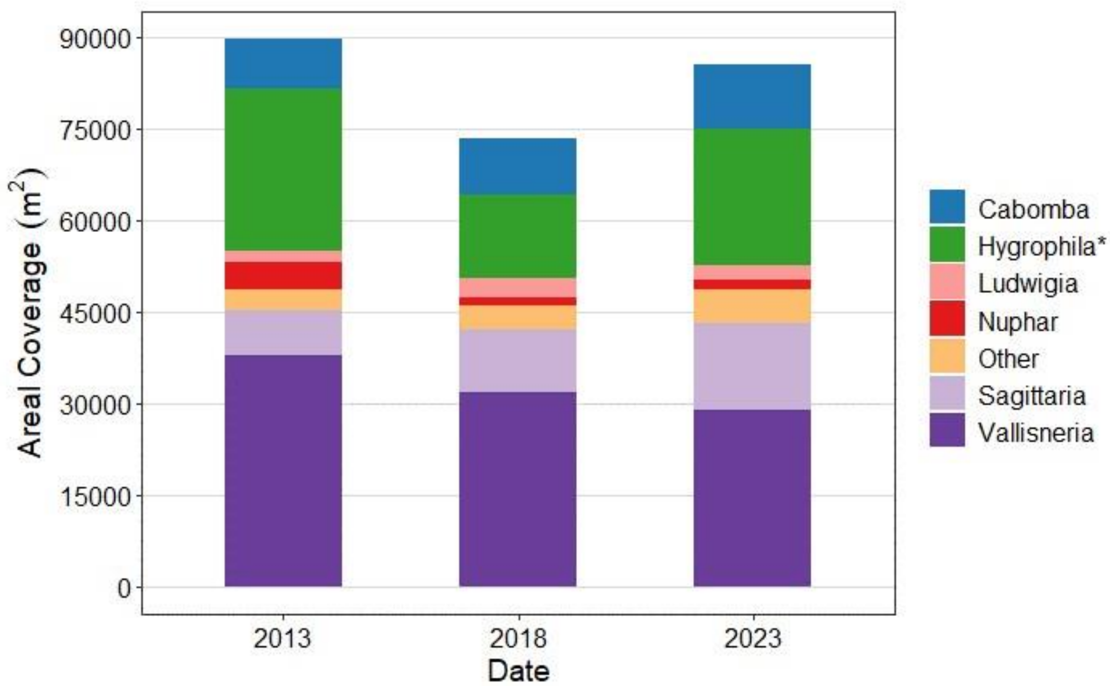


**Figure 7. Rooted aquatic vegetation ($m^2$) composition among taxa from HCP benchmark mapping events in the Comal Springs and River in 2013, 2018, and 2023.**

## *Long-term Biological Goal Reach Mapping*

Long-term biological goal reach mapping occurred in spring and fall, as well as low-flow events in July and August.

### *Upper Spring Run Reach*

In 2023, the Upper Spring Run reach was impacted heavily by low springflow conditions due to the continued drought. As a result, both spring and fall vegetation cover were below their respective long-term averages yet still remained higher than the low-flow average (Figure 8). Across all four mapping events, aquatic vegetation coverage remained similar with the highest coverage in the fall (1,668 $m^2$) and lowest coverage in the August low-flow event (1,426 $m^2$) (Figure 8). *Sagittaria* continued to be the most dominant plant taxa regardless of flow conditions, although *Cabomba* increased throughout the year to a maximum of 149 $m^2$ in the August low-flow event. The continued expansion of *Cabomba* was likely a result of higher sediment deposition and lack of scour due to consistent low flows. These conditions also favored the growth of the macroalgae, *Chara*, which increased to 365 $m^2$ (Figure 9). Benthic and epiphytic algae, dominated by *Spirogyra*, were prominent in spring (660 $m^2$) and the July low-flow event (251 $m^2$), but reduced considerably by the August low-flow event (63 $m^2$). However, algae increased again to 235 $m^2$ by fall. Bryophytes were largely absent across all mapping events. Reduced bryophyte coverage were influenced by low flows in 2022 and 2023, but also represent a continuation of the declining trend in this reach observed since 2019, despite more typical flow conditions in 2019-2020 (Figure 9).

## *Landa Lake Reach*

Aquatic vegetation coverage in Landa Lake typically exhibits less annual variability and less impact from flow disturbance events compared to other study reaches. Results in 2023 were no exception, with both spring and fall similar in total coverage (13,923–14,445 $m^2$). However, both were well below their respective seasonal averages (Figure 8). Landa Lake was dominated by *Vallisneria* and *Sagittaria*. *Vallisneria* usually accounts for greater than 50% of the total coverage and both of these strongly-rooted species tend to remain consistent in coverage across seasons (BIO-WEST 2001-2023). While *Vallisneria* continued to expand in areas where velocity remained consistent, reduced water velocity in some areas caused *Vallisneria* to retreat slightly. In addition to reduced water velocities, HCP restoration activities (i.e., benthic barriers) contributed to slight reductions in *Vallisneria* coverage. Denuded areas appeared below the Landa Lake islands and along the eastern edge. Reduction of *Vallisneria* in these areas allowed other competitors (i.e., *Cabomba*) to expand. Expansion of *Cabomba* occurred as a result of natural reductions in *Vallisneria* and active planting related to HCP restoration activities. *Cabomba* coverage began increasing in fall 2022. By the July 2023 low-flow mapping event, *Cabomba* covered over 1,000 $m^2$ and persisted above 900 $m^2$ for the remainder of the year. In contrast, *Cabomba* ranged from 239 $m^2$ to 432 $m^2$ in previous years with higher flow (e.g., 2019-2021). Bryophytes were not abundant in Landa Lake during any mapping event and continued to follow the decreasing trend of recent years (Figure 9). Epiphytic and benthic algae were present in varying abundance throughout Landa Lake. The annual Comal River Restoration Report provides more information regarding the restoration of native vegetation in the Landa Lake reach (BIO-WEST 2023b).

## *Old Channel Reach*

Total rooted vegetation in the Old Channel reach in 2023 remained below long-term averages. The highest vegetation coverage occurred in fall (198 $m^2$) and the lowest coverage occurred in the July low-flow event (124 $m^2$) (Figure 8). Although rooted vegetation coverage slightly decreased, bryophytes were abundant. Bryophyte coverage increased from spring (544 $m^2$) to the August low-flow event (652 $m^2$), and decreased in fall (581 $m^2$). This coverage was not represented in total areal coverage calculations, which exclusively quantify rooted vegetation (Figure 9). Bryophytes were dense along the bare stream bed as well as within rooted vegetation.

As a result of smothering by bryophytes, large reductions in *Cabomba* occurred by spring 2023 (Figure 9). Coverages in the past several years being well below long-term averages were due to *Hygrophila* historically dominating the reach prior to restoration, whereas non-rooted bryophytes now dominate. Therefore, lower coverages should not be interpreted as an indicator of degraded conditions, but instead represent an improvement in Fountain Darter habitat conditions within this reach.

## *Upper New Channel Reach*

In 2023, both spring and fall mapping showed higher than average vegetation coverage in the Upper New Channel (Figure 8). Spring vegetation coverage was 1,195 $m^2$ and decreased during the summer low-flow events to 605 $m^2$ but increased again to 1,801 $m^2$ by fall. Heavy recreation in this reach likely impacted aquatic vegetation coverage during summer months, but coverage quickly rebounded in fall. Aquatic vegetation in this reach has benefited from the prolonged absence of flood pulses within the Dry Comal Creek watershed. Additionally, *Cabomba* increased from spring to fall. Although bryophytes remained abundant in the reach through most of the year, this vegetation type was greatly reduced by fall and almost entirely replaced by filamentous algae, which was noted as unusually abundant in the reach during fall 2023 (Figure 9).

## *Lower New Channel Reach*

The spring and fall coverages for 2023 in the Lower New Channel were similar to or greater than their respective long-term averages, with a decreasing trend from spring to fall (Figure 8). Vegetation coverage was 2,677 $m^2$ in spring and remained similar through the July low-flow mapping event. However, by August, vegetation coverage was substantially reduced to 484 $m^2$ (Figure 8). This was a direct result of high recreation and reduced water depth (approximately 2 ft in most areas), allowing recreators to walk along the bottom. A large decrease in *Cabomba* was the driving factor in reduction of overall vegetation coverage. The two dominant species in this reach, *Cabomba* and *Hygrophila*, lose biomass during high flows and recreation, but can quickly recover once river conditions stabilize. This was observed in 2023 as spring, July, and August mapping all trended consecutively lower, with a subsequent gain in vegetation coverage in fall (2,193 $m^2$) (Figure 8 and 9).

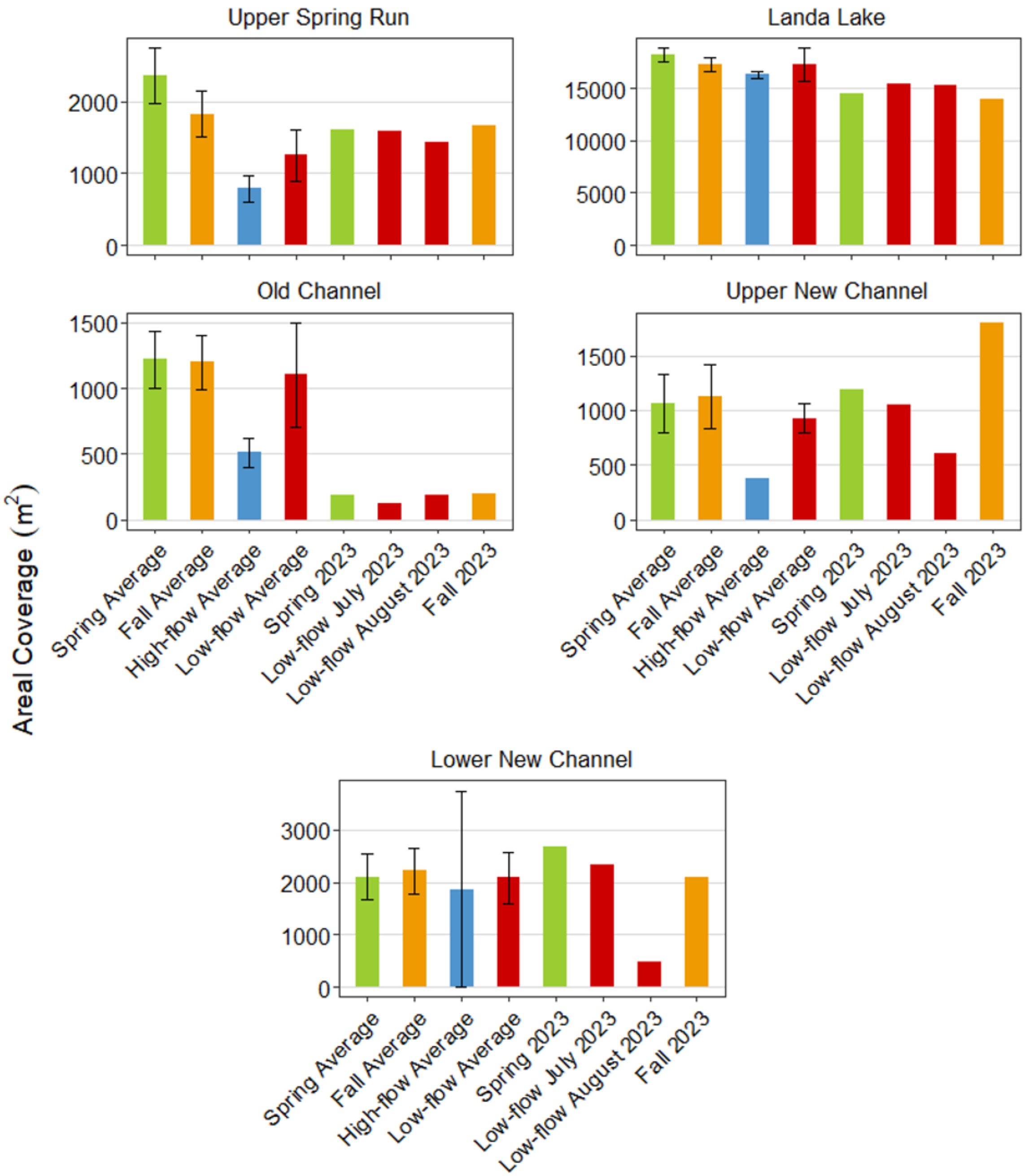


**Figure 8.** **Areal coverage (m$^2$) of rooted aquatic vegetation among study reaches in the Comal Springs/River. Long-term (2001–2023) study averages are provided with error bars representing 95% confidence intervals.**

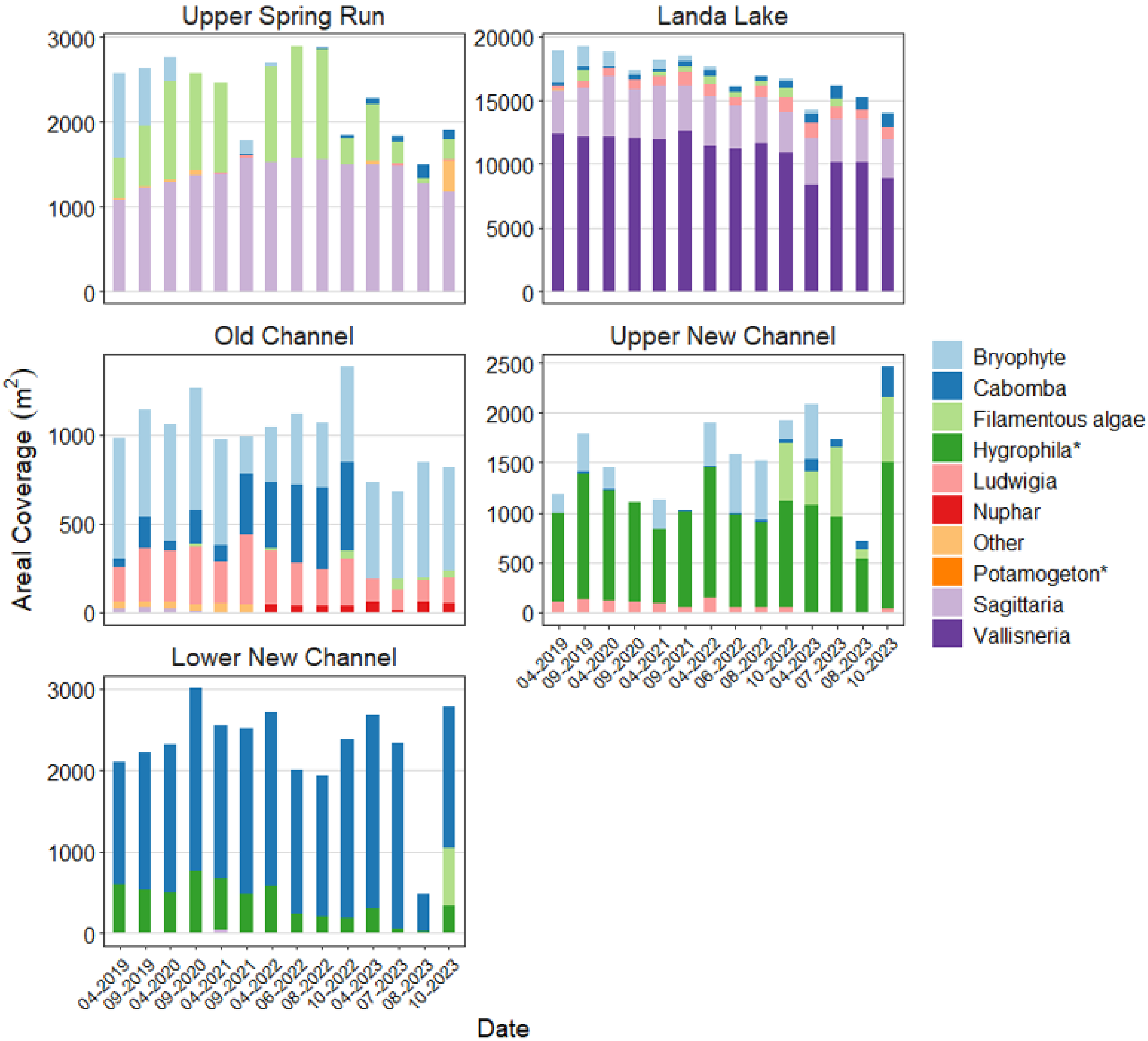


**Figure 9.** **Aquatic vegetation coverage (m²) among taxa from 2019–2023 in the Comal Springs/River. (*) in the legend denotes non-native taxa.**

# Fountain Darter

A total of 2,472 Fountain Darters were observed at 124 drop-net samples in 2023. Drop-net densities ranged from 0.00–134.00 darters/m$^2$. Community summaries and raw drop-net data are included in appendices E and G, respectively. Habitat conditions observed during drop-netting can be found in Table 4. Timed dip-netting resulted in a total of 1,056 Fountain Darters during 15 person-hours (p-h) of effort. Site CPUE ranged from 14–182 darters/p-h. Fountain Darters were detected at 222 out of 300 random-stations and reach-level percent occurrence among monitoring events ranged from 0–100%. A summary of occurrences per reach and vegetation taxa can be found in Table 5. Visual surveys in Landa Lake resulted in 76 darters observed and densities ranged from 2.95–3.72 darters/m$^2$ (bryophyte coverage = 10–30%) (Appendix E, Figure E11).

**Table 4. Habitat conditions observed during 2023 drop-net sampling in the Comal Springs/River. Physical habitat parameters include counts of dominant vegetation (median % composition) and dominant substrate type sampled. Depth/velocity and water quality parameters include medians (min-max) of each variable among all drop-net samples.**

| HABITAT PARAMETERS | USR | LL | OC | NC |
|---|---|---|---|---|
| **Vegetation** | | | | |
| *Bryophyte*[1] | 2 (70%) | 4 (80%) | 6 (100%) | 4 (75%) |
| *Cabomba*[1] | 4 (100%) | 6 (100%) | 0 | 4 (100%) |
| Filamentous algae[1] | 4 (100%) | 2 (85%) | 0 | 0 |
| *Hygrophila*[1] | 0 | 0 | 0 | 6 (100%) |
| *Ludwigia*[1] | 6 (90%) | 6 (100%) | 6 (100%) | 2 (95%) |
| Open | 6 (100%) | 6 (100%) | 6 (100%) | 4 (100%) |
| *Sagittaria*[2] | 6 (100%) | 6 (100%) | 0 | 0 |
| Vallisneria[2] | 0 | 6 (100%) | 0 | 0 |
| **Substrate** | | | | |
| Cobble | 3 | 3 | 1 | 0 |
| Gravel | 17 | 6 | 6 | 1 |
| Sand | 0 | 3 | 1 | 4 |
| Silt | 8 | 24 | 10 | 15 |
| **Depth-velocity** | | | | |
| Water depth (ft) | 1.9 (0.2–3.4) | 2.3 (0.7–3.8) | 2.8 (1.3–3.1) | 2.6 (1.0–3.8) |
| Mean column velocity (ft/s) | 0.0 (0.0–0.2) | 0.0 (0.0–0.4) | 0.2 (0.0–0.7) | 0.1 (0.0–0.9) |
| 15-cm column velocity (ft/s) | 0.0 (0.0–0.1) | 0.0 (0.0–0.2) | 0.0 (0.0–0.5) | 0.1 (0.0–0.6) |
| **Water quality** | | | | |
| Water temperature (°C) | 23.7 (20.6–26.9) | 23.8 (20.9–26.5) | 25.4 (22.3–26.9) | 23.5 (21.8–26.2) |
| DO (mg/L) | 6.4 (4.7–10.2) | 7.5 (4.2–11.5) | 9.7 (8.3–11.2) | 8.7 (2.9–10.7) |
| DO % saturation | 74.3 (55.2–124.9) | 87.8 (36.7–107.0) | 111.3 (100.0–137.7) | 103.3 (9.3–113.2) |
| pH | 7.4 (7.3–8.3) | 7.4 (7.0–7.8) | 7.7 (7.6–7.9) | 7.8 (7.5–9.5) |
| Specific conductance (µs/cm) | 565 (554–680) | 567 (561–655) | 563 (540–583) | 566 (562–632) |

[1]Denotes ornate vegetation taxa with complex leaf structure
[2]Denotes long broad or ribbon-like, austere-leaved vegetation taxa

**Table 5.** **Summary of vegetation types sampled among reaches during 2023 random-station surveys in the Comal Springs/River and the percent occurrence of Fountain Darters in each vegetation type and reach. Raw numbers represent the sum of detections per reach-vegetation type combination.**

| VEGETATION TYPE | USR | LL | OC | NC | Total | Occurrence (%) |
|---|---|---|---|---|---|---|
| Bryophyte[1] | 0 | 1 | 66 | 0 | 67 | 98.5 |
| *Cabomba*[1] | 2 | 22 | 0 | 30 | 54 | 72.2 |
| *Chara*[1] | 2 | 0 | 0 | 0 | 2 | 50.0 |
| Filamentous algae[1] | 4 | 0 | 0 | 0 | 4 | 100.0 |
| *Ludwigia*[1] | 0 | 24 | 53 | 0 | 77 | 84.4 |
| *Nuphar*[2] | 0 | 0 | 1 | 0 | 1 | 100.0 |
| *Potamogeton*[2] | 0 | 1 | 0 | 0 | 1 | 0.0 |
| *Sagittaria*[2] | 22 | 37 | 0 | 0 | 59 | 42.4 |
| *Vallisneria*[2] | 0 | 35 | 0 | 0 | 35 | 60.0 |
| **Total** | 30 | 120 | 120 | 30 | 300 | 74.0 |
| **Occurrence (%)** | 23.3 | 70.0 | 94.2 | 60.0 | - | - |

[1]Denotes ornate vegetation taxa with complex filamentous or leaf structure
[2]Denotes long broad or ribbon-like, austere-leaved vegetation taxa

## *Population Demography*

### ***Seasonal population trends***

Median Fountain Darter density in 2023 was higher in the spring (7.00 darters/$m^2$) and summer (6.50 darters/$m^2$) than fall (0.50 darters/$m^2$). Variation in density (i.e., interquartile range) was also lowest in fall (4.75 darters/$m^2$) compared to other seasons (17.50–24.00 darters/$m^2$) (Figure 10A). Current median CPUE was also high in spring (101 darters/p-h) and decreased from summer (54 darters/p-h) to fall (46 darters/p-h) (Figure 10B). Median occurrence also decreased from spring (100%) to fall (25%) (Figure 10C). In addition, random dip-net sampling in January represented the first winter event (not shown in Figure 10) and had the second highest median occurrence rate (73%) in 2023. All three indices aligned with 5-year and long-term trends in spring and summer, though were lower than expected in fall. Differences were minor for density and catch rates compared to occurrence, which was 35% lower than its 5-year median in fall. Also of note, 2023 density data were more closely aligned with the 5-year data than the long-term (see next section for more details) (Figure 10).

In summary, patterns in population performance aligned with historical data in all seasons but fall. Densities and catch rates were not substantially lower than past observations, which may be best explained by spatial variation in population responses. For example, catch rates were generally lower than expected across all reaches except New Channel. Spatial patterns in density were similar, demonstrating that despite lower index values in some areas, increases in New Channel helped resist substantial population declines overall (see next section for further discussion). In contrast to density and catch rates, fall occurrence rates were much lower than historical expectations, possibly due to several factors. First, no darters were observed at Upper Spring Run. Habitat conditions are currently poor in this reach which has experienced limited to zero springflow the past two years (BIO-WEST 2023a). Second, percent occurrence at Landa Lake was also lower than expected, possibly due to lower overall habitat suitability this year.

Lower darter prevalence may also in part be explained by the location of randomized samples within suitable vegetation (e.g., *Cabomba* near the slough arm). Regardless of potential effects of spatial stochasticity, low flows appear to have impacted Landa Lake, though previous low-flow sampling provide reasonable optimism that the population will rebound (Figure E8).

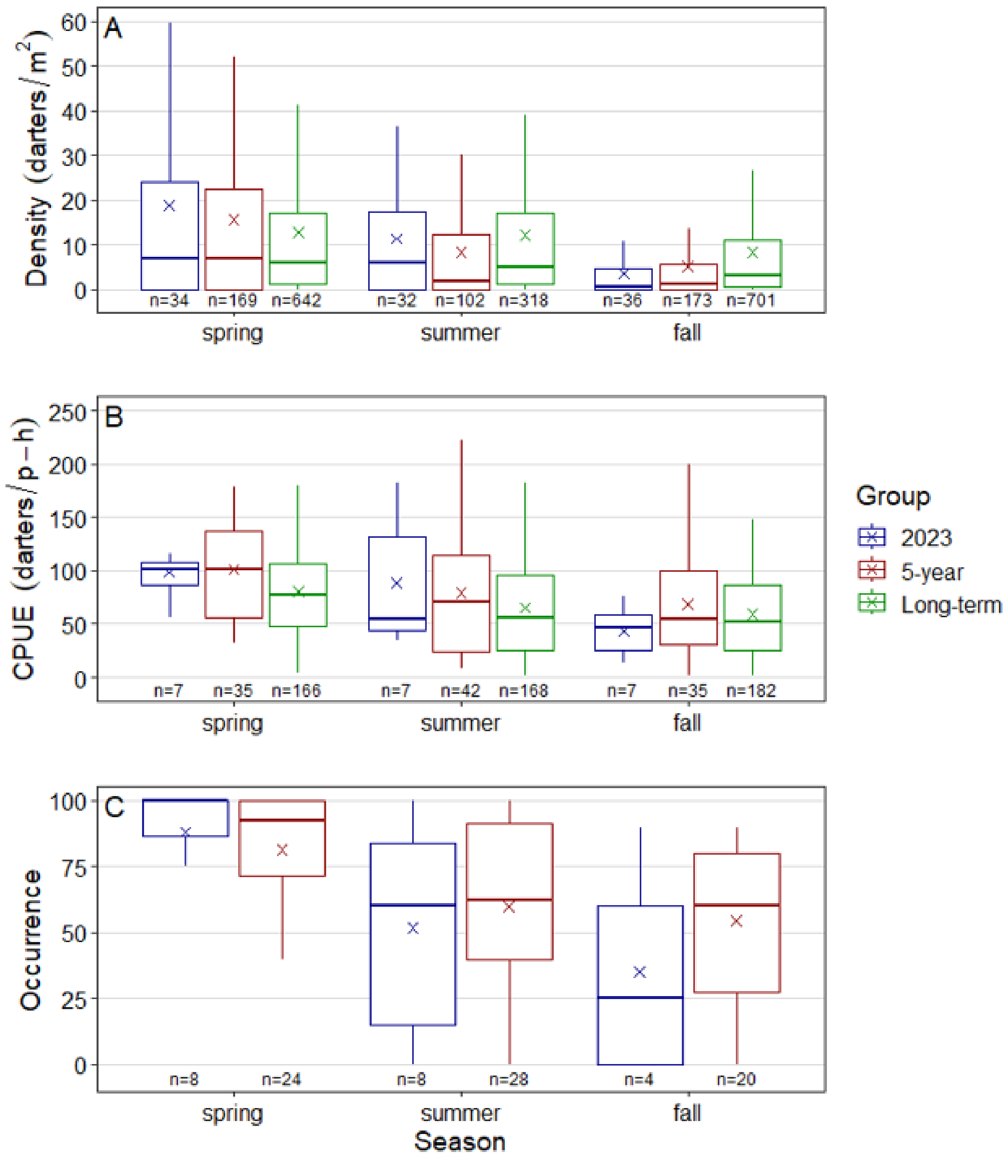


**Figure 10.** **Boxplots comparing Fountain Darter density from drop-net sampling (A), catch-per-unit-effort (CPUE) from timed dip-netting (B), and percent occurrence from random station dip-netting (C) among seasons in the Comal Springs/River. Temporal groups include 2023, 5-year (2019–2023), and long-term (2001–2023) observations. The thick horizontal line in each box is the median, x represents the mean, and the upper/lower bounds of each box represents the interquartile range. Whiskers represent minimum/maximum values up to 1.5 times the interquartile range. The "n" values along the x-axes represent the number of samples per category.**

### ***Drop-net sampling density trends***

Patterns in Fountain Darter density in 2023 varied among reaches. Median density at Upper Spring Run was 0.00 darters/m$^2$ for all 2023 events and upper quartiles were higher in summer (0.88 darters/m$^2$) than spring and fall (0.38 darters/m$^2$). Lower densities have persisted in this reach since summer 2022. At Landa Lake, median density decreased from spring (18.00 darters/m$^2$) to summer (12.75 darters/m$^2$), though both estimates were above the long-term median (10.50 darters/m$^2$). Upper quartiles showed a similar pattern and were much greater than the long-term (24.00 darters/m$^2$) in spring (53.38 darters/m$^2$). Density sharply declined by fall, with most observations below the long-term lower quartile (2.50 darters/m$^2$), though several outliers (14.00 and 20.00 darters/m$^2$) not displayed in Figure 11 were higher. Density trends at Old Channel were similar to Landa Lake, except that median density in fall (3.50 darters/m$^2$) was more aligned with the long-term (4.00 darters/m$^2$), though the upper quartile estimate was 4.75 darters/m$^2$ lower than the long-term. Trends in density at New Channel deviated from historical expectations much more than other reaches. Median density decreased from spring to fall (23.50–8.00 darters/m$^2$), but all three events in 2023 exhibited median density about 4–12 times greater than the long-term median (2.00 darters/m$^2$) (Figure 11).

Median density the past five years were not strongly correlated ($r < 0.70$) among reaches, indicating spatially asynchronous trends in the Comal Springs/River System. While trends varied spatially, general patterns in density showed some similarities were evident between certain reaches. Densities at Upper Spring Run and New Channel displayed discontinuous temporal patterns, where abrupt large increases in density were usually followed by sharp declines below long-term trends that extend for longer durations. This results in greater variability in long-term datasets from these reaches. In contrast, Landa Lake and Old Channel demonstrated more regular seasonal oscillations. Density fluctuations typically followed long-term expectations, peaking during spring (Figure 11). Differences in these general temporal patterns among reaches are likely best explained by dissimilarities in habitat stability. Populations that exhibit discontinuous trends are usually associated with greater environmental variation (i.e., Upper Spring Run, New Channel), whereas seasonal oscillations are more typical in areas with more stability (i.e., Landa Lake, Old Channel) and driven mainly by timing of reproduction (Berryman 2002).

Results displayed variable reach-level responses to continued low-flow conditions. Differences were likely explained by responses of vegetation to reduced flows which limited available resources and possibly led to population regulation. First, lower overall habitat suitability at Upper Spring Run and Landa Lake partially explains their density trends this year. Lower densities at Upper Spring Run are coupled with changes in bryophyte coverage, which is a taxon sensitive to low flows (Suren 1996). Substantial declines in Landa Lake, particularly in fall 2023, are likely related to decreases of bryophytes due to low flows. Although bryophytes were limited within Landa Lake during fall 2023, they were present in areas too deep for drop-net sampling and therefore were not sampled in fall. It is likely that their exclusion influenced overall densities in the reach. Abrupt declines in density at the lake by fall 2023 may also be a product of over compensatory dynamics typical for this reach (i.e., large seasonal swings in density) in conjunction with lower habitat quality (Shoemaker et al. 2020). Very high densities in spring and summer this year could partially be attributed to increased recruitment rates in fall 2022 as a result of low and stable flows (McCargo and Peterson 2010, Katz and Freeman 2015). Based on evidence of habitat degradation at Landa Lake, the more abrupt decrease in density observed in fall 2023 was possibly due to lower availability of resources to sustain elevated population levels, resulting in intense competitive population regulation over a short time frame (Berryman 2002, Shoemaker et al. 2020). Despite this, increases in density are expected by spring 2024 given typical patterns in reproduction and recruitment, and densities should return to typical levels once optimal vegetation (bryophytes) increase in coverage (Figure E9).

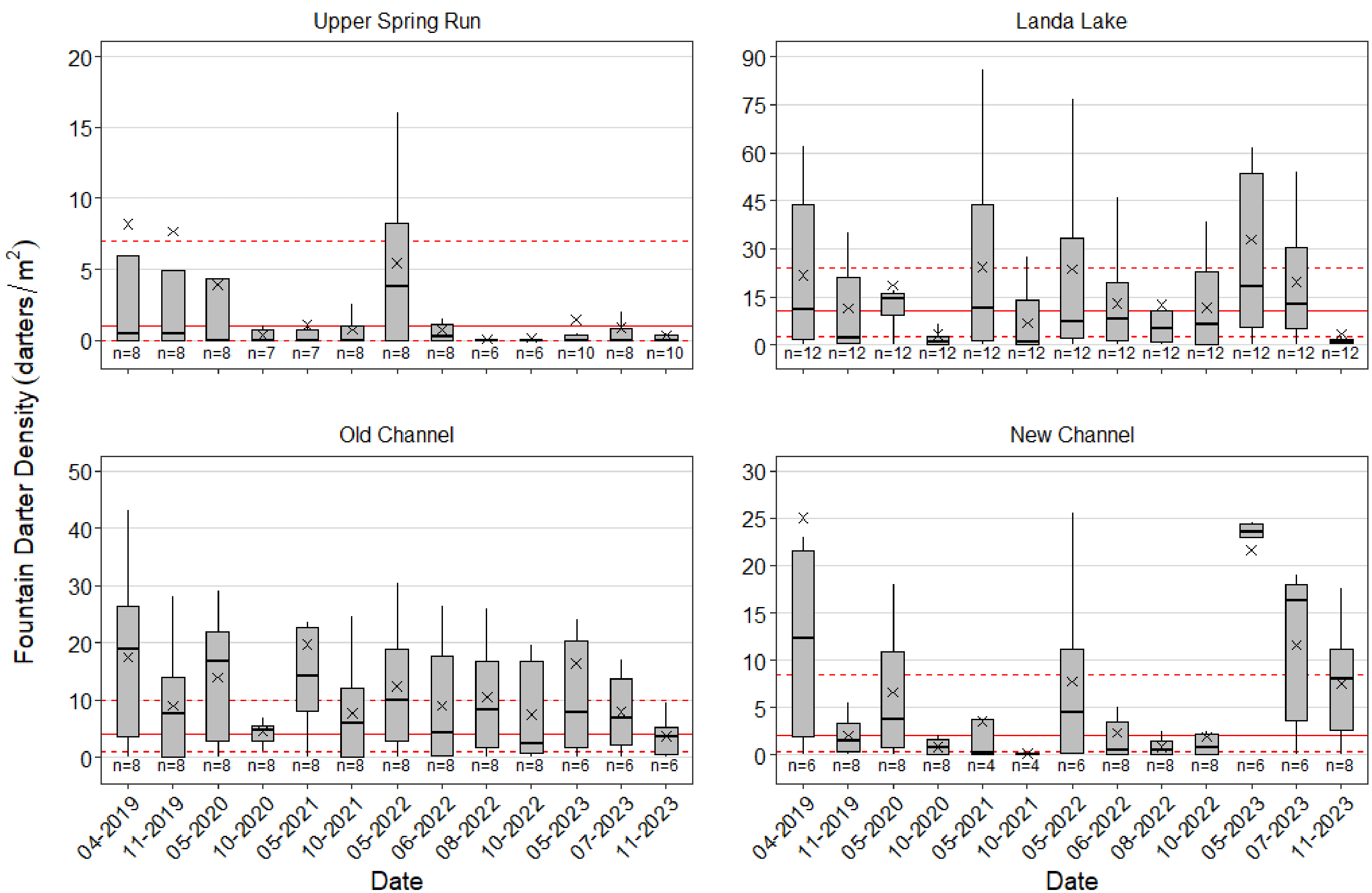


**Figure 11. Boxplots displaying temporal trends in Fountain Darter density (darters/m$^2$) among study reaches from 2019–2023 during drop-net sampling in the Comal Springs/River. The thick horizontal line in each box is the median, x represents the mean, and the upper/lower bounds of each box represents the interquartile range. Whiskers represent minimum/maximum values up to 1.5 times the interquartile range. The "n" values along the x-axes represent the number of drop-net samples in each category. Solid and dashed red lines denote long-term (2001–2023) medians and interquartile ranges, respectively.**

Abrupt increases in density at New Channel this year were somewhat surprising but can again be explained by the influence of flow on habitat conditions. Recruit densities were high in this reach in spring (relative density: 49.6%) and fall (relative density: 33.1%) resulting from expansion of more suitable vegetation (e.g., bryophyte, *Hygrophila*) due to flow stability (Katz and Freeman 2015). Low variability observed in spring can be partially explained by open habitats not being sampled, due to the ubiquitous distribution of filamentous algae in wadable areas. Since open habitats typically result in extremely low densities, their exclusion greatly decreases variability. Nonetheless, these results exemplify how Fountain Darter responses to low flows vary spatially. It is well recognized that spatially asynchronous population dynamics help facilitate long-term persistence, and this appears to be the case for Fountain Darters in the Comal system (Stowe et al. 2020, Larsen et al. 2021). In summary, negative effects of low flows were not a ubiquitous trend at the system-level. Research on relative influences between density- independent and -dependent factors could help identify what mechanisms drive spatial differences in population trends and provide a more complete understanding on effects of reduced flows.

### ***Size structure and recruitment trends***

Five-year trends in Fountain Darter size structure and recruitment were consistent among seasons, though several years did not align with expectations in summer and fall. In general, smaller darters were more frequent in spring during the peak reproductive period, as seen by lower median lengths (15–17 mm) and higher recruitment rates (45.9–57.6%). Violin plots depicting five-year trends further demonstrate a greater proportion of smaller darters during the spring and higher recruitment rates in years with left-skewed distributions. Patterns in size structure and recruitment observed in spring closely aligned with long-term trends from 2021–2023. Size structure in 2019 and 2020 also aligned with past observations, though recruitment was higher than expected. In summer and fall 2023, results also generally met expectations, displaying higher median lengths (24–26 mm and 23–27 mm, respectively), left-skewed size distributions, and lower recruitment (21.1–35.5% and 16.1–45.2%, respectively) compared to spring. Notable exceptions for recruitment included summer 2021 (35.5%) and fall 2022 (45.2%) (Figure 12).

Foutain Darter recruitment in the fall was above long-term expectations for the second consecutive year but at a lower magnitude than 2022. Increased fall recruitment also differed spatially the past two years. Recent recruits were most prevalent at Landa Lake and Old Channel in fall 2022 compared to >50% of recent recruits being observed at New Channel in 2023. It was previously suggested that stable and/or low flows increases young-of-year survival (BIO-WEST 2022a), which other fisheries studies also observed and suggested as a potential resilience mechanism against reduced flows (McCargo and Peterson 2010, Katz and Freeman 2015). Water temperature is also considered a limiting factor on Fountain Darter egg and larval production, though exceedance of optimal temperature thresholds from previous laboratory studies do not adequately explain patterns of recruitment observed in 2023. Temperatures stayed below production thresholds at Landa Lake and were exceeded at similar frequencies at Old Channel and New Channel in summer. Based on this, attenuated recruitment rates would be expected for these riverine reaches in fall 2023 if water temperature was the driving mechanism. That said, the laboratory-derived temperature thresholds are difficult to apply directly to wild populations because the temperature fluctuations imposed during the McDonald et al. (2007) study trials do not exactly match natural patterns observed in the wild. However, high recruitment within the

New Channel in 2023 suggest other factors such as habitat availability and density-dependent mechanisms influence recruitment. More formal analyses are needed to elucidate the relative influence of water temperature, habitat, and density-dependent mechanisms on Fountain Darter demography (Berryman 2002, Dennis et al. 2006).

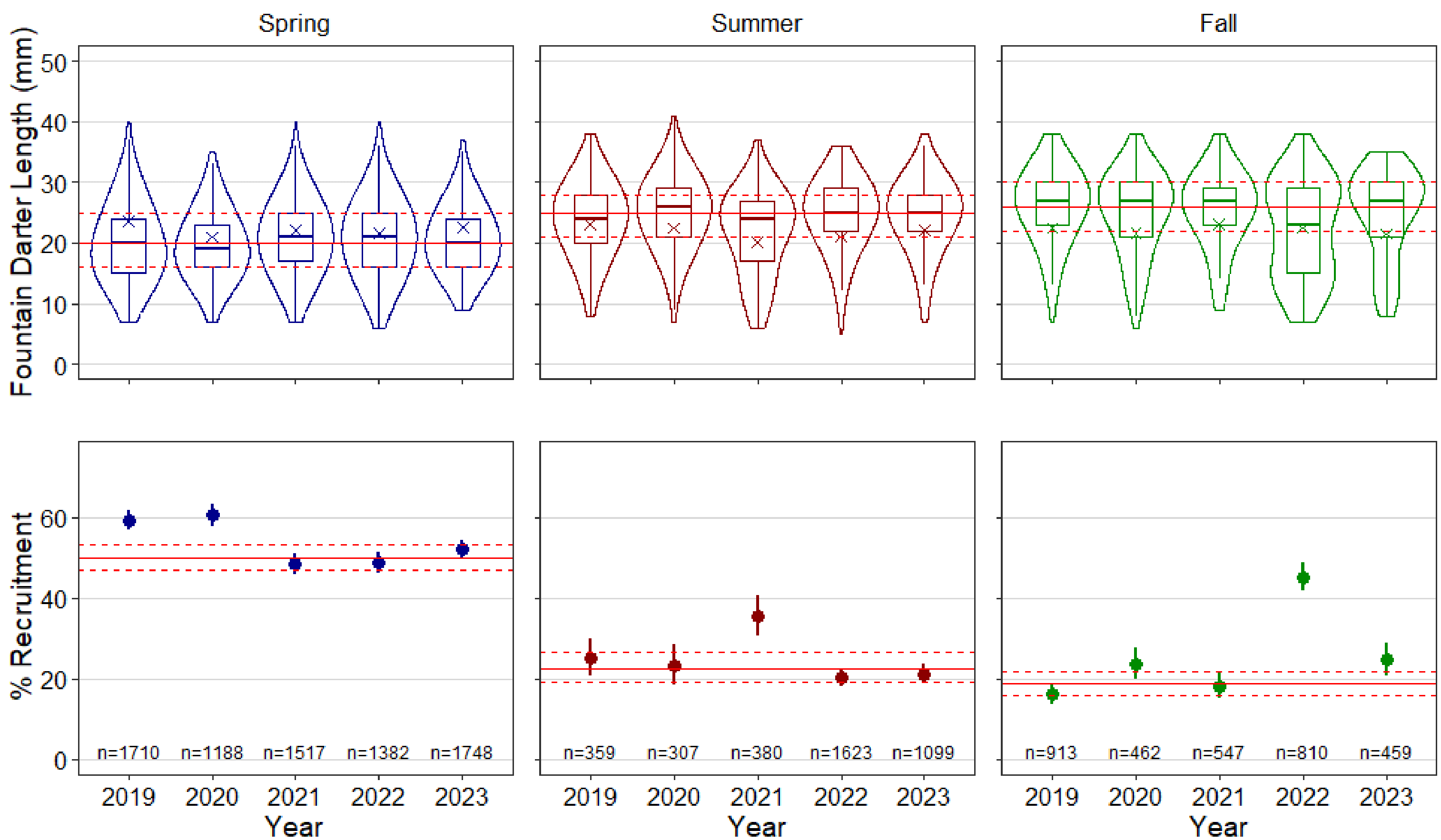


**Figure 12.** **Seasonal trends of Fountain Darter size structure (mm; top row) and percent recruitment (bottom row) in the Comal River from 2019–2023. Spring and fall trends are based on drop-net and timed dip-net data in aggregate, whereas summer trends are based on timed dip-net data only. Size structure is displayed with boxplots (median, quartiles, range) and violin plots (probability density; polygons outlining boxplots). The thick horizontal line in each box is the median, x represents the mean, and the upper/lower bounds of each box represents the interquartile range. Whiskers represent minimum/maximum values up to 1.5 times the interquartile range. The "n" values along the x-axis of the top row represent the number of Fountain Darter length measurements in each distribution. Recruitment is the percent relative abundance (± 95% CI) of darters ≤20 mm. Long-term (2001–2023) trends in size structure are represented by median (solid red line) and interquartile range (dashed red lines). Recruitment is compared to the long-term mean percentage (solid red line) and 95% CI (dashed red lines).**

## *Habitat Use and Suitability*

### ***Density trends among vegetation taxa***

Median densities in 2023 were highest in bryophyte (16.50 darters/$m^2$) and *Hygrophila* (15.50 darters/$m^2$). Taxa with intermediate densities included *Cabomba* (9.75 darters/$m^2$) and *Ludwigia* (9.00 darters/$m^2$). Among these taxa, median density was higher than expected in *Hygrophila* whereas others aligned with long-term data. Median density was higher in *Vallisneria* (3.75 darters/$m^2$) and lower in filamentous algae (0.75 darters/$m^2$), with filamentous algae being considerably lower than expected based on long-term data. In open habitats and *Sagittaria*, median density was 0.00 darters/$m^2$ and mirrored historical data (Figure 13). Greater densities within ornate taxa aligned with expectations based on historical data and past research on Fountain Darter habitat associations (Schenck and Whiteside 1976, Linam et al. 1993, Alexander and Phillips 2012, Edwards and Bonner 2022).

Slightly higher than typical densities in *Vallisneria* were directly related to bryophytes being present within, creating greater complexity in physical structure that is more suitable for darters. Higher densities in *Hygrophila* in 2023 was somewhat surprising and warrants further investigation. Differences observed in filamentous algae density are likely related to taxa specific patterns that are overlooked because algae are usually identified at a coarse taxonomic level. This may also explain why past studies show conflicting results on the use of filamentous algae by Fountain Darters (Linam et al. 1993, Alexander and Phillips 2012, Edwards and Bonner 2022).

### ***Size structure among vegetation taxa***

Boxplot summary statistics and violin plots showed that Fountain Darter size structure varied among vegetation taxa sampled in 2023. Median lengths were most frequently 23 mm, with minimum and maximum medians observed in filamentous algae (15 mm) and open (26 mm), respectively. Filamentous algae had the highest relative proportion of small darters, though counts were lowest among this vegetation taxa. Size structure distributions in *Hygrophila*, *Ludwigia*, and *Vallisneria* were left-skewed and had a higher prevalence of larger adults. The uniform distributional shape exhibited by bryophyte and *Cabomba* supports these taxa were important habitats across all life stages in 2023 (Figure 14).

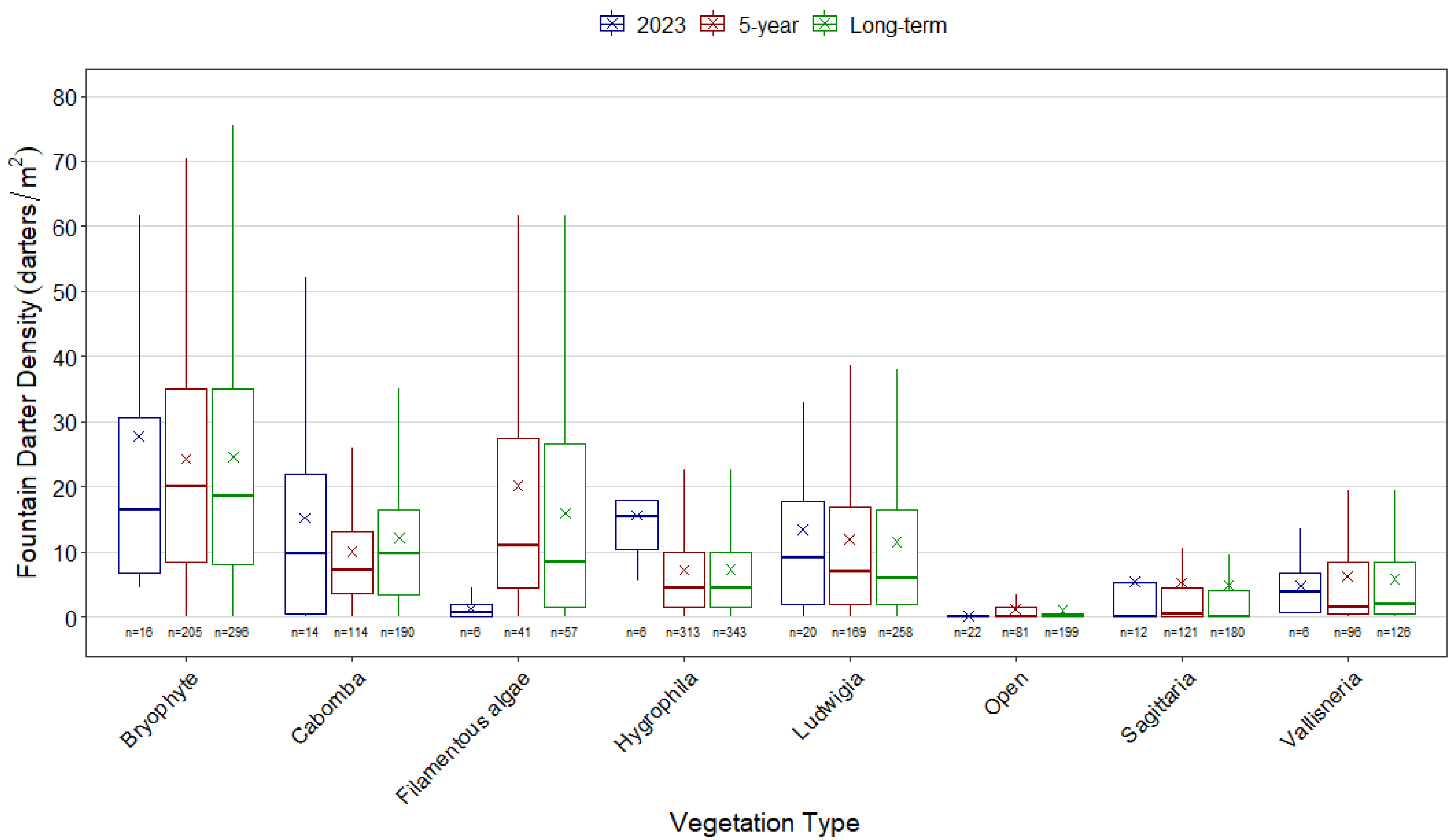


**Figure 13.** **Boxplots displaying 2023, 5-year (2019–2023), and long-term (2001–2023) drop-net Fountain Darter density (darters/m²) among vegetation types in the Comal Springs/River. The thick horizontal line in each box is the median, x represents the mean, and the upper/lower bounds of each box represents the interquartile range. Whiskers represent minimum/maximum values up to 1.5 times the interquartile range. The "n" values along the x-axes represent drop-net sample sizes per group.**

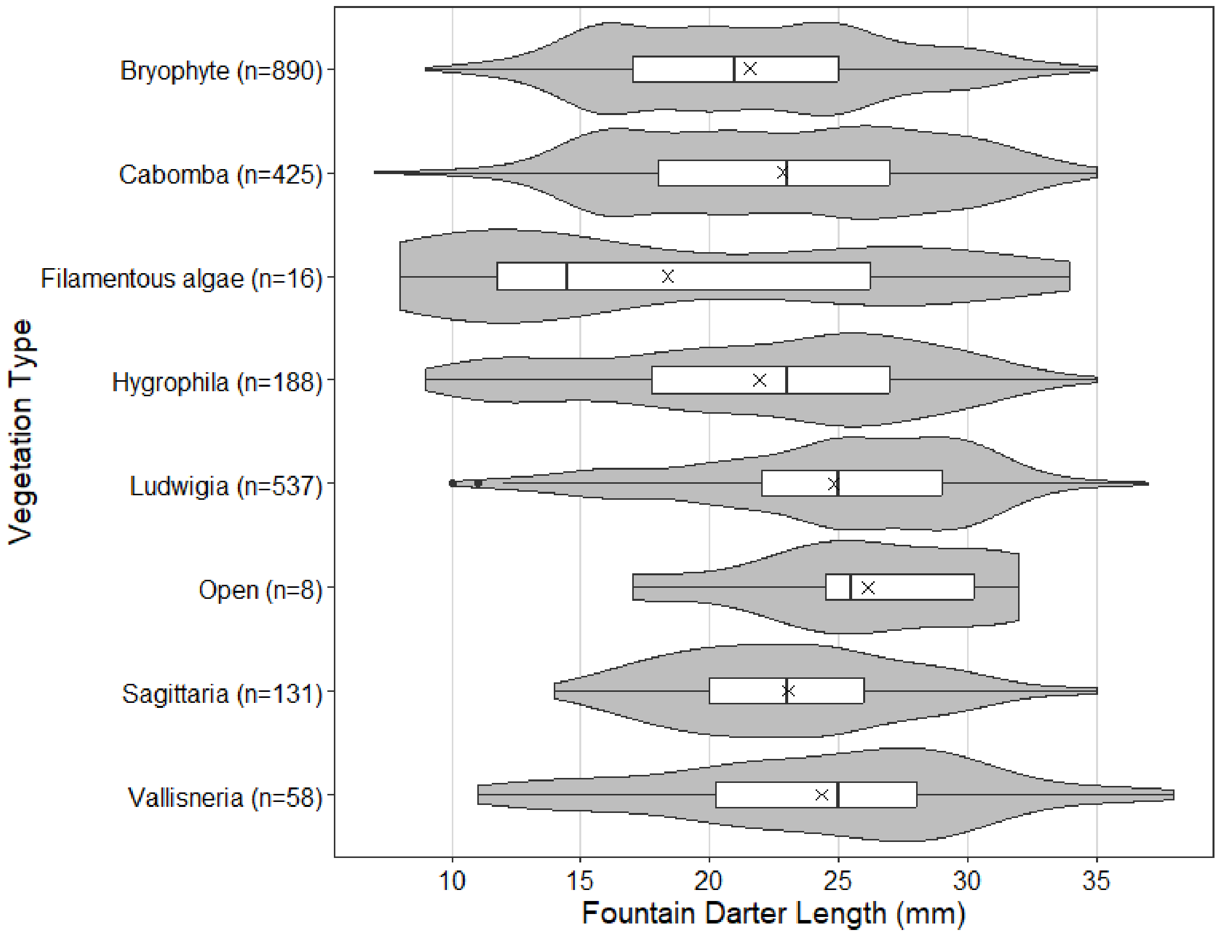


**Figure 14. Boxplots and violin plots (grey polygons) displaying Fountain Darter lengths among dominant vegetation types during 2023 drop-net sampling in the Comal Springs/River. The thick horizontal line in each box is the median, x represents the mean, and the upper/lower bounds of each box represents the interquartile range. Whiskers represent minimum/maximum values up to 1.5 times the interquartile range, and outliers beyond this are designated with solid black circles. The "n" values represent the number of Fountain Darter length measurements per vegetation type.**

Compared to previous years, bryophyte is the only taxa that displays consistent size structure. For example, size classes that utilize *Ludwigia* have differed annually, and a greater proportion of small darters were within *Cabomba* in 2023 than 2022 (BIO-WEST 2022a, 2023a) (Figure 14). This suggests ontogenetic shifts in habitat use may vary temporally or spatially. Changes in habitat use among size classes may depend on habitat conditions such as depth, velocity, or substrate at a given location. For example, vegetation taxa that occur in variable flow conditions (e.g., *Ludwigia*) would likely have lower proportions of juveniles if sampling was mostly in swift habitats within a given year.

### ***Habitat suitability***

Temporal trends in Fountain Darter habitat suitability at Upper Spring Run displayed a cyclical pattern and fluctuated around the long-term mean. Overall Habitat Suitability Index (OHSI) decreased from spring 2019 (0.57) to fall 2021 (0.42), then increased up to summer 2022 (0.54). For the remaining time period, OHSI continued to decrease to minimums in spring and fall 2023 (~0.41). At Landa Lake, OHSI was stable from 2019–2021 (0.57–0.62). OHSI slightly decreased, but also remained stable from 2022 to spring 2023 and declined again to the 5-year minimum in fall 2023. Similar to Upper Spring Run, temporal patterns in Old Channel were cyclical (0.48–0.59) and fluctuated within the limits of long-term trends. OHSI at Upper New Channel displayed distinct shifts in suitability. OHSI was slightly below the long-term mean from 2019–2021 (0.39–0.44) and was above it from 2022–2023 (0.47–0.52), with the exception of an abrupt decline in summer 2023 (August; 0.38). Temporal patterns at Lower New Channel were mostly near or above (0.48–0.62) the long-term mean other than a sharp decrease that also occurred in summer 2023 (0.38) (Figure 15).

Vegetation taxa most associated with changes in habitat suitability varied among reaches. Changes in suitability at Upper Spring Run was mostly driven by changes in bryophyte and filamentous algae coverages. Declines in OHSI at Upper Spring Run were never substantial due to increased coverage of *Cabomba* when bryophyte decreased. Both of these taxa provide high quality Fountain Darter habitat and their varying responses to springflow help improve physical habitat conditions in this reach under low flows. Landa Lake suitability was also most associated with changes in bryophyte coverage, which has decreased since 2022, though *Cabomba* shows a similar inverse relationship as seen in Upper Spring Run. In contrast, the cyclical pattern observed in Old Channel is mostly driven by variation in coverage of *Cabomba*, which dropped to zero in 2023. Lastly, the abrupt declines in OHSI in the New Channel in August 2023 were attributed to decreased coverages of *Cabomba* and *Hygrophila*, though OHSI returned to high condition by fall 2023 (Figure 15).

Patterns in habitat suitability directly attributed to some of the observed Foutain Darter population trends. Low flows may have facilitated decreased coverages of bryophyte at Upper Spring Run and Landa Lake in 2023 (Suren 1996). That said, abrupt increases in bryophytes occurred at Upper New Channel in the spring, suggesting other mechanisms are influencing the dynamics of this taxon. Nonetheless, consistently lower densities and occurrence rates observed by the fall indicate potential negative effects of extended periods of habitat degradation within Comal Springs. That said, the inverse relationship between bryophyte and *Cabomba* in some reaches likely buffered against further declines in habitat quality and may help maintain habitat redundancy during periods of reduced flow (Magoulick and Kobza 2003).

Higher habitat suitability at New Channel directly reflected the enhanced population condition observed. As mentioned previously, positive responses by Fountain Darters and their habitat at this reach were surprising at such low-flow conditions in a reach far from spring inputs. Additional research on how dynamics of vegetation assemblages differ between spring and riverine environments would be worth exploring further. In summary, observed trends in habitat suitability help partially explain the positive and negative population responses of Fountain Darters in the Comal system. Future assessments may benefit from incorporating other relevant habitat factors (e.g., recent flow regime characteristics, depth, velocity, and/or substrate) or controlling for sources of spatiotemporal variation (e.g., reach, time of year) to provide more complete realizations of habitat suitability.

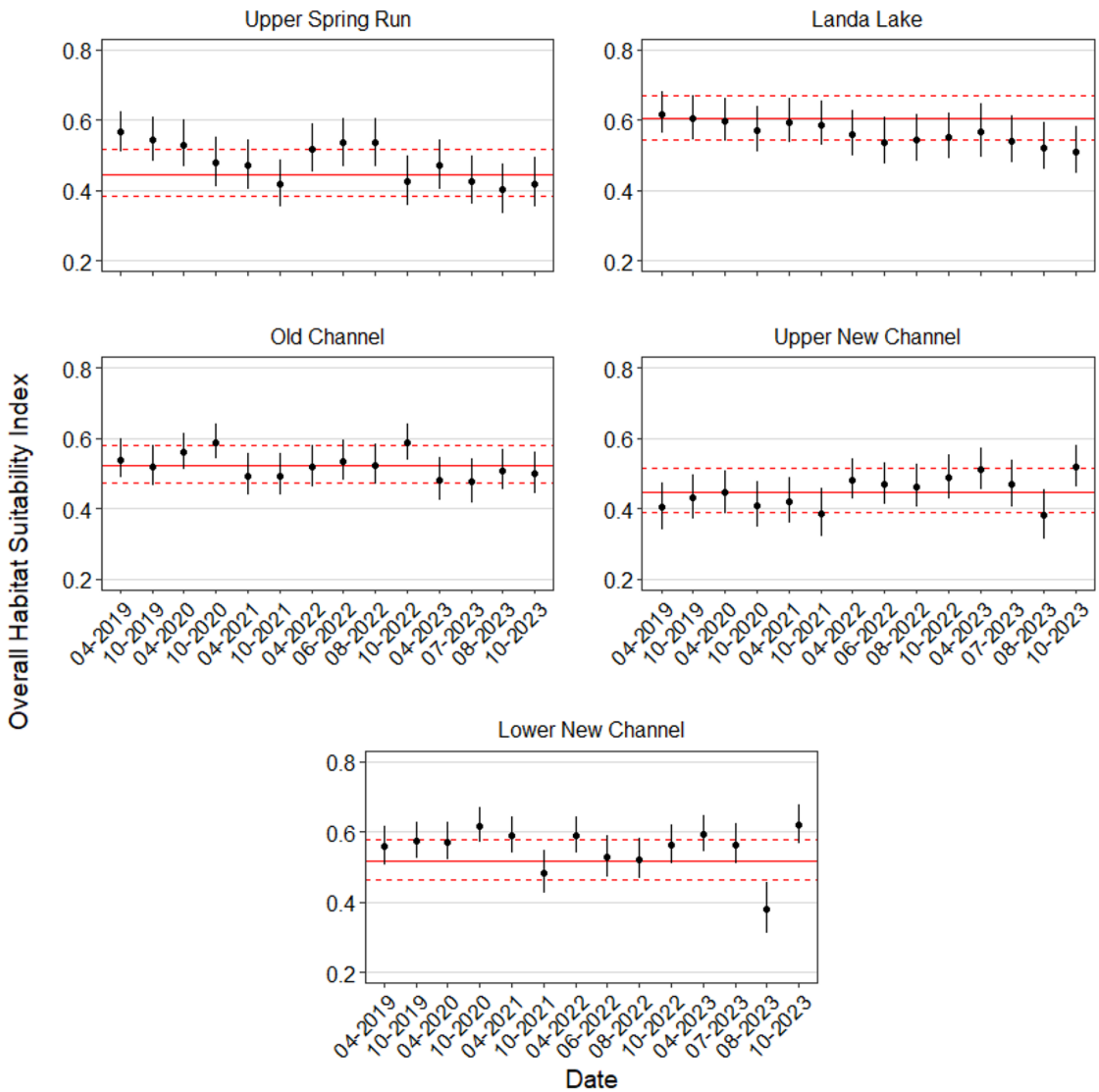


**Figure 15.** **Overall Habitat Suitability Index (OHSI) (±95% CI) from 2019–2023 among study reaches in the Comal Springs/River. Solid and dashed red lines denote means of long-term (2003–2023) OHSI and 95% CI, respectively.**

# Fish Community

A total of 11,971 fishes represented by 8 families and 21 unique species were observed in the Comal Springs/River System during 2023 sampling. Complete summaries of segment-level community composition can be found in Appendix E. Fish assemblage structure (percent relative abundance) varied from spring environments to riverine areas. Assemblages at upstream spring environments were dominated by *Gambusia* sp. at Upper Spring Run (37.4%) and by Guadalupe Roundnose Minnow (*Dionda nigrotaeniata*) at Landa Lake (65.2%); whereas downstream riverine areas at Old Channel and New Channel were dominated by Mexican Tetra (*Astyanax* *argentatus*; 27.9—37.7%). Other dominant species in riverine areas included Mimic Shiner (*Paranotropis volucellus*) and Texas Shiner (*Notropis amabilis*) at Old Channel (7.4% and 9.6%, respectively) and New Channel (12.1% and 9.6%, respectively). Fountain Darter ranked 3rd in abundance at Upper Spring Run (10.8%), 4$^{th}$ at New Channel (10.0%), and 5$^{th}$ at Landa Lake (5.8%) and Old Channel (5.9%) (Appendix E, Table E3).

Temporal trends in fish communities varied between and within study segments. Species richness and diversity were generally higher in riverine areas and lowest at Landa Lake. At Upper Spring Run, species richness and diversity were intermediate and more similar to riverine segments than to spring segments. Five-year trends in species richness usually varied from event to event and displayed no detectable patterns. No apparent trends in diversity were observed at Upper Spring Run and New Channel. In contrast, diversity generally increased from 2019–2021 at Landa Lake (0.49–1.45) then declined from 2022–2023. Diversity at Old Channel (1.29–2.15) has generally increased since 2019, though it did vary for some events (Figure 16), suggesting that community composition in Old Channel has become more heterogenous in recent years (Figure 16).

Temporal trends in richness of spring fishes aligned with community-level observations and were generally stable throughout the study area. Spring fishes' richness ranged from 4–6 species across all segments, generally not changing by more than one species from one event to the next. Relative density of spring fishes showed no emergent patterns at Upper Spring Run, Landa Lake, or New Channel, although relative density at Landa Lake was higher and more consistent than other segments. The general pattern of relative density at Upper Spring Run was varied, while the pattern at New Channel was more stable, similar to Landa Lake. Relative density was noticeably lower in two events at Upper Spring Run (August 2022, 37.7%; July 2023, 25.8%) and one event at New Channel (fall 2021, 46.1%). However relative densities returned to normal levels at successive sampling events. At Old Channel, relative density of spring fishes showed apparent cyclical patterns. Relative density first decreased from spring 2019 (80.7%) to fall 2020 (54.6%). This was followed by a large subsequent increase in spring 2021 (80.6%), after which it decreased again to fall 2022 (65.0%) (Figure 17). Beginning in summer 2023, spring fishes relative density increased again through fall, where it reached the greatest relative density in the past five years (84.3%).

Temporal trends in Fountain Darter density from 2019–2023 were based on microhabitat sampling data. Trends in 2023 were similar to Fountain Darter densities from drop-net sampling in which higher densities generally occurred in the spring and lower densities generally occurred in the fall (Figure 11). In 2023, median density at Upper Spring Run, Landa Lake, and New Channel were above the long-term in spring, while median density at Old Channel was below in spring. Median densities were below long-term expectations across all sites in summer and fall, except at New Channel which had higher median densities in the fall (Figure 18).

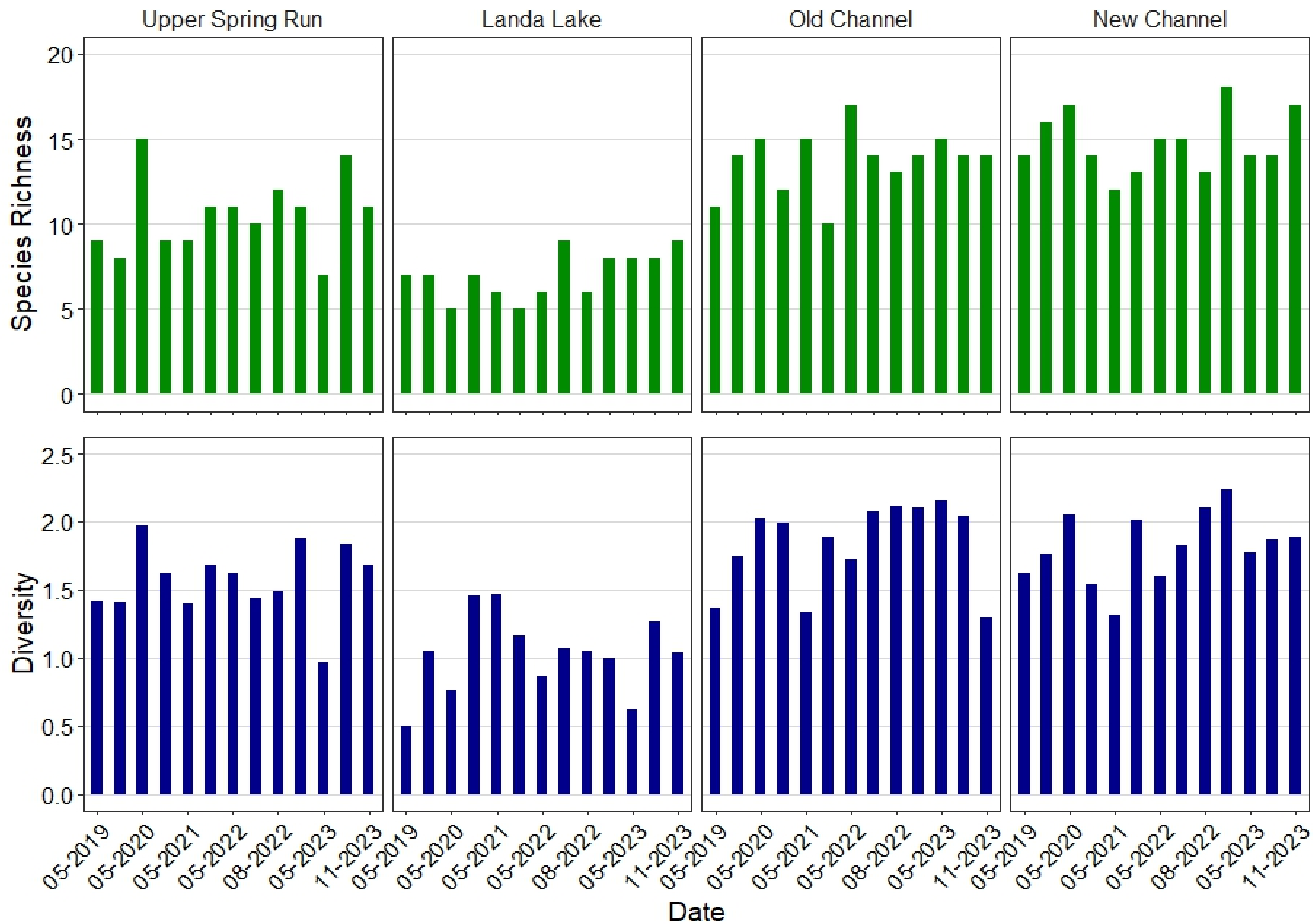


**Figure 16.** **Bar graphs displaying species richness (top row) and diversity (bottom row) from 2019–2023 based on all three fish community sampling methods in the Comal Springs/River.**

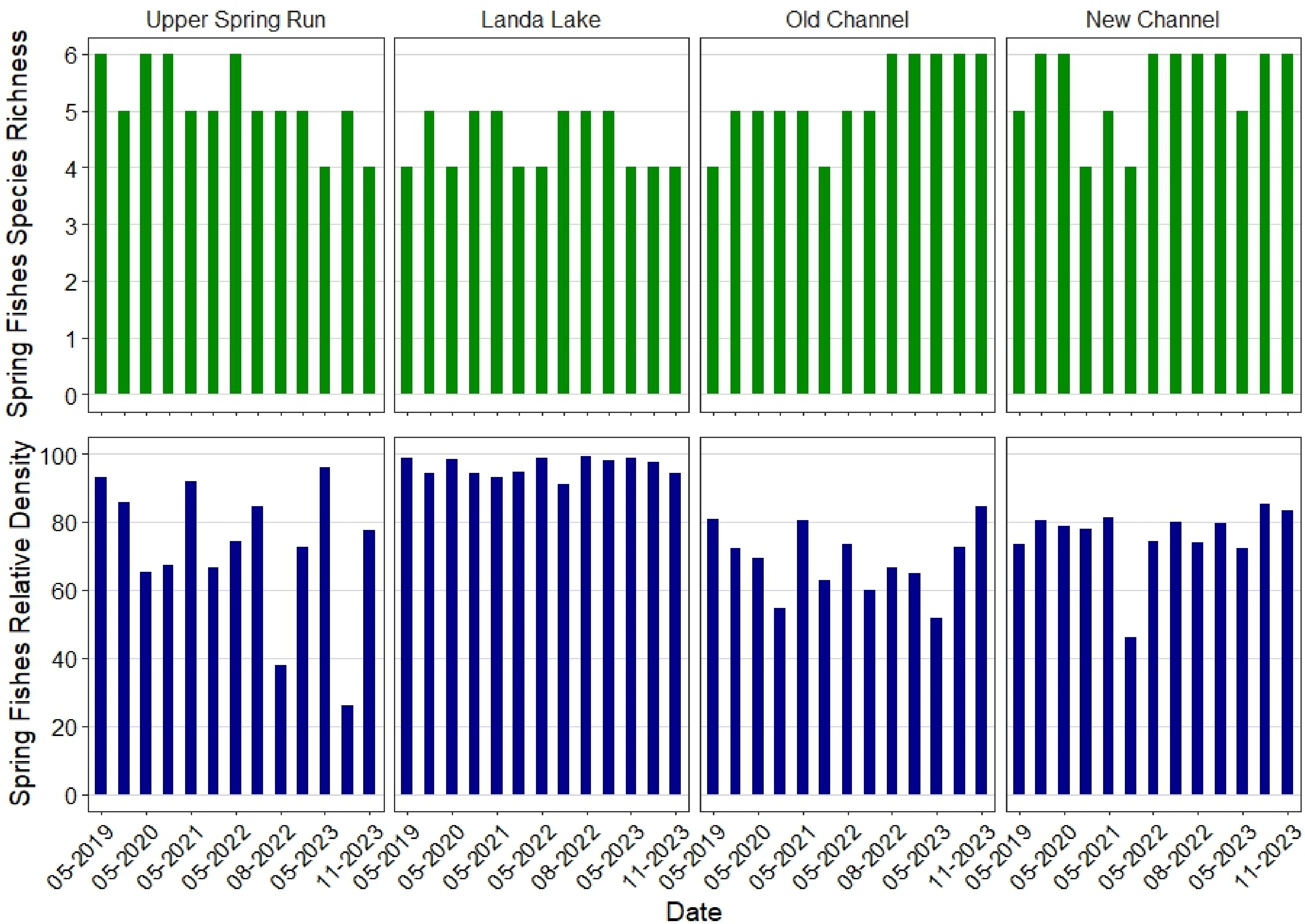


**Figure 17.** **Bar graphs displaying spring fish richness (top row) and relative density (RD; %) (bottom row) from 2019–2023 based on all three fish community sampling methods in the upper Comal Springs/River.**

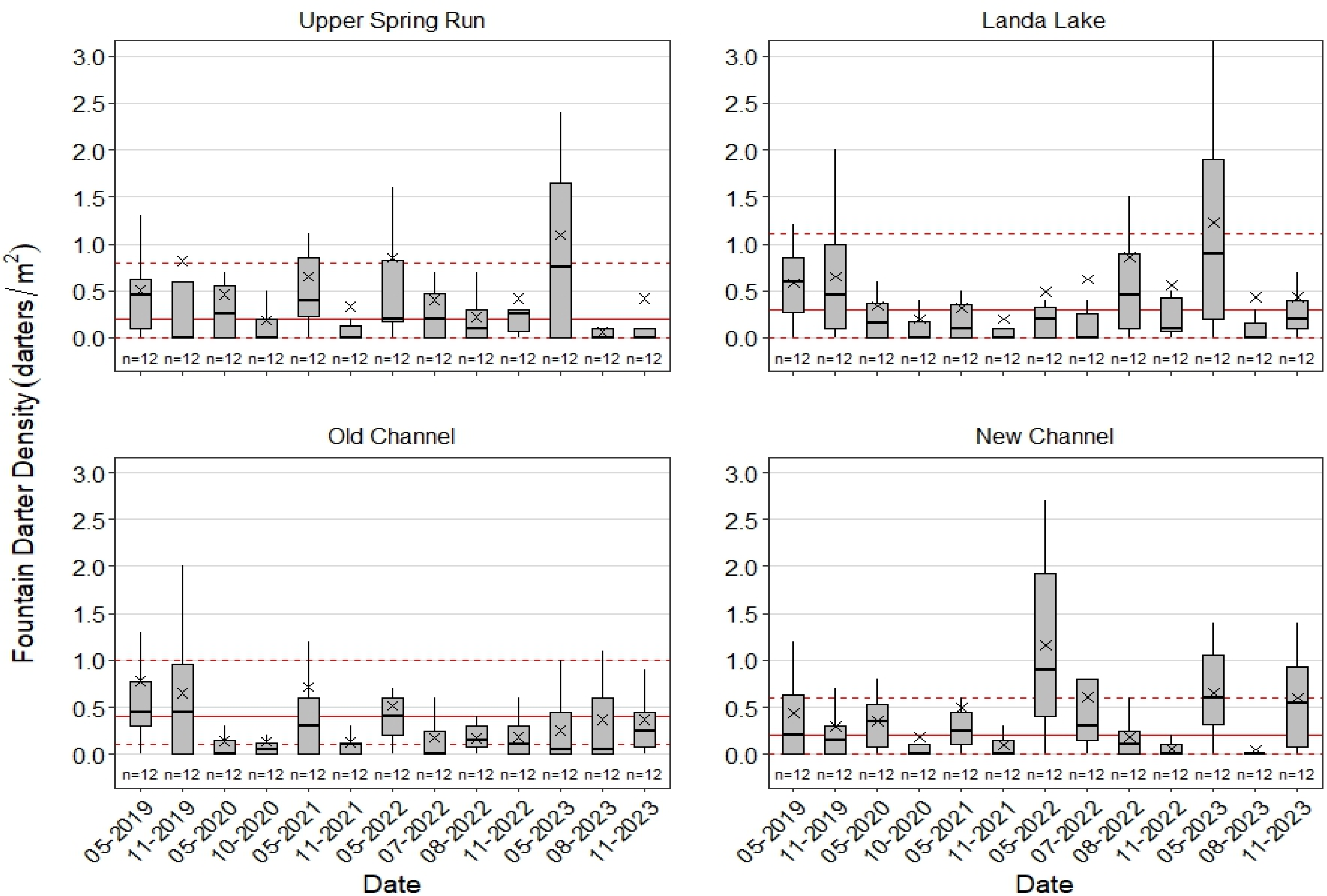


**Figure 18.** **Boxplots displaying temporal trends in Fountain Darter density (darters/m$^2$) among study reaches from 2019–2023 during fish community microhabitat sampling in the Comal Springs/River. The thick horizontal line in each box is the median, x represents the mean, and the upper/lower bounds of each box represents the interquartile range. Whiskers represent minimum/maximum values up to 1.5 times the interquartile range. The "n" values along the x-axes represent the number of microhabitat samples per category. Solid and dashed red lines denote long-term (2014–2023) medians and interquartile ranges, respectively.**

## Comal Springs Salamander

Although low springflows resulted in substantial reductions to surface salamander habitat in 2023, a total of 389 Comal Springs Salamanders were observed during 13 survey efforts. Sampling was not conducted at Spring Island Run during summer and fall and at Spring Run 1 during late summer and fall because these sites were completely desiccated. Across all sites, Comal Springs Salamander counts in spring, summer, and fall of 2023 were lower than the long-term averages. However, at sites that remained wetted, confidence interval overlap in summer and fall suggests counts may not be meaningfully lower given variability in the dataset (Figure 19). Five-year trends at Spring Island Run did not display any distinct patterns in CPUE, varying about 1 to 3 salamanders/p-h until this run dried up in summer 2023. From 2019 to 2023 Spring Island Outfall has varied from 8 salamanders/p-h to over 50 salamanders/p-h. Catch rates were consistently high from spring 2019 to spring 2022 but have been variable since that time. At Spring Run 3, salamander CPUE appeared to decrease over 2023, with the exception of a few high events in July and October 2023. The catch rate of 48.57 salamanders/p-h in October 2023 was the second highest recorded over the past five years. At Spring Run 1, trends appear to show a cyclical pattern until this spring run dried up in summer 2023 (Figure 20). Subsequent monitoring will help determine if returns to typical catch rates are maintained following dry conditions during this low-flow year.

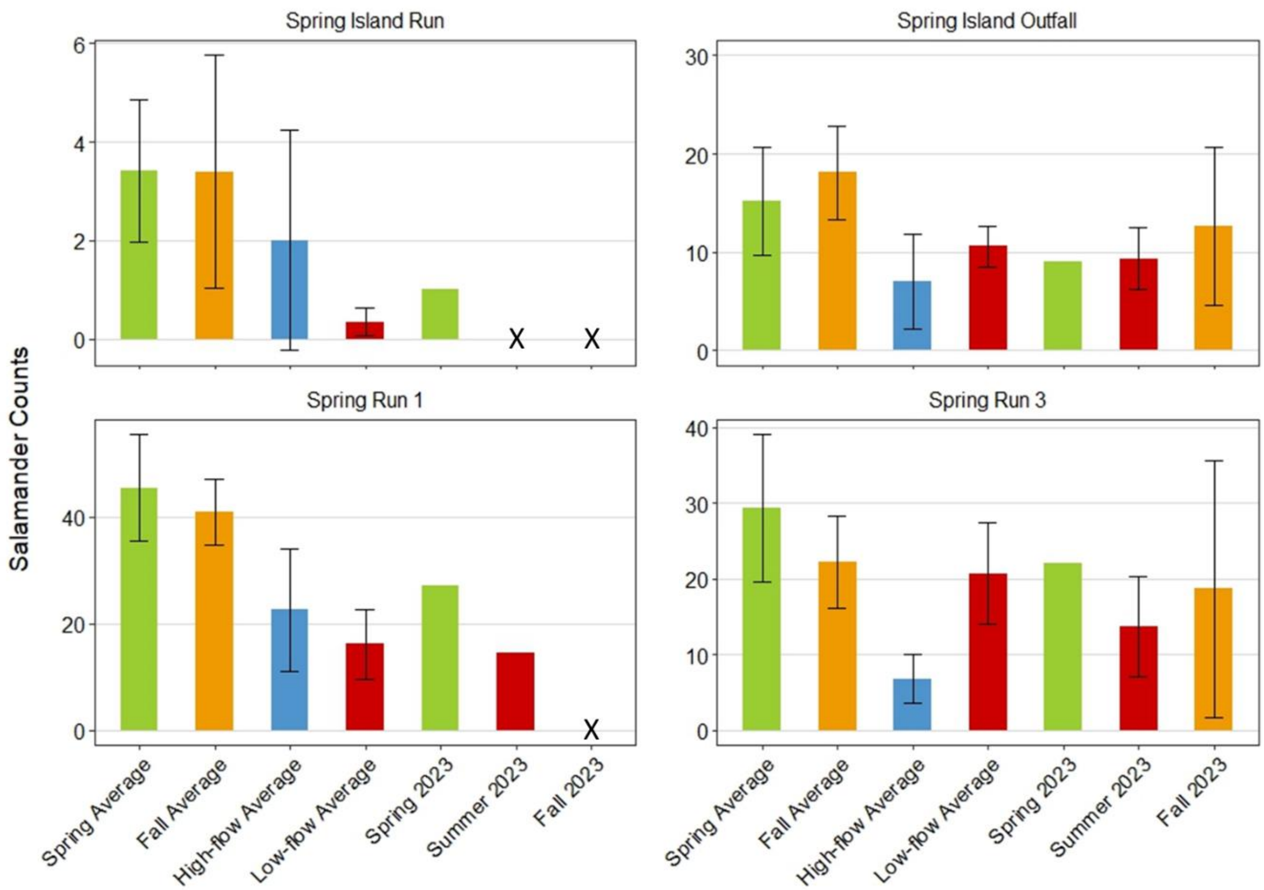


**Figure 19.** **Comal Springs Salamander counts among Comal Springs survey sites in 2023, with the long-term (2001–2023) average for each sampling event. Error bars for long-term averages represent 95% confidence intervals. X within dates at Spring Island Run and Spring Run 1 denotes lack of sampling due to dry conditions.**

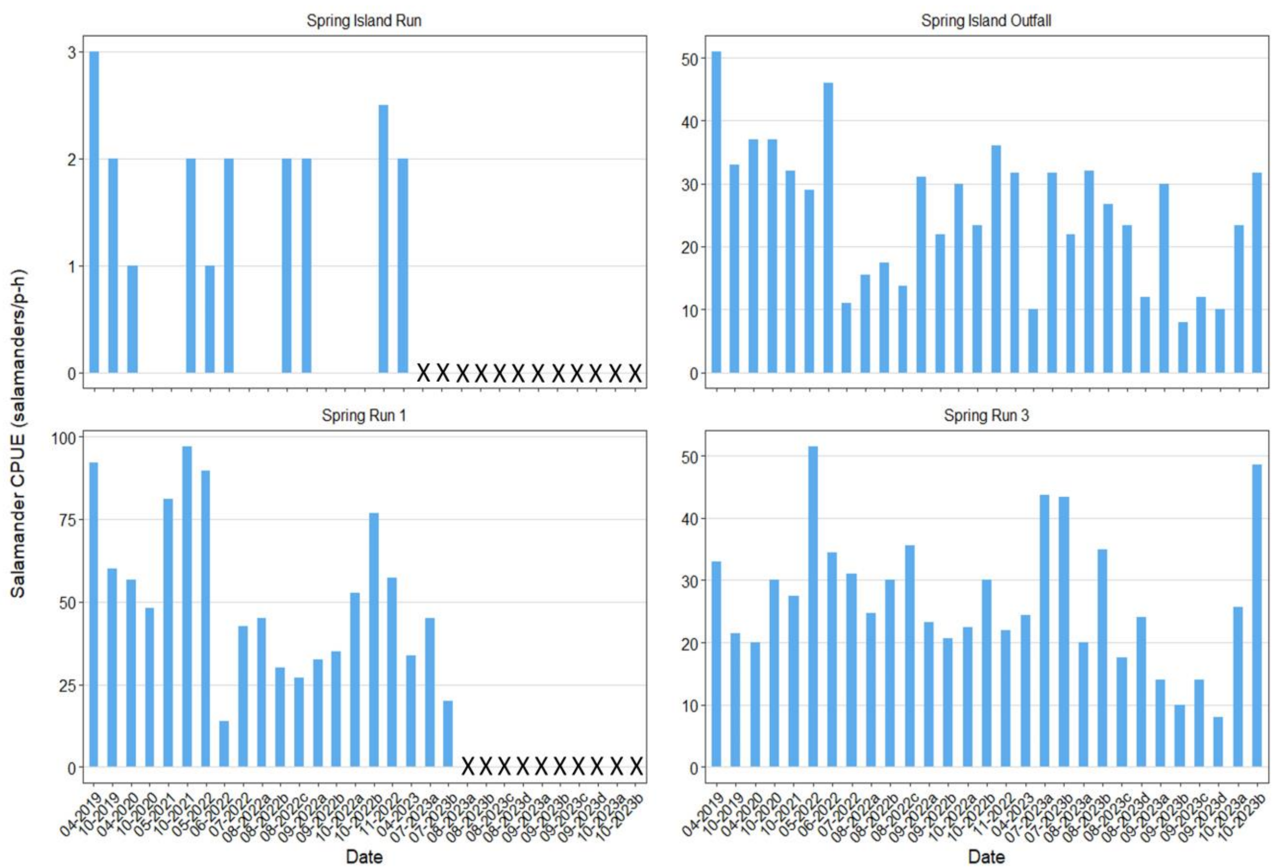


**Figure 20.** **Comal Springs Salamander catch-per-unit-effort (CPUE; salamanders/person-hr) among sites from 2019–2023 in the Comal Springs. No bar within dates at Spring Island Run denotes zero salamanders observed. X within dates at Spring Island Run and Spring Run 1 denotes lack of sampling due to dry conditions.**

# Macroinvertebrates

## *Drift-Net Sampling*

A total of 1,006 macroinvertebrates represented by 13 families and 19 taxa were collected during 144 drift-net hours. The total number of individuals collected was lower at Spring Run 1 (n = 113) than Spring Run 3 (n = 267) and Western Upwelling (n = 297), which can likely be attributed to reduced springflows in 2023. For example, the drift-net at Spring Run 1 was set at an alternate location than usual from fall 2022 through fall 2023 sampling due to the headwaters being dry (Figure 21). Across all sampling efforts, dominant taxa included amphipods (*Stygobromus* spp., 49.0%), ostracods (*Comalcandona tressleri*, 11.5%), and oligochaetes (*Eremidrilus* sp., 6.6%). The remaining taxa each represented less than 5% of the total catch. A total of 17 Peck’s Cave Amphipods (*Stygobromus pecki*) positively identified out of 332 total *Stygobromus* spp., 8 larval Comal Springs Riffle Beetles (*Heterelmis comalensis*), and 1 larval Comal Springs Dryopid Beetle (*Stygoparnus comalensis*) were observed in 2023 (Table 6). Full drift-net results are presented in Appendix E. Over the past 5 years, the median counts of *Stygobromus* spp. per cubic meter of water filtered most often aligned with the long-term median (0.02 *Stygobromus*/m$^3$). However, since fall 2022 median counts have been lower than the long-term, but means and upper quartiles have been relatively high (Figure 22). Lower counts at Spring Run 1 and Spring Run 3 in 2023 were likely attributed to the desiccated conditions at Spring Run 1 and reduced springflow at Spring Run 3 throughout the summer; whereas counts at Upwelling, where springflow was less variable, were higher and consistent with previous years.

**Figure 21. Photo displaying the habitat conditions and alternate drift-net location at Spring Run 1 during spring and fall sampling. This drift-net was moved from its usual location due to the headwaters being dry.**

**Table 6.** **Total numbers of endangered species collected at each site during drift-net sampling in May and November 2023. Full drift-net results are presented in Appendix E.**

| | SITE (TOTAL DRIFT-NET HOURS) | | |
|---|---|---|---|
| **TAXA** | **RUN 1 (48)** | **RUN 3 (48)** | **UPWELLING (48)** |
| **Crustaceans** | | | |
| Amphipoda | | | |
| Crangonyctidae | | | |
| *Stygobromus pecki* | 0 | 1 | 16 |
| **Insects** | | | |
| Coleoptera | | | |
| Dryopidae | | | |
| *Stygoparnus comalensis* | 1 | 0 | 0 |
| Elmidae | | | |
| *Heterelmis comalensis* | 0 | 8 | 0 |

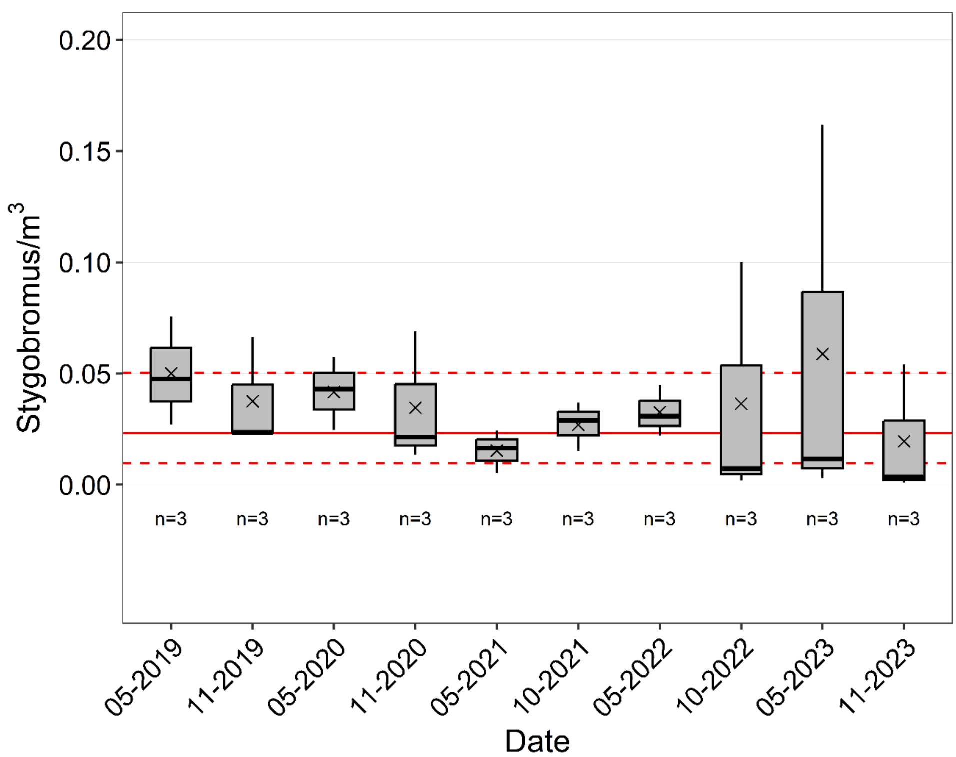


**Figure 22.** **Boxplots displaying *Stygobromus* spp. counts per cubic meter of water (*Stygobromus*/m$^3$) at Western Upwelling, Spring Run 1, and Spring Run 3 from 2019–2023. The thick horizontal line in each box is the median, x represents the mean, and the upper/lower bounds of each box represents the interquartile range. Whiskers represent minimum/maximum values up to 1.5 times the interquartile range. Solid and dashed red lines denote long-term (2003–2023) medians and interquartile ranges, respectively.**

## *Comal Springs Riffle Beetle*

A total of 115 adult Comal Springs Riffle Beetle (CSRB) were collected at 59 lures during spring and fall sampling efforts in 2023 and counts ranged from 0–21 beetles/lure. Beetles occupied 35.6% of lures across spring and fall. The CSRB low-flow sampling event from August to September yielded 12 CSRB on two lures at Western Shoreline; however, this was not included in seasonal and temporal analyses due to lower sample replication (n = 3) and set times (n = two weeks) per event. Likewise, the second low-flow sampling event from September to October included altered methods to assess occupancy during drought conditions and was excluded from seasonal and temporal analyses. A summary of the drought occupancy study is presented in Appendix I.

Median counts across both seasons for all three areas were zero beetles/lure, well below long-term trends. Mean beetles per lure across all areas were lower during fall than spring. The highest mean beetle counts were observed in spring at Western Shoreline (3.2 beetles/lure), spring at Spring Island (3.1 beetles/lure), and fall at Spring Island (2.7 beetles/lure) (Figure 23). The three lures at Spring Run 3 and two lures at Spring Island did not have any beetles, while the third lure at Spring Island was lost. In summary, counts in 2023 decreased from spring to fall across all sites. Overall, seasonal trends were lower than historical data and lures with higher counts were less frequent (Figures 23 and 24). Counts ranging from 12–21 beetles/lure were observed in 2023, but were rare and represented as outliers not shown in Figure 23 and 24.

When analyzed in conjunction with five-year and long-term datasets, a general temporal decline in the number of beetles per lure is evident across sites and seasons (Figure 23). Over the past five years, beetles per lure fluctuated within the range of historical variability from spring 2019 to spring 2021, but median counts have been well below the long-term medians since fall 2021 at all sites, except at Spring Island in spring 2022. Declines in 2022 and 2023 are likely influenced by the continued low springflow conditions experienced during this time period. When compared to previous low-flow events (summer 2009, 2011, 2013, and 2014), 2023 mean CSRB counts were similar at Spring Island (Appendix E, Figure E24) but were lower than previous low-flow events at Spring Run 3 and Western Shoreline (Appendix E, Figure E25 and E26). This suggests that extended low-flow conditions in 2022 and 2023 may be resulting in larger impacts than previous droughts. That being said, it is unclear whether the declines observed during low-flow periods are true population-level trends or if catch rates are potentially confounded by imperfect detection. Benthic invertebrates can move from surface habitats to subsurface habitats to seek refuge during low-flow periods (Williams and Hynes 1974, Dole-Olivier et al. 1997), and low-flow habitat utilization studies conducted by BIO-WEST in 2023 suggest that CSRB follow water levels down into the substrate when spring surface habitats are desiccated (Appendix I). Based on this, decreased CSRB counts may alternatively be explained by most individuals temporarily migrating into subsurface habitats (Kéry and Royle 2021). A two-year EAHCP CSRB study was initiated in 2023 to estimate spatiotemporal trends of CSRB sub-populations and to quantify functional relationships between relative abundance and various environmental features (e.g., flow, water quality, physical habitat) (BIO-WEST 2022c).

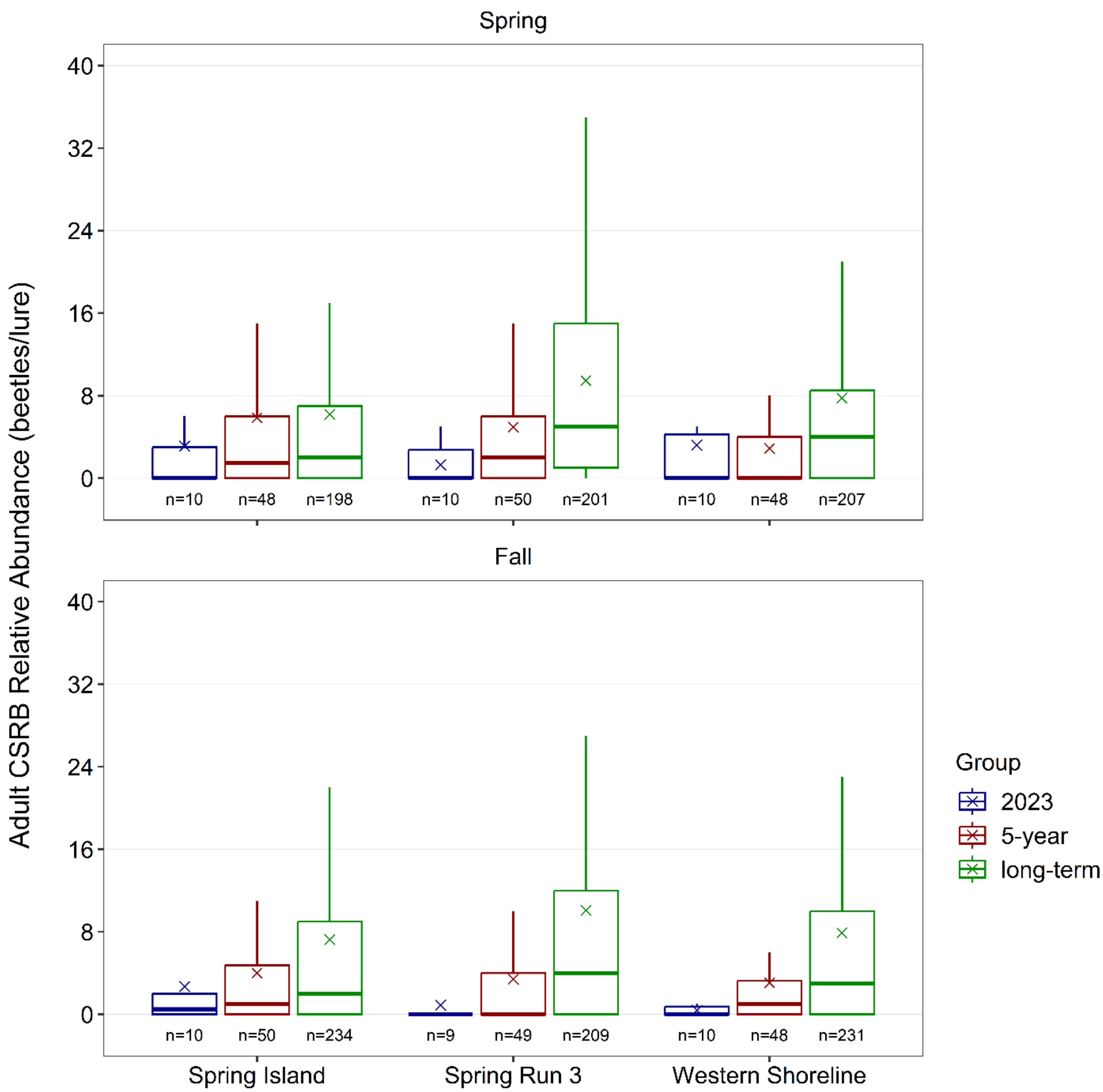


**Figure 23.** **Boxplots displaying 2023, 5-year (2019–2023), and long-term (2004–2023) trends in adult Comal Springs Riffle Beetle abundance per retrieved lure by season across sites in the Comal Springs. The thick horizontal line in each box is the median, x represents the mean, and the upper/lower bounds of each box represents the interquartile range. Whiskers represent minimum/maximum values up to 1.5 times the interquartile range. The "n" values along the x-axes represent the number of lures included in each category.**

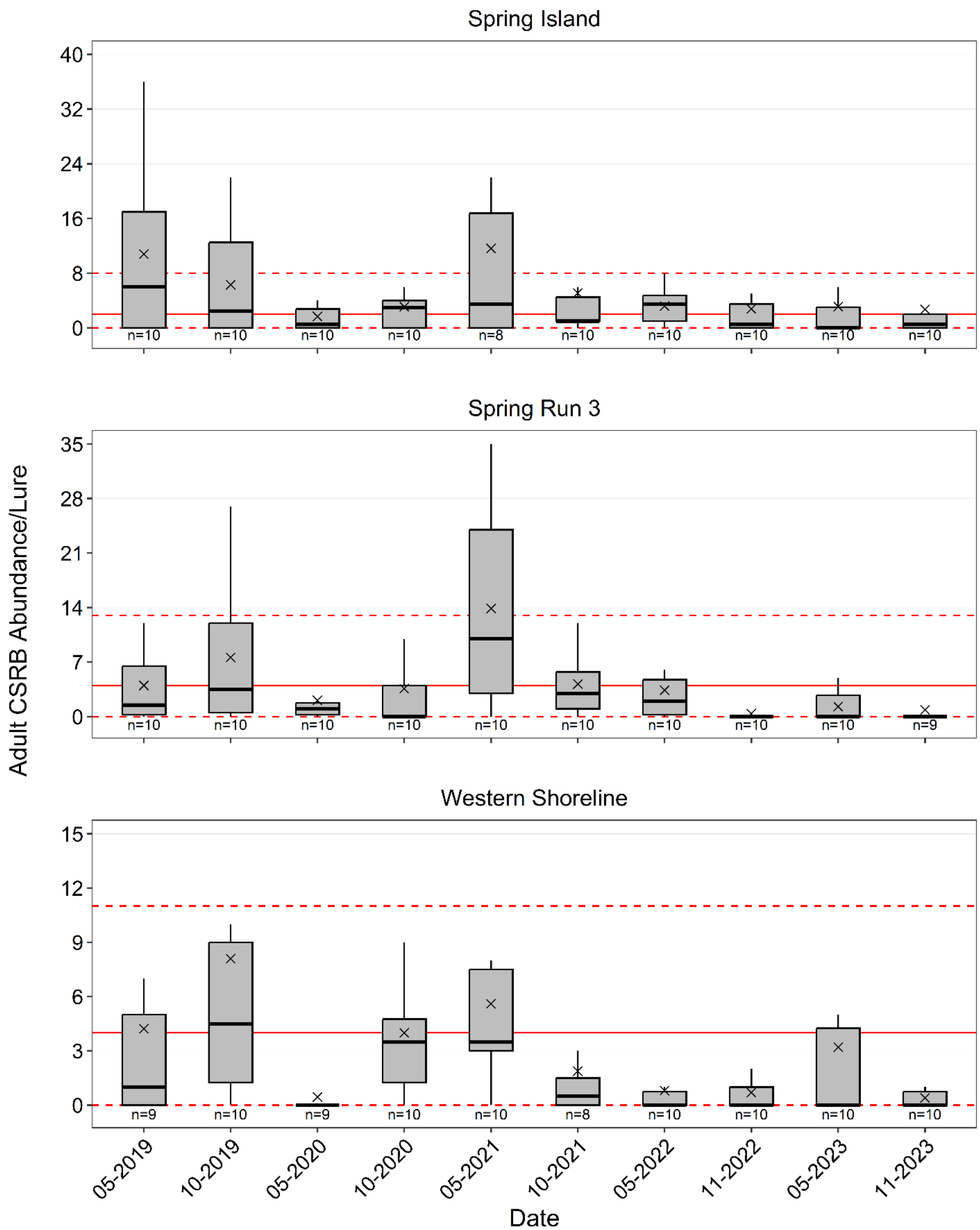


**Figure 24.** **Boxplots displaying temporal trends in adult CSRB abundance per retrieved lure among study reaches from 2019–2023 during lure sampling in Comal Springs. The thick horizontal line in each box is the median, x represents the mean, and the upper/lower bounds of each box represents the interquartile range. Whiskers represent minimum/maximum values up to 1.5 times the interquartile range. The "n" values along the x-axes represent the number of lures in each category. Solid and dashed red lines denote long-term (2004–2023) medians and interquartile ranges, respectively.**

## Benthic Macroinvertebrate Rapid Bioassessment

Benthic macroinvertebrate rapid bioassessment data was collected during both the spring and fall sampling events in 2023 (raw data presented in Appendix F). All samples in 2023 consisted of kick samples with suitable cobble-gravel habitat. Habitats sampled this year included cobble/gravel and root wads across sites. In addition, organic material was also sampled at each site, either in the form of debris jams or root wads. No supplement snag samples were taken. Cumulative scores and corresponding aquatic-life-use designations are displayed in Figure 25, while metric scores for calculating the B-IBI can be found in Table 6. A total of 787 and 743 individual macroinvertebrates, representing 35 and 38 unique taxa were sampled in spring and fall, respectively. Altogether, 48 unique taxa were represented among all samples from 2023.

**Table 7. Metric value scoring ranges for calculating the Texas RBP B-IBI (TCEQ 2014).**

| METRIC | SCORING CRITERIA | | | |
|---|---|---|---|---|
| | 4 | 3 | 2 | 1 |
| Taxa richness | >21 | 15–21 | 8–14 | <8 |
| EPT taxa abundance | >9 | 7–9 | 4–6 | <4 |
| Biotic index (HBI) | <3.77 | 3.77–4.52 | 4.56–5.27 | >5.27 |
| % Chironomidae | 0.79–4.10 | 4.11–9.48 | 9.49–16.19 | <0.79 or >16.19 |
| % Dominant taxon | <22.15 | 22.15–31.01 | 31.02–39.88 | >39.88 |
| % Dominant FFG | <36.50 | 36.50–45.30 | 45.31–54.12 | >54.12 |
| % Predators | 4.73–15.20 | 15.21–25.67 | 25.68–36.14 | <4.73 or >36.14 |
| Ratio of intolerant: tolerant taxa | >4.79 | 3.21–4.79 | 1.63–3.20 | <1.63 |
| % of total Trichoptera as Hydropsychidae | <25.50 | 25.51–50.50 | 50.51–75.50 | >75.50 or no Trichoptera |
| # of non–insect taxa | >5 | 4–5 | 2–3 | <2 |
| % Collector–gatherers | 8.00–19.23 | 19.24–30.46 | 30.47–41.68 | <8.00 or >41.68 |
| % of total number as Elmidae | 0.88–10.04 | 10.05–20.08 | 20.09–30.12 | <0.88 or >30.12 |

Benthic IBI scores ranged from 19 in spring at Landa Lake resulting in "Limited" designation, to 35 in spring at New Channel resulting in a "High" designation. Lower scores observed at Upper Spring Run and Landa Lake compared to riverine sites were likely due to differences in mesohabitats available for sampling. Specifically, these communities are naturally different compared to the "least-disturbed reference streams", which contain swifter riffle habitats. As such, higher scores would be expected at riverine sites due to a higher likelihood of supporting more fluvial specialists, resulting in greater taxa diversity overall. It should also be noted that most reference streams do not exhibit the stenothermal conditions present within the Comal Springs/River System and this may result in differing community composition. Based on this, the value of the score is less important in this spring-associated system than the consistency or trends in results per reach over time.

Aquatic-life-use designations in 2023 generally aligned with years prior and indicate stable trends at most reaches (Figure 25). Upper Spring Run and Old Channel were described as "Intermediate" for both seasons, with scores generally comparable to previous years. Aquatic-life-use at Landa Lake was ranked as "Limited" in the spring and "High" in the fall, a pattern also observed in 2022. Reduced water levels observed in Landa Lake from fall 2022 through 2023 might have increased velocity near the substrate in some areas, which in turn supported greater habitat diversity and resulted in higher scores than were observed historically when lake levels were higher. Other Place ranked as "Intermediate" for both seasons with scores notably lower since fall 2022. In contrast to Landa Lake, reduced flows at this riverine reach may have resulted in homogenization of habitats, and thus a reduction in fluvial specialists. Lastly, New Channel ranked as "High" during both seasons in 2023 which corresponds well with previous events (Figure 25). Additional monitoring will be needed to see if observed trends continue at Landa Lake and Other Place, as well as to generate a robust reference dataset for the development of scoring criteria specific to this unique ecosystem, providing a more accurate realization of ecological health.

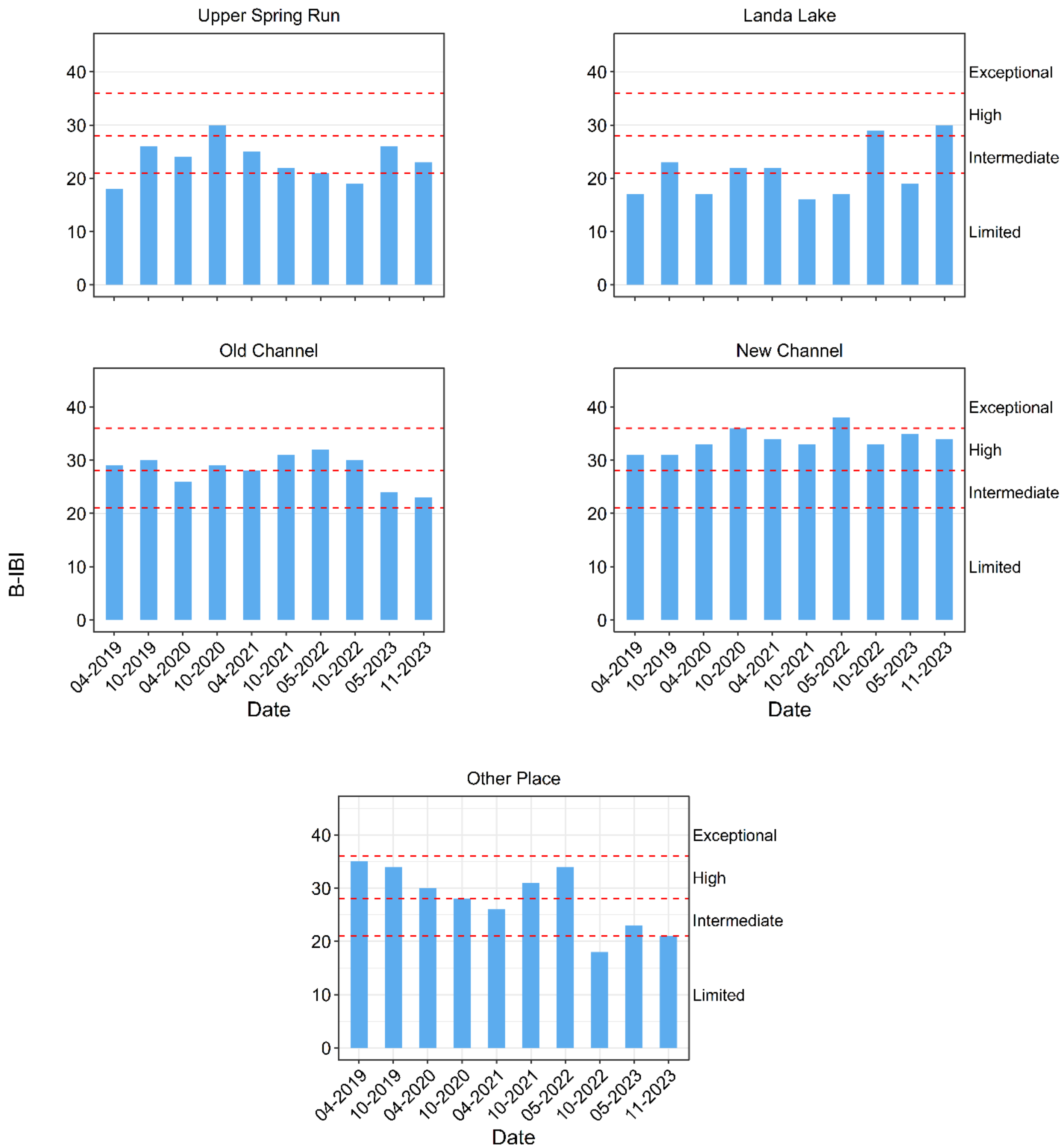


**Figure 25.** **Benthic macroinvertebrate Index of Biotic Integrity (B-IBI) scores and aquatic-life-use designations from 2019–2023 in the Comal Springs/River.**

# CONCLUSION

Results from 2023 biological monitoring in the Comal Springs/River system indicated continued declining trends in discharge from ongoing drought conditions and subsequent declines in some Covered Species population metrics. Median mean daily discharge in 2023 (121 cfs) was below median historical conditions and below 10$^{th}$ percentile flows for most months. Spatial patterns in water temperature fluctuation were typical, with low variation in reaches closer to springs (i.e., Landa Lake) and higher variation at reaches farther from springs (i.e., Other Place). Temperature exceedance of Fountain Darter larval and egg production thresholds increased in frequency and duration throughout the summer.

Habitat evaluations during low-flow events in the summer demonstrated degraded habitat conditions at upper spring reaches and spring runs (e.g., Spring Run 1 was dry throughout the summer). Where wetted surface habitat was available for Comal Springs Salamanders, counts and catch rates were slightly lower but comparable to previous years. Salamander monitoring following previous drought years suggests that Comal Springs Salamanders populations will return to Spring Run 1 and Spring Island Spring Run when surface flows return, however, continued monitoring is necessary to confirm this and document how quickly recolonization occurs. Degraded habitat conditions at upper spring reaches and spring runs also influenced spring macroinvertebrates (i.e., *Stygobromus* sp., CSRB). Lower CSRB counts this year, when compared to historical observations, suggests the current extended drought may have resulted in reduced abundance. However, subsurface migration of both salamanders and CSRB may yield reductions in counts that are not accurate representations of true population abundance. For CSRB, a separate population assessment is underway to gain a greater understanding of population dynamics.

Vegetation mapping demonstrated that seasonal patterns in total aquatic vegetation coverage varied spatially. Coverages at Upper Spring Run were lower than long-term averages and varied from previous years due to reductions in bryophyte and expansion of *Cabomba*. Habitat suitability indices at Landa Lake declined throughout the year as bryophyte coverage waned. Overall OHSI for Fountain Darters at Landa Lake declined to a 5-year minimum by fall, and Fountain Darter densities and occurrence decreased. Quality Fountain Darter habitat at Old Channel remained stable yet below average coverages of rooted vegetation occurred in this reach. However, these comparisons in the Old Channel reach should not be interpreted an indicator of degraded conditions, since non-native *Hygrophila* historically dominated the reach prior to restoration. Furthermore, Old Channel was the only reach to retain substantial bryophyte coverages through the lowest flows in August. In contrast to declining habitat conditions at Upper Spring Run and Landa Lake, above average vegetation coverages (e.g., expansion of *Cabomba*) in the spring at Upper and Lower New Channel reaches and fall at Upper New Channel were best explained by the prolonged absence of flood pulse events along Dry Comal Creek. Changes in vegetation structure and composition at New Channel were also demonstrated by a higher OHSI. Improved habitat conditions in this reach resulted in abrupt increases in Fountain Darter density. However, overall lower densities and occurrence rates observed in fall 2023 indicate potential negative effects of extended periods of habitat degradation in Comal Springs. That said, increases in density and occurrence in New Channel and expansion of *Cabomba* likely facilitated resistance to substantial declines in Fountain Darter populations.

Evidence of detectable temporal trends in fish communities varied among the selected metrics, as well as between and within study segments. Species richness and diversity were typically higher in riverine areas and lowest at Landa Lake. Five-year trends in species richness usually varied from event to event and displayed no detectable patterns. The increasing diversity observed at Landa Lake in previous years declined in 2023 which aligns with the degraded Fountain Darter habitat conditions observed. However, relative density of spring fishes remained consistently high and varied substantially less at Landa Lake than other segments. Temporal trends in richness of spring-associated fishes were congruent with community-level observations and generally stable throughout the study area.

In summary, 2023 biological monitoring provided insights into the current condition of the EAHCP Covered Species in the Comal Springs/River System, and documented important flow-ecology relationships driving population dynamics. Results indicated that Covered Species and aquatic vegetation appeared to be more impacted by reduced flows in spring run habitats compared to riverine habitats and Landa Lake, which suggests greater resilience potential than expected in some downstream areas. Despite declines observed in Covered Species habitats and population indices, historical data indicates that ecological conditions will likely improve when typical flows return. Subsequent monitoring efforts will provide opportunities to better understand the dynamics of this complex ecological system and how it responds to future hydrologic conditions.

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# Appendix G3 | **San Marcos Biological Monitoring Report**

**HABITAT CONSERVATION PLAN**

# BIOLOGICAL MONITORING PROGRAM

## San Marcos Springs/River Aquatic Ecosystem

**ANNUAL REPORT**

**December 2023**

**Prepared for:**

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# EXECUTIVE SUMMARY

The Edwards Aquifer Habitat Conservation Plan (EAHCP) Biological Monitoring Program continued to track biota and habitat conditions of the San Marcos Springs/River ecosystem in 2023 through a series of routine and Critical Period monitoring activities outlined in this report. Monitoring in the San Marcos system consisted of routine surveys specific to EAHCP Covered Species: Fountain Darter (*Etheostoma fonticola*), Texas Wild-rice (*Zizania texana*), and San Marcos Salamander (*Eurycea nana*). Community-level monitoring data were also collected on aquatic vegetation, fish, and benthic macroinvertebrates. In addition, reduced river discharge triggered Critical Period and species-specific low-flow sampling events starting in spring. The results from 2023 biological monitoring provide valuable data to further assess spatiotemporal trends of aquatic biota in the San Marcos Springs/River ecosystem, as well as an opportunity to better understand ecological responses under the extreme low-flow conditions observed.

In 2023, exceptional drought conditions persisted in central Texas as low precipitation and higher ambient temperatures experienced in 2022 continued. Exceptional drought conditions occurred throughout central Texas from January through August, impacting large portions of the Hill Country over the Edwards Aquifer Contributing Zone. As a result, river discharge in the San Marcos River was near or below 10$^{th}$ percentile conditions the entire year and represented the lowest flows observed since the inception of biological monitoring in 2000. Annual median daily mean discharge was lower in 2023 (88 cfs) than during previous low-flow monitoring events in 2006 (116 cfs), 2009 (96 cfs), 2011 (117 cfs), and 2022 (119 cfs). Flows first dropped below 85 cfs in April, triggering Critical Period sampling that was coupled with routine sampling. Additional species-specific sampling was triggered as flows declined, eventually hitting the lowest daily mean discharge observed since 1956 in September (66 cfs). Three low-flow habitat evaluations were also conducted this year as discharge declined. Low water levels during the final habitat evaluation in late August documented slightly degraded habitat conditions at Spring Lake and Spring Lake Dam. Further downstream, wetted width of the river channel was reduced, and aquatic vegetation coverage decreased, though high-quality Fountain Darter habitat persisted. Although precipitation events in October resulted in a small pulse, discharge conditions remained near 10$^{th}$ percentile levels through fall 2023.

The most conspicuous impact of low summer water levels on Covered Species within the San Marcos system was desiccation of stream edge areas occupied by Texas Wild-rice. As water levels dropped, Texas Wild-rice stands became dewatered in some areas, and terrestrial vegetation eventually took over. This resulted in substantial reductions to overall Texas Wild-rice coverage, dropping from over 15,000 m$^2$ in January to 8,210 m$^2$ in October. This represents the lowest coverage of Texas Wild-rice mapped since 2016, although coverage is still considerably above pre-EAHCP levels. Continued monitoring of Texas Wild-rice will be important in light of the ongoing drought and uncertainty of future flow conditions.

In addition to Texas Wild-rice, the influence of extremely low springflows was also evident on abiotic habitat and aquatic vegetation conditions which influence Fountain Darter populations. Water temperatures remained consistent in spring areas but were elevated relative to typical years in downstream areas. Under these extreme low-flow conditions, the maximum optimal water temperature threshold for Fountain Darter egg production (26 °C) was exceeded at City Park, Rio Vista, I-35, and Wastewater Treatment Plant more commonly and for longer durations

than in previous years. Despite this, Fountain Darter population metrics indicated increased densities at City Park and I-35 study reaches in both spring and fall, suggesting that exceedance of these laboratory-derived temperature thresholds may not be a strong predictor of wild Fountain Darter population performance. However, the health and condition of individual Fountain Darters was not analyzed, and application of laboratory derived temperature thresholds to wild populations is nuanced for several reasons. For example, although McDonald et al. (2007) did vary temperature for their laboratory trials, those temperature fluctuations do not exactly match natural diel patterns observed in the wild. Given availability of a tremendous amount of water temperature data in these systems, additional research is needed to evaluate the influence of naturally occurring diel temperature fluctuations on wild Fountain Darter population dynamics while accounting for variation in habitat quality and quantity.

System-wide vegetation coverage  remained similar from 2018 to 2023 while coverages among specific taxa changed. During this time, Texas Wild-rice and *Cabomba* increased the most in coverage with Texas Wild-rice becoming the most dominant species in the system in 2023. Conversely, *Potamogeton* and *Hydrilla* decreased. Reductions in *Hydrilla* were influenced by active HCP removal efforts. Another notable change in taxa from 2018 to 2023 was the increase in bryophyte abundance. Within the study reach in 2023, total aquatic vegetation coverage declined from spring to fall across all  reaches. Ubiquitous declines in vegetation coverage during 2023 were mainly attributed to decreased coverage of Texas Wild-rice due to low flows and recreation. However, Texas Wild-rice still remained the dominant vegetation taxa in all study reaches, and coverage of other taxa remained minimal in comparison. In general, Fountain Darter density and occurrence were higher in fall due to enhanced suitable habitat provided by bryophytes intermixed with other vegetation types. However, overall habitat suitability depicted degraded habitat conditions that conflicted with abundance and occurrence results, as said indices did not pick up on this observed habitat improvement, since they are based on dominant vegetation type. Conflicting results could be due to changes in vegetation composition (e.g., Texas Wild-rice coverage) and changes in microhabitat conditions unaccounted for in HSC models (e.g., % bryophyte within). Reductions in wetted habitat altered the river channel and the vegetation assemblage mainly within the I-35 reach. Amphibious species that could survive as emergent outcompeted other taxa.

Trends in San Marcos Salamander densities were variable among sites in 2023 and over the past five years. However, all sites showed relatively low densities in fall 2023, and low-flow impacts (e.g., siltation) to salamander habitats were noted. At a community scale, fish and macroinvertebrate community-level responses to low flows were not readily apparent. In general, no long-term temporal trends in overall or spring-associated fish diversity, richness, and relative density are evident from fish community monitoring data. Macroinvertebrate Index of Biotic Integrity (IBI) scores were generally consistent with past years.

Overall, 2023 biological monitoring provided insights into the current condition of the EAHCP Covered Species in the San Marcos Springs/River, as well as flow-ecology relationships of the broader aquatic community. During the lowest flow conditions observed since 1956, the system proved resilient. Texas Wild-rice coverage did substantially drop due to decreasing amounts of wetted habitat. However, total coverage of Texas Wild-rice remains over 8,000 $m^2$, well above pre-EAHCP levels. Reductions in wetted habitats did not negatively impact Fountain Darter population metrics, as catch rates and percent occurrence were comparable to previous data and densities increased in recent years. The sustained high densities observed at multiple reaches throughout 2022 and 2023 suggest that population increases may be driven by enhanced benthic habitat complexity due to increased amounts of bryophytes within riverine habitats. San Marcos Salamander habitat impacts were noted and densities declined at all sites in fall 2023, therefore additional monitoring is needed to examine future trends. Fish community and macroinvertebrate bioassessments revealed a healthy riverine community with a diversity of taxa similar to previous years. In summary, results from 2023 demonstrated resilience of aquatic communities and Covered Species populations to the extreme low-flow conditions observed. Subsequent monitoring efforts will provide opportunities to better understand the dynamics of this complex ecological system and further examine responses to varying hydrologic conditions.

# INTRODUCTION

The Edwards Aquifer Habitat Conservation Plan (EAHCP) was established in 2012 and supports the issuance of an Incidental Take Permit that allows the “incidental take” of threatened and endangered species (i.e., Covered Species) (Table 1) from otherwise lawful activities in the San Marcos Springs/River. Section 6.3.1 of the HCP established a continuation of biological monitoring in the San Marcos Springs/River. This biological monitoring program was first established in 2000 (formerly known as the Edwards Aquifer Authority [EAA] Variable Flow Study) and its original purpose was to evaluate the effects of variable flow on the biological resources, with an emphasis on threatened and endangered species. However, the utility of the HCP biological monitoring program has surpassed its initial purpose (EAHCP 2012), and biological data collected since the implementation of this monitoring program (BIO-WEST 2001–2023) now serves as the foundation for several underlying sections in the HCP, which include: (1) long-term biological goals (LTBGs) and management objectives (Section 4.1); (2) determination of potential impacts to Covered Species, “incidental take” assessment, and Environmental Impact Statement alternatives (Section 4.2); and (3) establishment of core adaptive-management activities for triggered monitoring and adaptive-management response actions (Section 6.4.4). As the HCP proceeds, biological monitoring program data, in conjunction with other available information, are essential to adaptive management. Current and future data collection will help assess the effectiveness and efficiency of certain HCP mitigation and restoration activities conducted in the San Marcos Springs/River and calculate the HCP habitat baseline and net disturbance determination and annual “incidental take” estimate (EAHCP 2012).

**Table 1. Covered Species directly sampled for under the Edwards Aquifer Habitat Conservation Plan in the San Marcos Springs/River ecosystem.**

| SCIENTIFIC NAME | COMMON NAME | ESA STATUS |
|---|---|---|
| **Plants** | | |
| *Zizania texana* | Texas Wild-rice | Endangered |
| **Amphibians** | | |
| *Eurycea nana* | San Marcos Salamander | Threatened |
| **Fish** | | |
| *Etheostoma fonticola* | Fountain Darter | Endangered |

This report provides the methodology and results for biological monitoring activities conducted in 2023 within the San Marcos Springs/River ecosystem. In addition to routine monitoring, Critical Period and species-specific low-flow sampling were triggered. The results include summaries of current physiochemical conditions, as well as current conditions of floral and faunal communities, all of which encompasses both routine and low-flow sampling. For all aquatic organisms, historic observations (BIO-WEST 2001–2023) are also used to provide context to current conditions.

# METHODS

## Study Location

The upper San Marcos River (San Marcos, Hays County, Texas) is fed by the Edwards Aquifer and originates at a series of spring upwellings in Spring Lake, which was impounded in the mid-1800s (Bousman and Nickels 2003). From the headwaters, the river flows about eight kilometers (km) before its confluence with the Blanco River, traversing two additional impoundments, Rio Vista Dam, and Capes Dam. The upper San Marcos River watershed is dominated by urban landcover and is subjected to recreational use. Spring inputs from the Edwards Aquifer provide stable physiochemical conditions, and springflow conditions are dictated by aquifer recharge and human water use (Sung and Li 2010). The upper San Marcos River maintains diverse assemblages of floral and faunal communities (Bowles and Arsuffi 1993; Owens et al. 2001) that include multiple endemic organisms, such as Texas Wild-rice (*Zizania texana*), Comal Springs Riffle Beetle (*Heterelmis comalensis*), San Marcos Salamander (*Eurycea nana*), and Fountain Darter (*Etheostoma fonticola*) among others.

## Sampling Strategy

Based on the long-term biological goals (LTBGs), and management objectives outlined in the HCP, study areas were established to conduct long-term monitoring and quantify population trends of the Covered Species (EAHCP 2012). The sampling locations selected are designed to cover the entire extent of Covered Species habitats, but they also allow for holistic ecological interpretation while maximizing resources (Figures 1–3). Comprehensive sampling within the established study area varies temporally and spatially among Covered Species. The current sampling strategy includes five spatial resolutions:

1. System-wide sampling
    a. Texas Wild-rice mapping: 1 event/year (summer)
    b. Aquatic vegetation mapping: 5-year intervals (spring)
2. Select longitudinal locations
    a. Water temperature: assessed year-round at permanent monitoring stations
3. Reach sampling
    a. Aquatic vegetation mapping: 2 events/year (spring, fall)
    b. Fountain Darter drop-net sampling: 2 events/year (spring, fall)
    c. Fountain Darter random-station dip-net surveys: 3 events/year (spring, summer, fall)
4. Springs Sampling
    a. San Marcos Salamander surveys: 2 events/year (spring, fall)
5. River section/segment
    a. Fountain Darter timed dip-net surveys: 3 events/year (spring, summer, fall)
    b. Fish community surveys: 2 events/year (spring, fall)
    c. Macroinvertebrate community sampling: 2 events/year (spring, fall)

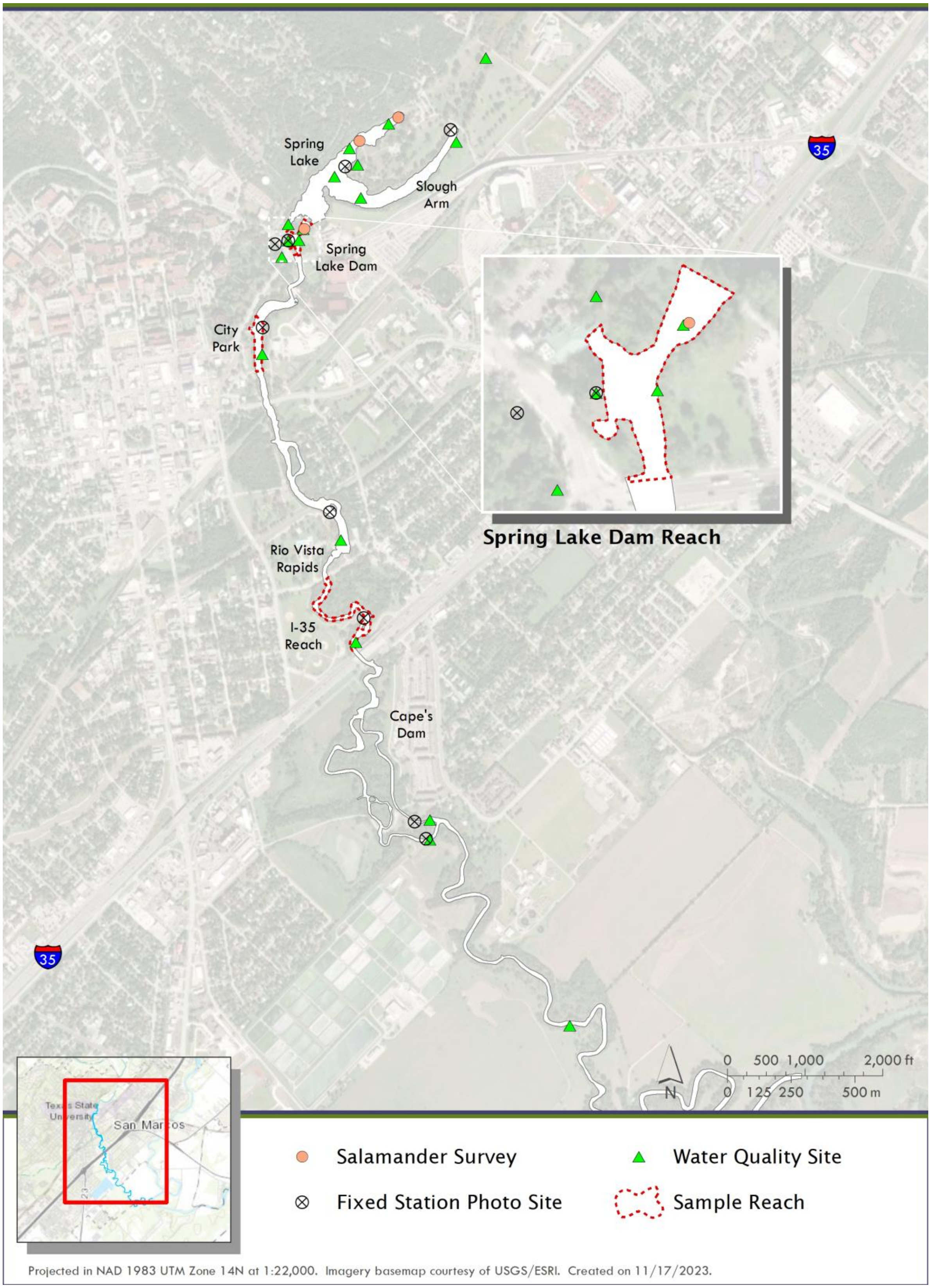


**Figure 1. Upper San Marcos River sample reaches, San Marcos Salamander survey sites, water quality sampling sites, and fixed-station photography sites.**

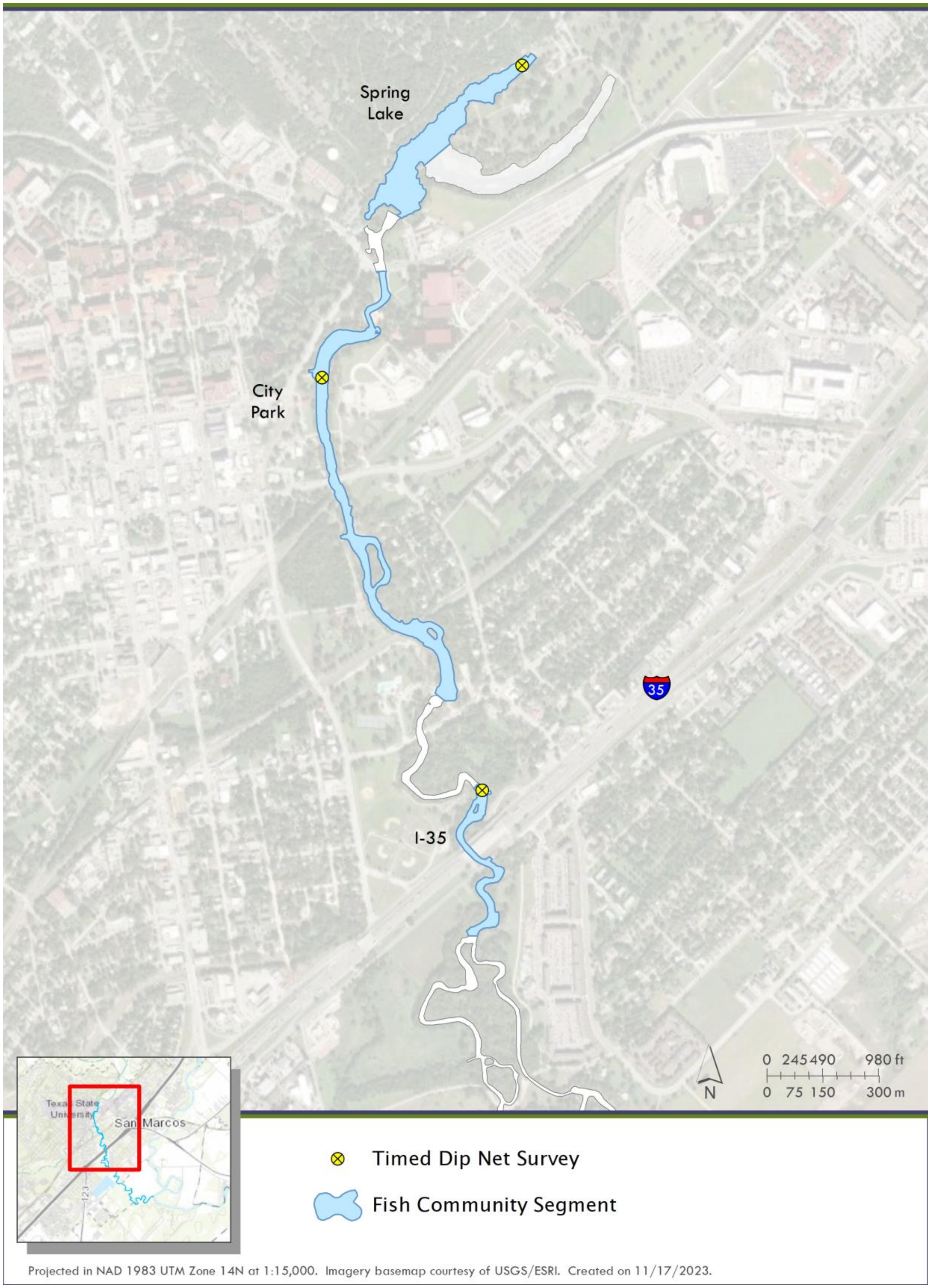


**Figure 2. Fish community sampling segments and dip-net timed survey sections for the upper San Marcos River.**


**Figure 3. Fish community sampling segments and dip-net survey sections for the lower San Marcos River.**

In addition to annual comprehensive sampling outlined above, low-flow sampling may also be conducted, but is dependent on HCP flow triggers, which include Critical Period low-flow sampling and species-specific sampling (EAHCP 2012). Due to sustained low flows, one Critical Period monitoring event (coupled with routine spring monitoring) and several species-specific triggers were met throughout the year. Texas Wild-rice physical measurements were triggered from January through the remainder of the year, San Marcos Salamander surveys were triggered from August through October, and Fountain Darter surveys were triggered in August (Appendix A). Critical Period habitat assessment results are presented in Appendix B.

The remaining methods sections provide brief descriptions of the procedures utilized for comprehensive routine, Critical Period, and species-specific sampling efforts. A more-detailed description of the gear types used, methodologies employed, and specific GPS coordinates can be found in the Standard Operating Procedures Manual for the HCP biological monitoring program for the San Marcos Springs/River ecosystem (EAA 2017).

# San Marcos River Discharge

River hydrology in 2023 was assessed using U.S. Geological Survey (USGS) stream gage data from January 1 through October 31. Mean daily discharge expressed in cubic feet per second (cfs) was acquired from USGS gage #08170500, which represents cumulative river discharge that encompasses springflow and local runoff contributions from the Sink Creek drainage. It should be noted that some of these data are provisional and are subject to revision at a later date (USGS 2023). The annual distribution of mean daily discharge was compared for the past 5 years using boxplots. The distribution of 2023 mean daily discharge was also summarized by month using boxplots. Monthly discharge levels were compared with long-term (1956–present) 10th, 50th (i.e., median), and 90th percentiles.

# Water Temperature

Spatiotemporal trends in water temperature (°C) were assessed using temperature data loggers (HOBO Tidbit v2 Temp Loggers) at the 11 permanent monitoring stations established in 2000. Data loggers recorded water temperature every 10 minutes and were downloaded at regular intervals. Prior to analysis, data processing was conducted to locate potential data logger errors per station by comparing time-series for the current year with previous years. Timeframes displaying temperatures that deviated substantially from historical data and didn't exhibit ecologically rational trends (e.g., discontinuities, ascending drift) were considered unreliable and omitted from the dataset. For analysis, the distribution of water temperatures for the current year was assessed among stations based on 4-hour intervals and summarized using boxplots. Water temperatures were also compared with maximum optimal temperature requirements for Fountain Darter larval (≥25 °C) and egg (≥26 °C) production (McDonald et al. 2007). Further, 25 °C is also the designated water temperature threshold within the HCP Fountain Darter LTBG study reaches (Spring Lake Dam, City Park, I-35) (EAHCP 2012). In the case of stations that surpassed either water temperature threshold during the year, the general timeframes in which those exceedances occurred are discussed in the text.

# Aquatic Vegetation

## *Mapping*

The team used a kayak for visual observations to complete aquatic vegetation mapping in sample reaches during the spring full system/routine monitoring, summer low-flow monitoring, and fall monitoring events. A Trimble GPS unit and external Tempest antenna set on the bow of the kayak was used to collect high accuracy (10–60 centimeter [cm]) geospatial data. A data dictionary with pre-determined attributes was loaded into the GPS unit for data collection in the field. Discrete patch dimensions and the type and density of vegetation were recorded from the kayak. In some instances, an accompanying free diver was used to provide additional detail and to verify surface observations. The discreteness of an individual vegetation patch was determined by the dominant species located within the patch compared to surrounding vegetation. Once a patch of vegetation was visually delineated, the kayak was maneuvered around the perimeter of the vegetation patch to collect geospatial data with the GPS unit, thus creating a vegetation polygon. Attributes assigned to each polygon included species type and percent cover of each of the four most-dominant species. The type of substrate (silt, sand, gravel, cobble, organic) was identified if substrate was a dominant feature within the patch. Rooted aquatic vegetation, floating aquatic vegetation, bryophytes, and algae were mapped as separate features. Only aquatic vegetation patches 1 meter (m) in diameter or larger were mapped as polygons. However, all Texas Wild-rice was recorded, with individual Texas Wild-rice plants too small to delineate as polygons mapped as points instead.

## *Data Processing and Analysis*

During data processing, Microsoft Pathfinder was used to correct spatial data and create shapefiles. Spatial data were projected using the Projected Coordinate System NAD 1983 Zone 14N. Post processing was conducted to clean polygon intersections, check for and correct errors, and calculate cover for individual discrete polygons as well as totals for all encountered aquatic plant species.

Vegetation types are described in the Results and Discussion sections by genus, except for Texas Wild-rice for which the common name is used. Vegetation community composition among taxa and grouped by native vs. invasive taxa are compared for the last five years using stacked bar graphs. Total surface area of aquatic vegetation, measured in square meters ($m^2$), is presented for each season using bar graphs and is compared with long-term averages (2001–present) from spring, fall, high-flow events, and low-flow events. High-flow and low-flow averages were calculated from Critical Period events. These events are based on predetermined river discharge triggers (Appendix A), which result in additional mapping events to assess flow-related impacts to the vegetation community. All total coverages were calculated solely based on rooted plant taxa.

# Texas Wild-rice Annual Observations

## *Mapping and Physical Observations*

In addition to aquatic vegetation mapping in the LTBG study reaches, Texas Wild-rice was mapped within Spring Lake and eight river segments using the same methods described above during routine summer mapping in July (Figure 4). Moreover, physical measurements were quantified during routine monitoring in spring and fall. Eighteen additional sampling events occurred during species-specific events triggered in January (n = 2), February (n = 1), March (n = 2), April (n = 1), May (n = 1), June (n = 2), July (n = 2), August (n = 2), September (n = 4), and October (n = 1).

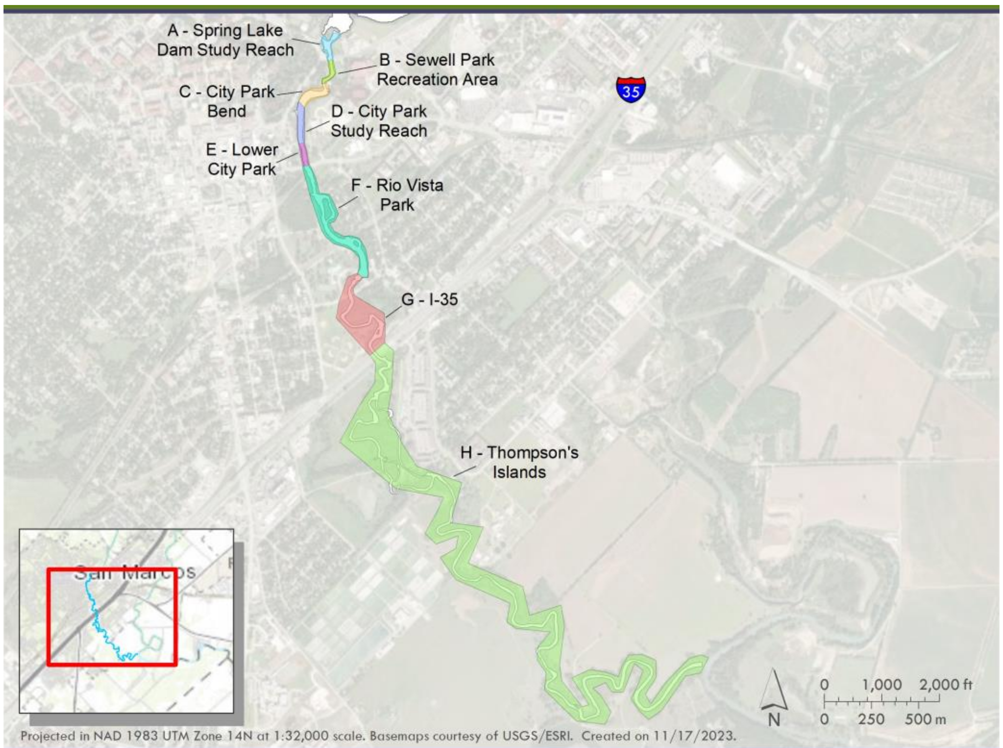


**Figure 4. Designated river segments for monitoring Texas Wild-rice coverage.**

At the beginning of the initial sampling activities in 2000, Texas Wild-rice stands throughout the San Marcos River were assessed and documented as being in "vulnerable" areas if they possessed one or more of the following characteristics: (1) occurred in shallow water (<0.5 feet); (2) revealed extreme root exposure because of substrate scouring; or (3) generally appeared to be in poor condition. The areal coverage of Texas Wild-rice stands in vulnerable locations were determined in 2023 by GPS mapping (see Aquatic Vegetation Mapping for details) in most instances. However, areal coverage of some smaller stands was measured using a method originally developed by the Texas Parks and Wildlife Department (J. Poole, pers. comm.). To do this, maximum length and maximum width were measured. The length measurement was taken at the water surface parallel to streamflow and included the distance between the bases of the roots to the tip of the longest leaf. The width was measured at the widest point perpendicular to the stream current. Percent cover was then estimated within the rectangle formed from the maximum length and maximum width measurements. The total area of the rectangle was then multiplied by the percent cover to estimate the areal coverage for each small stand.

### *Data Processing and Analysis*

Annual trends in total Texas Wild-rice coverage ($m^2$) within Spring Lake and all river segments are presented from 2001–present. Changes in Texas Wild-rice coverage ($m^2$, %) from April to August this year are also compared between the eight river segments. Results for changes in Texas Wild-rice coverage in Spring Lake can be found in Appendix E.

The conditions of vulnerable Texas Wild-rice stands were assessed by combining quantitative and qualitative observational measurements from the following metrics: (1) percent of stand that was emergent, (2) percent of emergent portions that were seeding, (3) percent of stand covered with vegetation mats or algae buildup, and (4) categorical estimation of root exposure. Water depth was measured in feet (ft) at the shallowest point in the Texas Wild-rice stand and velocity in feet per second (ft/s) was measured at the upstream edge of each stand. All results from the physical observations and vulnerable stands monitoring can be found in Appendix D.

## Fountain Darter

### *Drop-Net Sampling*

Drop-net sampling was utilized to quantify Fountain Darter densities and habitat utilization during the spring and fall monitoring events at established sample reaches (Figure 1). Drop-net stations were selected using a random-stratified design. In each study reach, two sample stations per vegetation strata were randomly selected based on dominant aquatic vegetation (including open areas) mapped prior to sampling (see Aquatic Vegetation Mapping for details). At each sample station, all organisms were first trapped using a 2 $m^2$ drop-net. Organisms were then collected by sweeping a 1 $m^2$ dip-net along the river bottom within the drop-net. If no fish were collected after the first ten dip-net sweeps, the station was considered complete, and if fish were collected, an additional five sweeps were conducted. If any Fountain Darters were collected on sweep 15, additional sweeps were conducted until no Fountain Darters were collected.

Most fishes collected were identified to species and enumerated. Two morphologically similar species, Western Mosquitofish (*Gambusia affinis*) and Largespring Gambusia (*Gambusia geiseri*), which are known to hybridize, were classified by genus (*Gambusia* sp.). Larval and juvenile fishes too small to confidently identify to species in the field were also classified by genus. All Fountain Darters and the first 25 individuals of other fish taxa were measured (total length expressed in millimeters [mm]).

Physiochemical habitat data were collected at each drop-net location. Water depth (ft) and velocity (ft/s) data were collected at the upstream end of drop-net samples using a HACH FH90 flowmeter and adjustable wading rod. Water-velocity measurements were collected at 15 cm above the river bottom to characterize flows that directly influence Fountain Darters. Mean-column velocity was measured at 60% of water depth when depths were less than three feet. At depths of three feet or greater, water velocities were measured at 20% and 80% of depth and averaged to estimate mean column velocity. Water quality was measured within each drop-net using a HydroTech multiprobe, which included water temperature (degrees Celsius [°C]), pH, dissolved oxygen (milligrams per liter [mg/L], percent saturation), and specific conductance (microsiemens per centimeter [µs/cm]). Mid-column water quality was measured at water depths less than three feet, whereas bottom and surface values were measured and averaged at depths of three feet or greater. Lastly, vegetation composition (%) was visually estimated and dominant substrate type was recorded within each drop-net sample.

## *Dip-Net Sampling*

Dip-net sampling was used to provide additional metrics for assessing Fountain Darter population trends and included qualitative timed surveys and random-station presence/absence surveys. All sampling was conducted using a 40x40 cm (1.6-mm-mesh) dip net, and surveys for both methods were conducted in spring, summer, and fall.

Timed dip-net sampling was conducted to examine patterns in Fountain Darter catch rates and size structure along a more extensive longitudinal gradient compared to drop-net sampling. Surveys were conducted within established survey sections and for a fixed amount of search effort (Spring Lake: 0.5 hour, City Park: 1.0 hour, I-35: 1.0 hour, Cypress Tree: 0.5 hour, Todd Island: 0.5 hour) (Figures 2 and 3). In each study reach, a single surveyor used a dip-net to collect Fountain Darters in a downstream to upstream fashion. Collection efforts mainly focused on suitable Fountain Darter habitat, specifically in areas with dense aquatic vegetation. Non-wadeable habitats (>1.4 m) were not sampled. All Fountain Darters collected were enumerated, measured (mm), and returned to the river at point of collection.

Random-station presence/absence surveys were implemented to assess Fountain Darter occurrence. During each monitoring event, sample stations were randomly selected within the vegetated area of each reach (Spring Lake: 10, Spring Lake Dam: 25, City Park: 20, I-35: 15) (Figure 1). At each random-station, presence/absence was recorded during four independent dips. To avoid recapture, collected Fountain Darters were returned to the river in areas adjacent to the random station being sampled. Habitat variables recorded at each station included dominant aquatic vegetation and presence/absence of bryophytes and algae.

## *Data Analysis*

Key demographic parameters used to evaluate Fountain Darter observations included population performance, size structure, and recruitment. Population performance was assessed using drop-net, timed dip-net, and random dip-net data. Counts of darters per drop-net sample were standardized as density (darters/$m^2$). Timed dip-net total darter counts per study reach were standardized as catch-per-unit-effort (CPUE; darters/person-hour [p-h]) for each sampling event. Random dip-net occurrence per station was based on whether or not a Fountain Darter was observed during any of the four dips and percent occurrence was calculated per sampling event at each reach as: (sum[darter presence]/sum[random stations])*100. Fountain Darter density, CPUE, and occurrence were compared among seasons using boxplots. In addition, density and CPUE seasonal observations were compared to the past five years and long-term observations (2001–present). Occurrence values were only compared to observations from the past five years due to the fact that Texas Wild-rice was excluded from sampling prior to 2017. Lastly, temporal trends in Fountain Darter density were assessed per sampling event for each study reach for the past five years using boxplots and compared to their respective long-term (2001–present) medians and quartiles (25th and 75th percentile).

Size structure and recruitment were assessed among seasons. Fall and spring were assessed by combining drop-net and timed dip-net data, and summer was assessed using timed dip-net data only. Boxplots coupled with violin plots were used to display the distribution of darter lengths per sampling event for each season for the past five years. Boxplots show basic length-distribution statistics (i.e., median, quartiles, range) and violin plots visually display the full distribution of lengths relative to each sampling event using kernel probability density estimation (Hintze and Nelson 1998). Recruitment was quantified as the percent of darters ≤20 mm during each sampling event. Based on a linear model built by Brandt et al. (1993) that looked at age-length relationships of laboratory-reared Fountain Darters, individuals of this size are likely less than 3 months old and not sexually mature (Brandt et al. 1993; Schenck and Whiteside 1976). Percent recruitment ±95% confidence intervals (beta distribution percentiles; McDonald 2014) were shown for the past five years by season and compared to their respective long-term averages.

Habitat use was assessed based on population performance and size structure among vegetation strata using drop-net and random station dip-net observations. Fountain Darter density by vegetation taxa was compared based on current, five-year, and long-term (2001–present) observations using boxplots. Long-term comparisons of Texas Wild-rice were not provided since 2020 was the first year this species was sampled via drop-netting. In addition, Texas Wild-rice was not sampled during spring or fall drop-netting due to river discharge dropping below 120 cfs. Proportion of occurrence was also calculated among vegetation types sampled during random-station dip-netting for the current year. Lastly, boxplots coupled with violin plots were used to display the distribution of darter lengths by vegetation taxa using drop-net data to examine habitat use among size classes for the current year. Open habitats and Texas Wild-rice were omitted from analysis due to limited darter counts (i.e., less than 3 darters total).

Habitat suitability was quantified to examine reach-level changes in habitat quality for Fountain Darters through time. First, Habitat Suitability Criteria (HSC) ranging from 0 (unsuitable habitat) to 1 (most suitable habitat) were built based on occurrence data for all vegetation types (including open habitat) that have been sampled using logistic regression (Manly et al. 1993). Resulting HSC were then multiplied by the areal coverage of each vegetation strata mapped during a biomonitoring event, and results were summed across vegetation strata to calculate a weighted usable area for each reach. To make data comparable between reaches of different sizes, the total weighted usable area of each reach was then divided by the total area of the reach, resulting in an Overall Habitat Suitability Index (OHSI) for each reach during each sampling event. Following this method, temporal trends of Fountain Darter OHSI ±95% CI were calculated per sampling event for each study reach (Spring Lake Dam, City Park, I-35) for the past five years. Long-term (2003–present) OHSI and 95% CI averages were also calculated to provide historical context to recent observations. Specific details on the analytical framework used for developing OHSI and evaluating its efficacy as a Fountain Darter habitat index, including methods to build HSC, can be found in Appendix H.

# Fish Community

## *Mesohabitat, Microhabitat, and Seine Sampling*

Fish community sampling was conducted in the spring and fall monitoring events to quantify fish assemblage composition/structure and to assess Fountain Darters in river segments and habitats (e.g., deeper areas) not sampled during drop-net and timed dip-net surveys. The following nine monitoring segments were sampled: Spring Lake, Sewell Park, Veterans Plaza, Rio Vista Park, Crooks Park, I-35, Thompson Island, Wastewater Treatment Plant, and Smith Property (Figures 2 and 3). Deeper habitats were sampled using visual transect surveys, and shallow habitats were sampled via seining.

A total of three mesohabitat transects were sampled at each segment during visual surveys. At each transect, four divers swam from bank-to-bank at approximately mid-column depth, enumerating all fishes observed and identifying them to species. After each mesohabitat transect was completed, microhabitat sampling was also conducted along four, five-meter-long PVC pipe segments (micro-transect pipes) placed on the stream bottom and spaced evenly along the original transect. Divers started at the downstream end and swam up the pipe searching through the vegetation, if present, and substrate within approximately 1 m of the pipe. All fishes observed were identified to species and enumerated. For both surveys, any individuals that could not be identified to species were classified by genus. At each micro-transect-pipe, total area surveyed ($m^2$), aquatic vegetation composition (%), and substrate composition (%) were recorded. Water depth (ft) and velocity (ft/s) data were collected in the middle of each micro-transect-pipe using a Marsh McBirney Model 2000 portable flowmeter and adjustable wading rod. At each micro-transect pipe, water-velocity measurements were taken 15 cm from the bottom, mid-column, and at the surface. Standard water-quality parameters were also recorded once at each transect using a handheld water-quality sonde.

In shallow habitats, at least three transects were sampled within each monitoring segment (except Spring Lake) via seining. At each of these, multiple seine hauls were pulled until the entire wadeable area had been covered. After each seine haul, fish were identified, measured (mm), and enumerated. To prevent recapture on subsequent seine hauls, captured fish were placed in a holding bucket containing river water. After completion of the transect, all fish were released from holding buckets. Total area surveyed ($m^2$) was visually estimated for each seining transect. Habitat data from each seine haul location included substrate and vegetation composition (%); water depth (ft); and velocity (ft/s) measured at 15 cm above the river bottom, at mid-column, and at the surface. Fish taxonomy herein follows the most recent guide published by the American Fisheries Society (AFS 2023).

## *Data Analysis*

To evaluate fish community results, all analyses were conducted using fishes identified to species; fishes identified to genus or family were excluded. Total counts of species from independent samples were first quantified as density ($fish/m^2$) to standardize abundance among the three gear types used. Results from multiple sites were combined to assess spatial longitudinal differences between Spring Lake, Upper River (Sewell Park, Veterans Plaza),

Middle River (Rio Vista Park, Crooks Park, I-35), and Lower River (Thompson Island, Wastewater Treatment Plant, Smith Property) (hereafter ‘study segments’).
Based on microhabitat sampling, temporal trends in Fountain Darter density were assessed per sampling event for each study reach for the past five years using boxplots and compared to their respective long-term (2014–present) medians and quartiles. Overall species richness and diversity using the Shannon’s diversity index (Spellerberg and Fedor 2003) for each study segment was assessed for the past five years and plotted with bar graphs. Richness and relative density (%; [sum(species *x* density)/sum(all species density)]*100) of spring-associated fishes (Table 2) were also quantified and presented in the same manner as species richness and diversity.

**Table 2. Spring-associated fishes within the San Marcos Springs system based on Craig et al. (2016).**

| SCIENTIFIC NAME | COMMON NAME |
|---|---|
| *Dionda nigrotaeniata* | Guadalupe Roundnose Minnow |
| *Notropis amabilis* | Texas Shiner |
| *Alburnops chalybaeus* | Ironcolor Shiner |
| *Astyanax argentatus* | Mexican Tetra |
| *Gambusia geiseri* | Largespring Gambusia |
| *Etheostoma fonticola* | Fountain Darter |
| *Percina apristis* | Guadalupe Darter |
| *Percina carbonaria* | Texas Logperch |

# San Marcos Salamander

## *Visual Surveys*

Salamander surveys were conducted during the spring, summer species-specific, and fall monitoring events at three sites within Spring Lake and the San Marcos River (Figure 1), which were previously described as habitat for San Marcos Salamander (Nelson 1993). Two of the sites are located within Spring Lake: the Hotel Site is adjacent to the old hotel, and the Riverbed Site was located across from the former Aquarena Springs boat dock. The third survey area, called the Spring Lake Dam Site, is located in the main river channel immediately downstream of Spring Lake Dam in the eastern spillway. This site is subdivided into three smaller areas to allow greater coverage of suitable salamander habitat.

SCUBA gear was used to sample habitats in Spring Lake, while a mask and snorkel were used in the site below Spring Lake Dam. For each sample, an area of macrophyte-free rock was outlined using flagging tape, and three timed surveys (five minutes each) were conducted by overturning rocks >5 cm wide and counting the number of San Marcos Salamanders observed underneath. Following each timed search, the total number of rocks surveyed was recorded to estimate the number of San Marcos Salamanders per rock in the area searched. The three surveys were averaged to yield the number of San Marcos Salamanders per rock. Densities of suitably sized rocks at each sampling site were determined using quadrats (0.25 $m^2$). Three random samples were taken in each area by randomly throwing the quadrat into the sampling area and counting the number of appropriately sized rocks. The three samples were then averaged to yield a density estimate of the number of suitable rocks in the sampling area. The area of each site was determined by measuring each sampling area with a tape measure.

## Data Analysis

Salamander densities (salamanders/$m^2$) are presented for each season using bar graphs and are compared with long-term (2001–present) spring, fall, high-flow event, and low-flow event averages. High-flow and low-flow averages were calculated from Critical Period events. These events are based on predetermined river discharge triggers (Appendix A), which result in additional survey events to assess flow-related impacts to the San Marcos Salamander population. Temporal trends in salamander density were also assessed per sampling event for each study site for the past five years using bar graphs.

# Macroinvertebrates

## Rapid Bioassessment Sampling

Rapid Bioassessment Protocols (RBPs) are tools for evaluating biotic integrity and overall habitat health, based on the community of organisms present (Barbour et al. 1999). Macroinvertebrates are the most frequently used biological units for RBPs because they are ubiquitous, diverse, and there is an acceptable working knowledge of their taxonomy and life histories (Poff et al. 2006, Merritt et al. 2008).

BIO-WEST performed sampling and processing of freshwater benthic macroinvertebrates, following Texas RBP standards (TCEQ 2014). Macroinvertebrates were sampled with a D-frame kick net (mesh size 500 micrometers [µm]) by disturbing riffle or run habitat (consisting primarily of cobble-gravel substrate) for five minutes while moving in a zig-zag fashion up-stream. Invertebrates were then randomly distributed in a tray and subsamples were taken by scooping out random portions of material and placing them into a separate sorting tray.

All macroinvertebrates were picked from the tray before another subsample was taken. This process was continued until a minimum of 140 individuals were picked to represent a sample. If the entire sample did not contain 140 individuals, the process was repeated again until this minimum count was reached. Macroinvertebrates were collected in this fashion from Spring Lake, Spring Lake Dam, City Park, and I-35 reaches, during spring and fall sampling (Figure 1).

## Sample Processing and Data Analysis

Picked samples were preserved in 80% denatured ethanol, returned to the laboratory, and identified to TCEQ-recommended taxonomic levels (TCEQ 2014). This is usually genus, though members of the family Chironomidae (non-biting midges) and class Oligochaeta (worms) were retained at those taxonomic levels. The 12 ecological measures or metrics of the Texas RBP benthic index of biotic integrity (B-IBI) were calculated for each sample. Each metric represents a functional aspect of the macroinvertebrate community, related to ecosystem health, and sample values are scored from 1 to 4 based on benchmarks set by reference condition streams for the state of Texas. The aggregate of all 12 metric scores for a sample represent the B-IBI score for the reach that sample was taken from. The B-IBI point-scores for each sample are compared to benchmark ranges and are described as having aquatic-life-uses as “Exceptional”, “High”, “Intermediate”, or “Limited”. In this way, point-scores were calculated and the aquatic-life-use for each sample reach was evaluated. Temporal trends in B-IBI scores were assessed per sampling event for each study site for the past five years using bar graphs.

# RESULTS and DISCUSSION

In 2023, central Texas experienced a continuation of low precipitation and higher ambient temperatures observed in 2022. Exceptional (as designated by the National Weather Service [NWS]) drought conditions occurred throughout central Texas from January through August, covering large portions of the Hill Country. Drought conditions eased slightly to the NWS extreme classification during fall. As described in the next section, river discharge in the San Marcos River was below median historical conditions for the entire year and represents the lowest flows observed since 1956 when the U.S. Geological Survey (USGS) gage was installed. Median mean daily discharge was lower in 2023 (88 cfs) than during previous low-flow years in 2006 (116 cfs), 2009 (96 cfs), 2011 (117 cfs), and 2022 (119 cfs). Minimum mean daily discharge in 2023 declined to the lowest discharge (66 cfs) observed since 1956. Furthermore, low flows have persisted since fall 2022, and unlike previous low-flow years, flows did not return to normal levels by this fall (2023). Over this extended period of low flows, habitat conditions throughout the San Marcos River declined, namely with reduced wetted areas in most reaches.

San Marcos River monthly median discharge decreased throughout the year triggering three full system habitat evaluations at 85 cfs, 70 cfs, and 65 cfs. Habitat quality documented for the Covered Species varied spatially during the evaluations at these three flow tiers. At 85 cfs in June, habitat quality for the San Marcos Salamander and Fountain Darter (i.e., aquatic vegetation) remained suitable at Spring Lake and Spring Lake Dam despite lower water levels, algae build up, and siltation. Suitable Fountain Darter habitat also persisted further downstream at City Park and I-35, though total wetted area was reduced at I-35. Texas Wild-rice was impacted the most under these drought conditions due to reductions in wetted area and terrestrial competitors.

At 70 and 65 cfs in August, habitat conditions for all Covered Species appeared consistent with those observed in June, with some exceptions. By the end of August, habitat conditions were mostly similar to previous evaluations at Spring Lake and Spring Lake Dam. However, lower water levels resulted in degraded habitat quality in some areas that exhibited higher-than-average amounts of algae build up and siltation. All reaches experienced declines in aquatic vegetation coverage and wetted area. Warmer water temperatures above 25 °C were documented at stations further downstream from Spring Lake but were infrequent. See Appendix B for a complete summary of Critical Period low-flow habitat evaluation memorandums.

In summary, total river discharge in the San Marcos River System in 2023 was the lowest since the inception of biological monitoring in 2000. Noticeably lower water levels impacted Texas Wild-rice, while other vegetation more suitable for Fountain Darter habitat was less affected. Based on past low-flow years, it remains important to keep tracking the system-wide habitat conditions for the Covered Species as these lower-than average discharge levels continue to persist. The remaining sections in the Results and Discussion describe current trends in river discharge, water temperature, Covered Species populations, and select floral and faunal communities through the San Marcos Springs/River system during this low-flow year.

## River Discharge

Over the last five years, annual median daily mean discharge in the San Marcos River decreased from 2019 (232 cfs) to 2023 (88 cfs), with 2023 values representing the lowest median annual flows observed since 1956 (59 cfs). Maximum mean daily discharge was lowest in 2023 (205 cfs) and highest in 2021 (579 cfs), with 2021 being the only year where mean daily discharge exceeded 400 cfs. Minimum mean daily discharge mirrored median trends, decreasing from 2019 (155 cfs) to 2023 (66 cfs). Variation in discharge (i.e., interquartile range) was generally low and was highest in 2019 (64 cfs), 2021 (57 cfs), and 2022 (60 cfs) relative to 2020 (24 cfs) and 2023 (11 cfs) (Figure 5A).

Monthly median discharge trends in 2023 varied minimally around or slightly below long-term 10th percentile magnitudes. Median discharge only exceeded 100 cfs in May (101 cfs). After May, median discharge decreased through September (70 cfs), then slightly increased in October (80 cfs). Variation in discharge within months was also minimal, with interquartile ranges from 1–11 cfs (Figure 5B).

Routine spring sampling occurred in April, when daily discharge ranged from 82–104 cfs. As flows descended below 100 cfs following the spring sampling event, species-specific sampling remained engaged, which included a habitat assessment and biweekly Texas Wild-rice physical measurements. Discharge further decreased below 80 cfs in August, requiring additional habitat assessments, Texas Wild-rice physical measurements, aquatic vegetation mapping, Fountain Darter dip-netting (n = 1 event), and salamander surveys (n = 3 events). Mean daily discharge remained below long-term 10th percentile (80 cfs) in October during routine fall sampling (Figure 5B).

## Water Temperature

Median water temperature varied about 2 °C among stations and ranged from 21.4 °C at Spring Lake Deep to 23.3 °C at I-35. Variation in water temperature (i.e., interquartile range) exhibited a longitudinal gradient, generally increasing from upstream to downstream. Temperature regimes in Spring Lake had minimal variability (0.0–0.2 °C) and variation in riverine stations generally increased with distance downstream from the Chute (1.2 °C) to Wastewater Treatment Plant (3.7 °C) (Figure 6). Longitudinal trends in 2023 matched expectations based on previous years and are typical within spring-associated ecosystems, where water temperatures increase in magnitude and variation further downstream from spring inputs (Kollaus and Bonner 2012).

Fountain Darter egg and/or larval production thresholds were never exceeded in Spring Lake, but exceedances increased with distance from spring source at riverine stations from Spring Lake Dam to Wastewater Treatment Plant. Total number of days water temperatures exceeded the Fountain Darter larval production threshold ranged from 20 to 40 days. Total exceedance time was approximately 20 days at Spring Lake Dam and City Park, approximately 30 days at Rio Vista Park and Thomspon Island, and approximately 40 days at I-35 and Wastewater Treatment Plant. Across stations, water temperature most frequently exceeded 25 °C in August (9–12 days) and September (2–12 days). Median total days of larval production exceedance per month generally increased from March (1 day) to August (12 days) and decreased by October (2 days). In August and September, one to two 4-hour measurements above this threshold were typically observed per day at downstream riverine stations but reached 3 measurements per day at Thompson Island Artificial and Wastewater Treatment Plant.

Across stations, water temperatures exceeded the Fountain Darter egg production threshold from 3 to 28 days per month during June to September. Total exceedance days was minimal at City Park (8 days) and Rio Vista Park (3 days) but was higher from I-35 (13 days) to Wastewater Treatment Plant (24 days). Across all stations, median total days of egg production exceedance per month generally increased from May (0 days) to August (10 days) and decreased to September (4 days). Total daily 4-hour measurements above this threshold were zero to one per day across all stations except Thompson Island Artificial and Wastewater Treatment Plant in August (1–3 per day) and September (0–6 per day).

Among the study reaches, temporal patterns in exceedance of the 26 °C optimal egg production threshold were noted when 2023 exceedance frequencies were compared to previous years. Although the threshold was not exceeded at Spring Lake Dam, exceedances were more common at downstream study reaches in 2022 and 2023. At City Park, the egg production threshold was not exceeded in 2020 or 2021, whereas it was exceeded for 31 days in 2022 and 8 days in 2023. At I-35, the threshold was not exceeded from 2020-2022 but was exceeded for 13 days in 2023. However, based on patterns in Fountain Darter population demography at these study reaches in summer and fall 2023, elevated water temperatures in summer 2023 did not have a strong negative affect on overall population state or recruitment rates (see subsequent sections for more details).

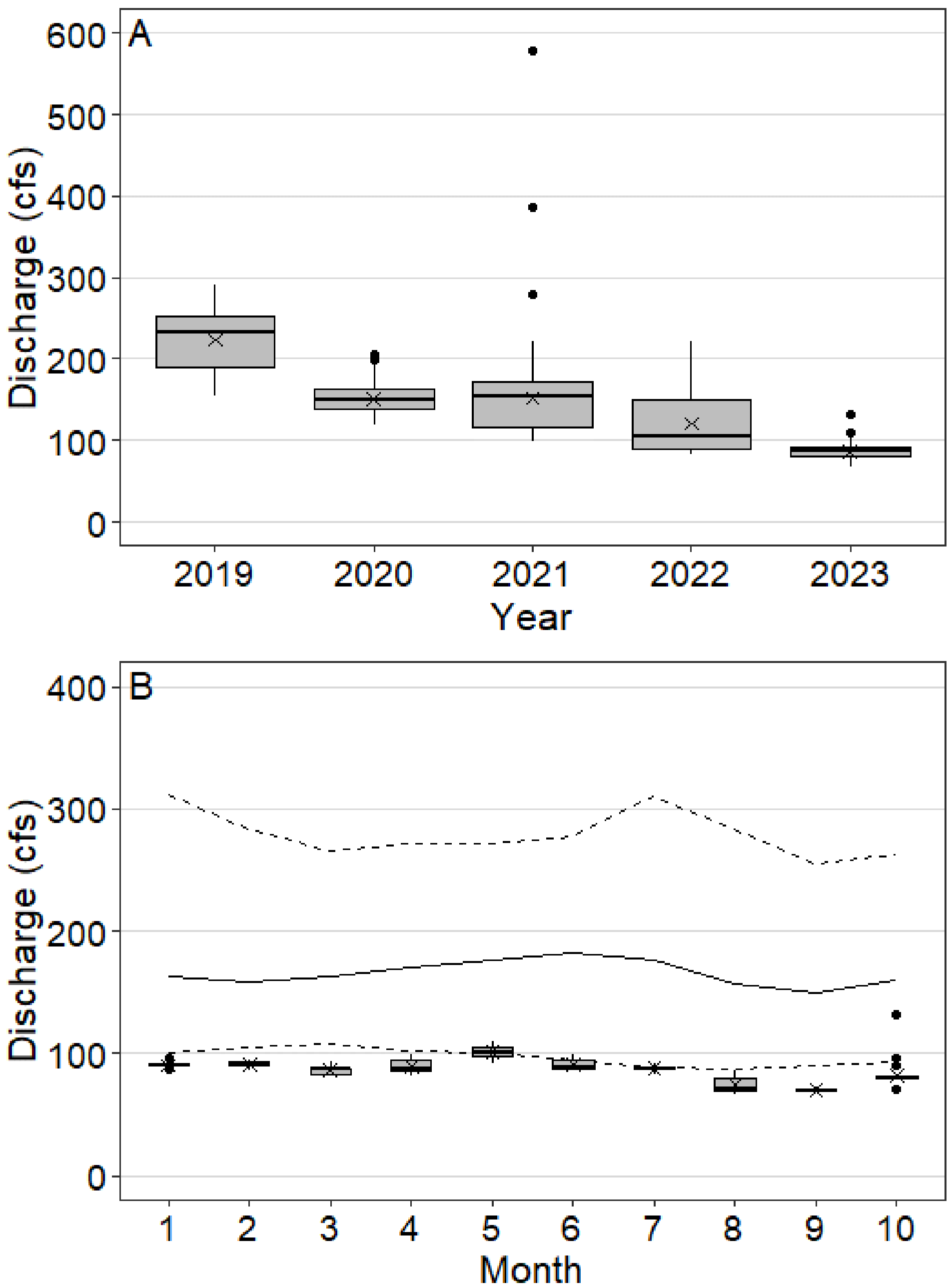


**Figure 5.** **Boxplots displaying San Marcos River mean daily discharge annually from 2019–2023 (A) and among months (January–October) in 2023 (B). Each month is compared to the 10th percentile (lower dashed line), median (solid line), and 90th percentile (upper dashed line) of their historical (1956–2023) daily means. The thick horizontal line in each box is the median, x represents the mean, and the upper/lower bounds of each box represents the interquartile range. Whiskers represent minimum/maximum values up to 1.5 times the interquartile range, and outliers beyond this are designated with solid black circles.**

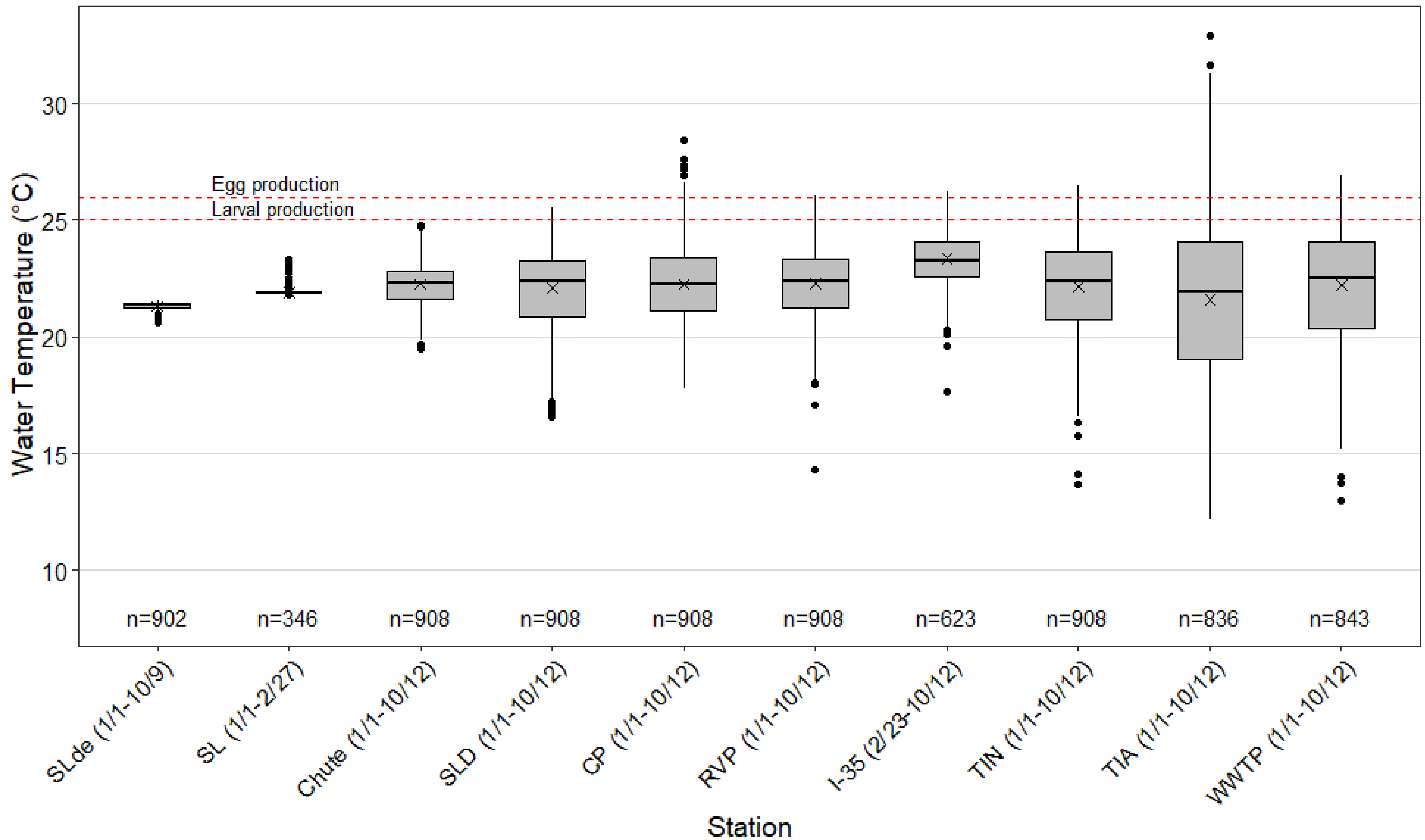


**Figure 6. Boxplots displaying 2023 water temperatures at logger stations (data collection timeframe [Month/Day]). Water temperature data are based on measurements collected at 4-hour increments. Stations include Spring Lake Deep (SLde), Spring Lake (SL), Chute, Spring Lake Dam (SLD), City Park (CP), Rio Vista Park (RVP), I-35, Thompson's Island Natural Channel (TIN), Thompson's Island Artificial Channel (TIA), and Wastewater Treatment Plant (WWTP). The thick horizontal line in each box is the median, x represents the mean, and the upper/lower bounds of each box represents the interquartile range. Whiskers represent minimum/maximum values up to 1.5 times the interquartile range, and outliers beyond this are designated with solid black circles. The "n" values along the x-axis represent the number of individual temperature measurements in each distribution. The red dashed lines indicate maximum optimal temperatures for Fountain Darter larval (≥25 °C) and egg (≥26 °C) production (McDonald et al. 2007).**

# Aquatic Vegetation

## *HCP Benchmark Full System Mapping*

The HCP full system baseline vegetation mapping occurred in April to May 2023 and marks the third HCP benchmark mapping event since implementation of the EAHCP. Previous full system mapping events occurred in 2013 and 2018. In each event, aquatic vegetation was mapped from Spring Lake Dam to just below Stoke's Park/ Thompson's Island. Due in part to HCP restoration activities, there was an increase in percent composition of native aquatic vegetation between 2013 and 2018 (BIO-WEST 2018). Texas Wild-rice was the native species to increase the most during this period.

Overall San Marcos River discharge decreased between 2018 and 2023. The San Marcos River system experienced flows near the historical median in 2018 (~160 cfs), but annual medians steadily declined from 2019 to 2023, bottoming out at 88 cfs in 2023 (Figure 5A). Despite a reduction in flow across the five year period, aquatic vegetation coverage was approximately 38,000 $m^2$ (Table 3). Although total amount of vegetation was similar, coverages among taxa changed. In 2018, coverage of Texas Wild-rice was 10,224 $m^2$ (Figure 7). Coverage of Texas Wild-rice increased by 2023 (15,317 $m^2$) becoming the dominant aquatic plant species in the system. *Cabomba* had the second largest increase in coverage over the five year period which was likely a result of restoration planting and natural expansion during reduced flow conditions. Plant species with reduced cover between 2018 and 2023 include *Potamogeton* and *Hydrilla*. *Hydrilla* was reduced as a direct result of removal efforts associated with HCP restoration. Many locations where *Hydrilla* was dense in 2018 are now occupied by Texas Wild-rice or other native species. Additionally, *Potamogeton* has slowly been replaced by Texas Wild-rice in several areas. Other notable observations made during the mapping event include the expansion of *Myriophyllum aquaticum*, *Alternanthera philoxeroides,* and *Panicum repens* to new sections of the river. Furthermore, there was a notable increase in bryophyte abundance in slackwater areas which have increased as flows declined. 2023 was unique to previous years in that it was the first year that bryophyte coverage was large enough to map in the San Marcos system. Coverage of this non-rooted plant reached 1,284 $m^2$ in 2023.

**Table 3. A comparison of the notable changes in vegetation assemblages observed in the 2013, 2018, and 2023 HCP Benchmark mapping events.**

| Taxa | 2013 Coverage ($m^2$) | 2018 Coverage ($m^2$) | 2023 Coverage ($m^2$) |
|---|---|---|---|
| *Cabomba* | 3,114 | 1,039 | 5,080 |
| *Hydrilla* | 18,927 | 12,685 | 6,045 |
| *Hygrophila* | 10,778 | 7,112 | 4,720 |
| *Ludwigia* | 139 | 330 | 415 |
| *Potamogeton* | 3,053 | 1,233 | 118 |
| *Sagittaria* | 2,556 | 3,485 | 1,948 |
| *Nuphar* | 123 | 125 | 287 |
| *Hydrocotyle* | 173 | 220 | 613 |
| *Zizania* | 4,892 | 10,224 | 15,317 |
| Other species | 9,608 | 1,921 | 3,804 |
| **Total** | **53,363** | **38,374** | **38,347** |

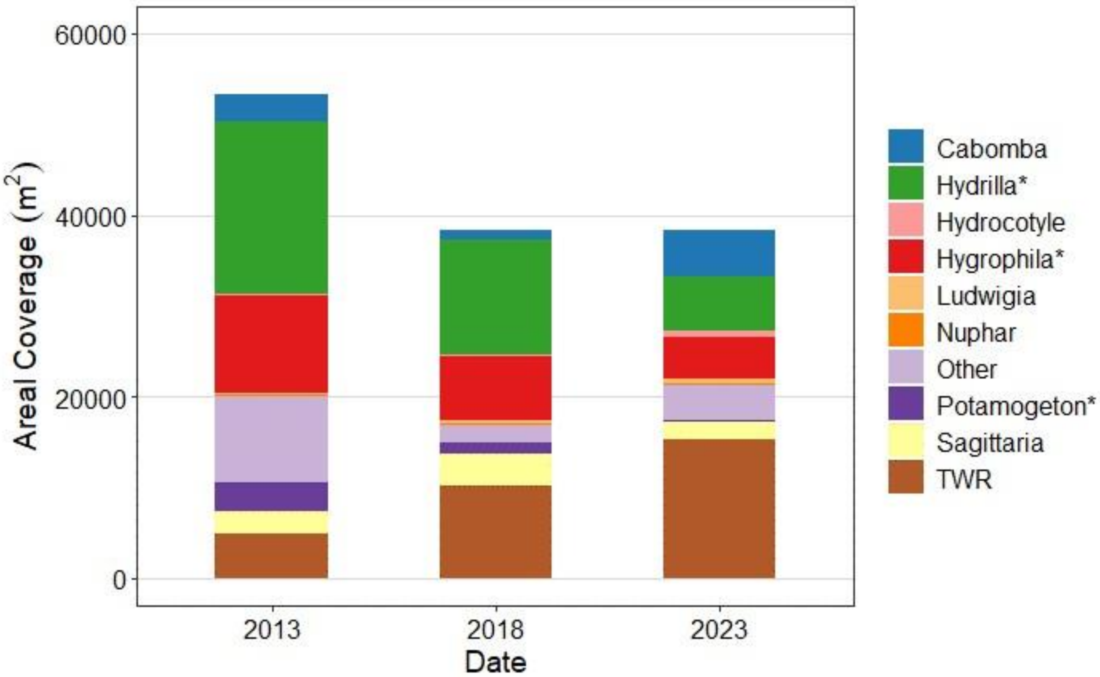


**Figure 7. Aquatic vegetation ($m^2$) composition among taxa during full system mapping of the San Marcos Springs and River in 2013, 2018, and 2023.**

## *Long-term Biological Goal Reach Mapping*

Long-term biological goal reach mapping occurred in spring and fall, as well as one low-flow event in July.

## *Spring Lake Dam Reach*

The Spring Lake Dam reach has been a popular recreation area over the past decade, when access is allowed. In 2023, recreation impacts to the vegetation community were noticeable and compounded by prolonged low flows. Since the beginning of the year, this reach was marked by shallower depths and slower velocity culminating in the establishment of a gravel bar island near the confluence of Sessoms Creek. Spring 2023 vegetation coverage was near the long-term average (1,469 $m^2$) but down compared to spring 2022 (2,077 $m^2$; Figure 8). As flows decreased in 2023, vegetation coverage decreased by 256 $m^2$ to 1,213 $m^2$ in the July low-flow event. Much of the vegetation loss during this time was observed in species other than Texas Wild-rice which decreased slightly from 1,073 $m^2$ in the spring to 1,033 $m^2$ in the July low-flow event. Vegetation coverage continued to decline throughout the year and fall mapping recorded a total vegetation coverage of 982 $m^2$. Of the total vegetation coverage in fall, 80% (786 $m^2$) was Texas Wild-rice, with only 196 $m^2$ of other species (Figure 9), including *Potamogeton illinoensis* and *Hydrocotyle verticillata*. Bryophytes were associated with *Hydrocotyle verticillata* in both the spring and fall.

### *City Park Reach*

Total vegetation coverage in City Park reach was lower than long-term averages in the spring (3,215 $m^2$), declined well below long-term low-flow averages in July (2, 227 $m^2$), and was markedly lower than fall averages by fall of 2023 (1,667 $m^2$; Figure 8). City Park reach maintains the highest vegetation coverage among study reaches but also receives the greatest impact from recreation as tubing, wading, and swimming are all popular activities here. Based on this, large variations in vegetation coverage are common, yet long-term seasonal patterns (spring to fall decrease) tend to remain consistent (Figure 8). However, in 2023, typical recreational impacts were exacerbated by continued and sustained low flows. Texas Wild-rice was dominant within this reach accounting for 92-96% of total vegetation across 2023 mapping events despite decreasing from spring (2,954 $m^2$) to summer (2,142 $m^2$) and fall (1,585 $m^2$) (Figure 9). *Cabomba caroliniana*, which has been observed to increase in both Comal and San Marcos systems during low flows, was the second most dominant species and exhibited improved persistence compared to previous years. Another interesting change in vegetation assemblage was the presence of bryophytes associated with *Cabomba* and Texas Wild-rice in 2023 amounting to 236 $m^2$ in spring and persisting into fall.

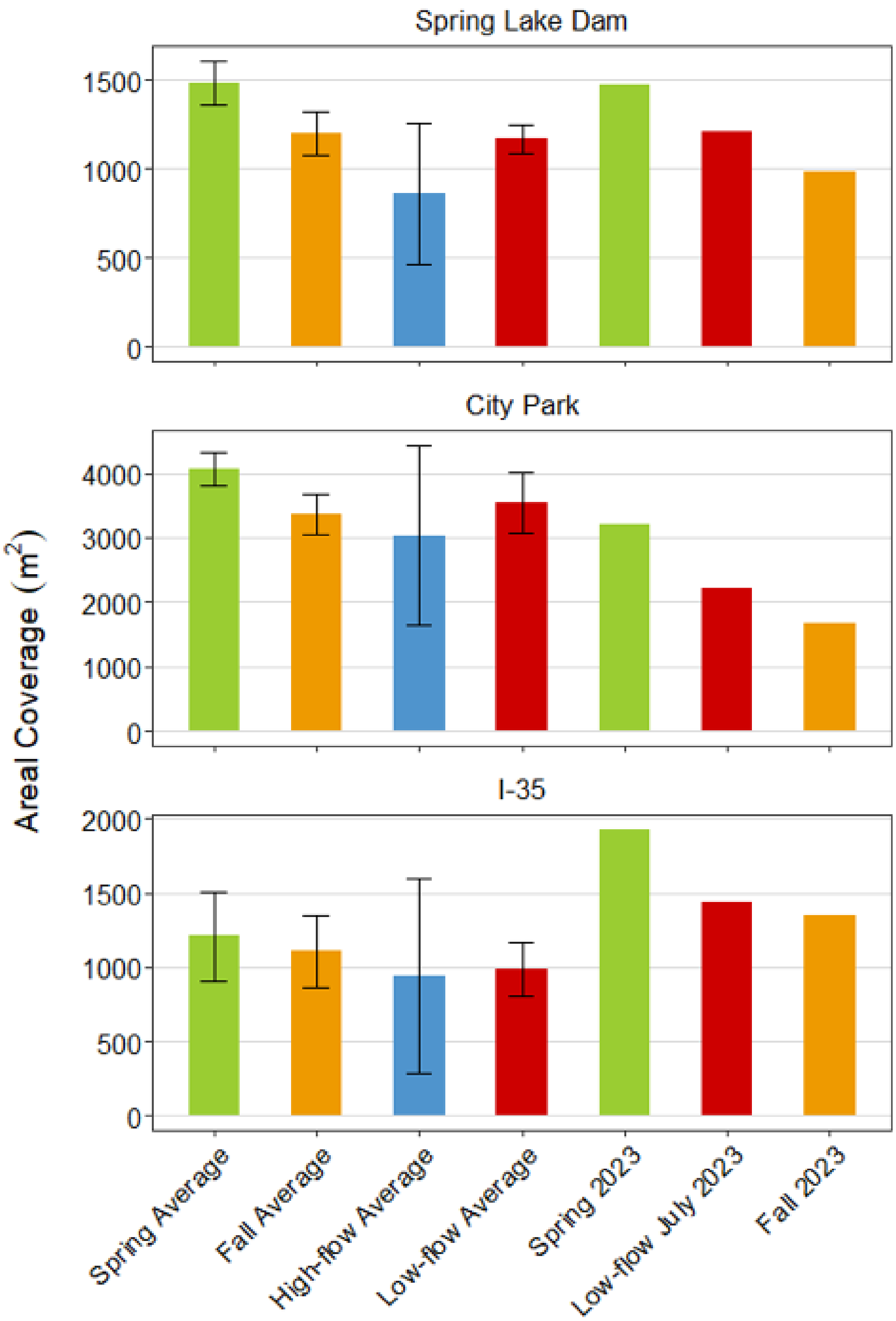


**Figure 8.** **Areal Coverage (m$^2$) of aquatic vegetation among study reaches in the San Marcos River. Long-term (2001–2023) study averages are provided with error bars representing 95% confidence intervals.**

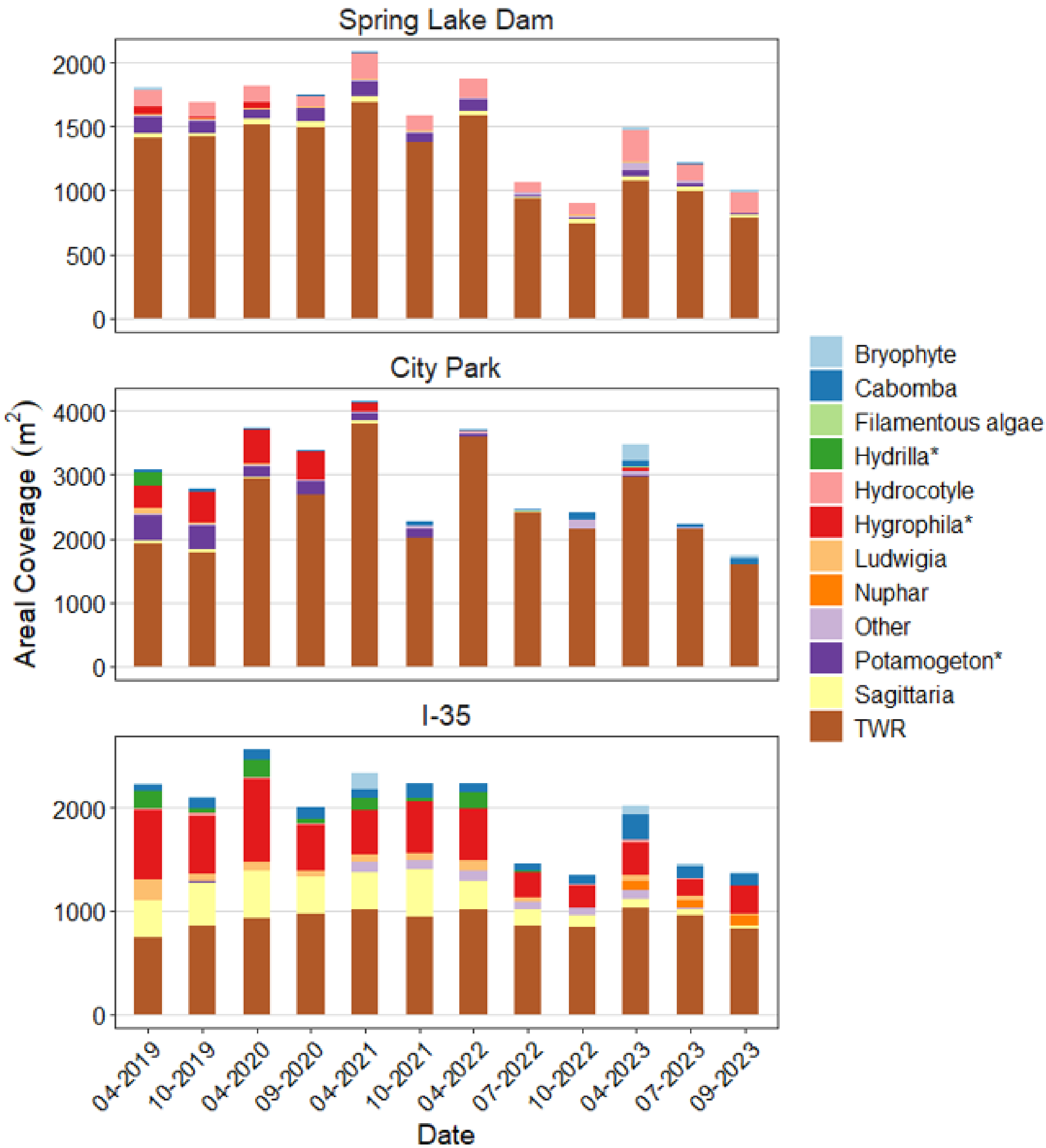


**Figure 9.** **Aquatic vegetation ($m^2$) composition among taxa (top row) from 2019–2023 in the San Marcos River. (*) in the legend denote non-native taxa.**

### *I-35 Reach*

Texas Wild-rice was the dominant species in the I-35 reach, accounting for 54-66% of total vegetation coverage across mapping events in 2023 (Figure 9). Texas Wild-rice coverage decreased from spring (1,030 $m^2$) to summer (950 $m^2$) and fall (822 $m^2$). As the drought persisted approximately 450 $m^2$ of submerged aquatic habitat in the lower section became dewatered. This changed the cover and distribution of vegetation in the area. Amphibious species such as *Hygrophila polysperma* and *Sagittaria platyphylla* continued to survive as emergent plants while species like *Cabomba caroliniana* declined or shifted to deeper water. Additionally, bryophytes were present in all three mapping events with the highest coverage of 82 $m^2$ occurring in spring. Although bryophytes are sporadically observed in the historical data, their persistence in this reach throughout the year is uncommon. However, slower water velocities resulting from low-flow conditions likely allowed for this unrooted vegetation to persist.

## Texas Wild-rice

### *Texas Wild-rice Mapping*

In 2023, Texas Wild-rice was mapped three times, during the full system mapping event early in the year, during the annual summer mapping event in July/August, and during the low-flow (<80 cfs) sampling event in September/October. Low flows increased above the 80 cfs trigger but remained below 90 cfs for the remainder of the fall. Full system maps are located in Appendix C. Results of the 2023 full system mapping event demonstrated Texas Wild-rice coverage was 15,317 $m^2$, an increase from the 2022 annual mapping event. However, Texas Wild-rice coverage decreased throughout the remainder of 2023. The coverage during the annual mapping event in July/August was 11,821 $m^2$, while the coverage during the low-flow sampling event in September/October was 8,211 $m^2$. This represents the lowest coverage of Texas Wild-rice mapped since 2016 and suggests a continuing trend of decreasing Texas Wild-rice coverage since its peak in April 2021 (Figure 10).

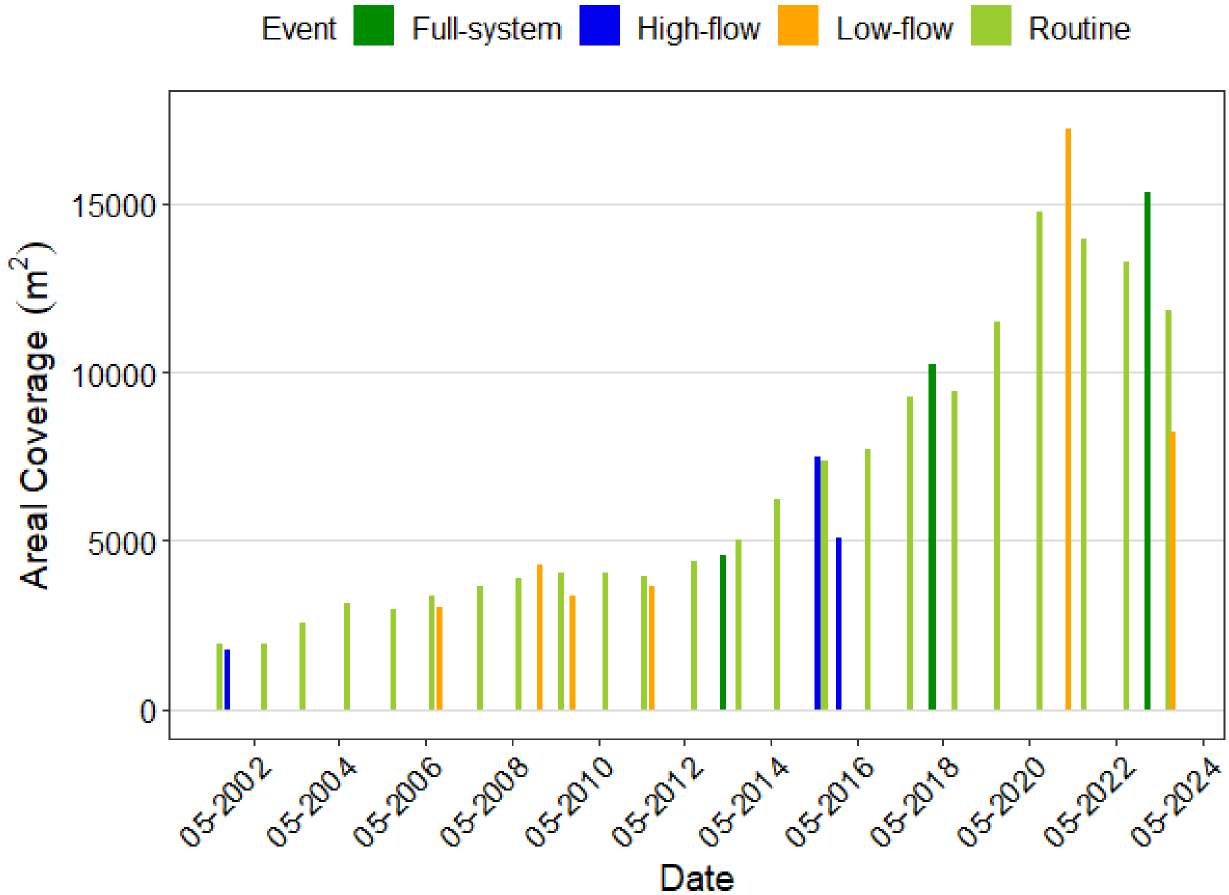


**Figure 10.** **Texas Wild-rice areal coverage ($m^2$) from 2001–2023 in the upper San Marcos River.**

This year's annual (summer) mapping event occurred during substantially reduced discharge (~70–90 cfs) and high levels of recreation in the river. Reduced water levels from low flows led to some Texas Wild-rice becoming dewatered and stranded on islands or along banks. As flows continued to decrease, reaching a low of approximately 66 cfs in August, the soil dried out causing these Texas Wild-rice stands to perish and be replaced by terrestrial or riparian vegetation. Recreation in the summer of 2023 also had negative impacts to Texas Wild-rice coverage located adjacent to several public access areas, including the Spring Lake Dam and City Park study reaches.

Between the July/August 2022 and July/August 2023 annual mapping events, Texas Wild-rice coverage decreased by 1,452 $m^2$, with losses in five of eight segments and Spring Lake. The largest percent loss (24%) in Texas Wild-rice occurred in Segment F, Veramendi Park to Rio Vista Park, with cover decreasing by 500 $m^2$ (Table 4). A large portion of Texas Wild-rice around the Purgatory Creek confluence was lost due to lower water levels that left several Texas Wild-rice stands desiccated. Texas Wild-rice cover also decreased substantially (nearly 300 $m^2$) in Segment E, Lower City Park. Losses in this segment were largely attributed to recreation as pathways were created through the rice. Texas Wild-rice declined slightly in several other segments. Much of the Texas Wild-rice (71 $m^2$) in Segment B, Sewell Park, was replaced by emergent or terrestrial plant species as the water level decreased. However, most of this loss had already occurred by late 2022.

Although Texas Wild-rice was lost in some areas, it expanded in three segments. The largest percent increases occurred in the most downstream segments. Segment H, below I-35, continued to increase in Texas Wild-rice coverage (84 $m^2$). In recent years, Texas Wild-rice has steadily increased throughout this segment largely as a result of heightened natural expansion above Cape's dam coupled with reduced overall flow conditions and the limited nature of large flow pulses experienced the past few years. In contrast to trends in previous years, Segment A increased in Texas Wild-rice cover by 29 $m^2$ (Table 4).

In summary, due to dropping water levels, Texas Wild-rice declined steadily across 2023 sampling events. The cumulative effects of low flow and recreation resulted in observable losses during the September/October mapping event. Plants were extirpated in areas where the substrate had been desiccated or eroded away by foot traffic or shear velocity flows. While similar losses were apparent in 2022, the prolonged period of dewatering in 2023 exacerbated the impacts to Texas Wild-rice (Figure 11).

**Table 4. Change in cover amount ($m^2$) of Texas Wild-rice between July/August 2022 and July/August 2023 annual mapping.**

| RIVER SEGMENT | JULY/AUGUST 2022 COVERAGE | JULY/AUGUST 2023 COVERAGE | COVERAGE CHANGE | PERCENT CHANGE |
|---|---|---|---|---|
| A. Spring Lake Dam Study Reach | 1,004 | 1,033 | +29 | +3 |
| B. Sewell Park | 1,017 | 946 | -71 | -7 |
| C. City Park bend | 3,802 | 3,277 | -525 | -14 |
| D. City Park Study Reach | 2,424 | 2,173 | -251 | -10 |
| E. Lower City Park | 1,516 | 1,223 | -293 | -19 |
| F. Veramendi Park to Rio Vista Park | 2,126 | 1,626 | -500 | -24 |
| G. I-35 Study Reach | 866 | 954 | +88 | +10 |
| H. Below I-35 | 419 | 503 | +84 | +20 |
| Spring Lake | 99 | 86 | -13 | -13 |

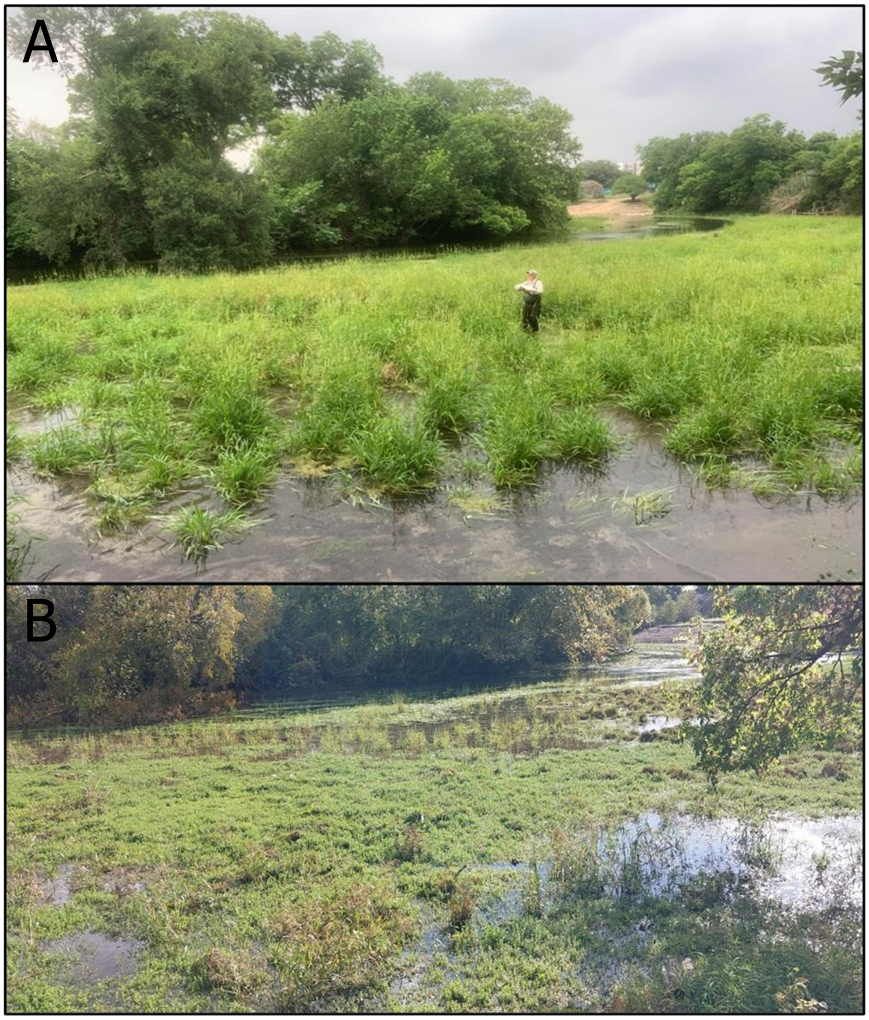


**Figure 11.** **(A) A large stand of emergent Texas Wild-rice at upper City Park in May 2023. (B) The same area at upper City Park in September 2023, after dewatering led to its replacement by terrestrial vegetation (*Ceratopteris thalictroides* and *Bacopa monnieri* ).**

# Fountain Darter

A total of 528 Fountain Darters were observed at 48 drop-net stations across spring and fall 2023. Drop-net densities ranged from 0.00–37.00 fish/m$^2$. Community summaries and raw drop-net data are included in Appendix E and Appendix G, respectively. Habitat conditions observed during drop-netting can be found in Table 5. Texas Wild-rice was not sampled in 2023 due to river discharge dropping below 120 cfs. Timed dip-netting resulted in a total of 551 Fountain Darters during 10.50 person-hours (p-h) of effort. Site CPUE ranged from 6–112 fish/p-h. Lastly, Fountain Darters were present at 99 out of 240 random-stations and reach-level percent occurrence among monitoring events ranged from 0–73%. A summary of occurrences per reach and vegetation taxa can be found in Table 6.

**Table 5. Habitat conditions observed during 2023 drop-net sampling. Physical habitat parameters include counts of dominant vegetation (median % composition) and dominant substrate type sampled. Depth-velocity and water quality parameters include medians (min-max) of each variable among all drop-net samples.**

| HABITAT PARAMETERS | SLD | CP | I-35 |
|---|---|---|---|
| **Vegetation** | | | |
| Bryophyte[1] | 0 | 2 (95%) | 0 |
| *Cabomba*[1] | 0 | 4 (93%) | 4 (98%) |
| *Hydrocotyle*[1] | 4 (100%) | 0 | 0 |
| *Hygrophila*[1] | 0 | 2 (88%) | 4 (95%) |
| *Ludwigia*[1] | 0 | 0 | 2 (100%) |
| Open | 4 (100%) | 4 (100%) | 4 (100%) |
| *Potamogeton*[2] | 4 (95%) | 2 (90%) | 0 |
| *Sagittaria*[2] | 4 (100%) | 0 | 4 (95%) |
| **Substrate** | | | |
| Cobble | 8 | 0 | 0 |
| Gravel | 5 | 5 | 2 |
| Sand | 0 | 2 | 8 |
| Silt | 3 | 7 | 8 |
| **Depth-velocity** | | | |
| Water depth (ft) | 0.8 (0.2–2.3) | 2.1 (0.8–3.0) | 1.9 (0.5–3.4) |
| Mean column velocity (ft/s) | 0.4 (0.0–2.1) | 0.2 (0.0–0.7) | 0.2 (0.0–1.4) |
| 15-cm column velocity (ft/s) | 0.3 (0.0–2.1) | 0.1 (0.0–0.5) | 0.2 (0.0–1.3) |
| **Water quality** | | | |
| Water temperature (°C) | 22.2 (21.8–22.8) | 22.4 (21.1–23.4) | 22.2 (18.8–23.4) |
| DO (ppm) | 7.8 (6.8–8.5) | 8.8 (7.4–9.9) | 8.6 (7.0–10.3) |
| DO % saturation | 89.2 (78.7–99.2) | 101.2 (85.7–115.5) | 94.8 (79.9–120.2) |
| pH | 7.4 (4.3–7.9) | 7.5 (4.3–7.9) | 7.6 (4.3–8.0) |
| Specific conductance (µs/cm) | 639 (624–650) | 640 (628–651) | 646 (621–650) |

[1]Denotes ornate vegetation taxa with physical characteristics that create complex structure
[2]Denotes long broad or ribbon-like, austere-leaved vegetation taxa

**Table 6. Summary of vegetation types sampled among reaches during 2023 random-station surveys in the San Marcos Springs/River and the percent occurrence of Fountain Darters in each reach and vegetation type. Raw numbers represent the sum of detections per reach-vegetation type combination.**

| VEGETATION TYPE | SL | SLD | CP | I-35 | Total | Occurrence |
|---|---|---|---|---|---|---|
| *Cabomba*[1] | 13 | 0 | 13 | 9 | **35** | **62.9** |
| *Ceratophyllum*[1] | 5 | 0 | 0 | 0 | **5** | **0.0** |
| *Heteranthera*[1] | 0 | 2 | 0 | 0 | **2** | **0.0** |
| *Hydrocotyle*[1] | 0 | 10 | 0 | 0 | **10** | **90.0** |
| *Hygrophila*[1] | 0 | 0 | 0 | 14 | **17** | **71.4** |
| *Limnophila*[1] | 0 | 0 | 0 | 1 | **1** | **100.0** |
| *Ludwigia*[1] | 0 | 0 | 0 | 3 | **3** | **66.7** |
| *Myriophyllum*[1] | 3 | 0 | 0 | 0 | **3** | **33.3** |
| *Nasturtium*[1] | 0 | 0 | 1 | 0 | **1** | **100.0** |
| *Nuphar*[2] | 0 | 0 | 0 | 1 | **1** | **0.0** |
| *Potamogeton*[2] | 0 | 2 | 0 | 0 | **2** | **50.0** |
| *Sagittaria*[2] | 19 | 1 | 0 | 3 | **23** | **34.8** |
| Texas Wild-Rice[2] | 0 | 45 | 66 | 29 | **140** | **31.4** |
| **Total** | **40** | **60** | **80** | **60** | **240** | **41.2** |
| **Occurrence** | **15.0** | **25.0** | **52.5** | **60.0** | **-** | **-** |

[1]Denotes ornate vegetation taxa with physical characteristics that create complex structure
[2]Denotes long broad or ribbon-like, austere-leaved vegetation taxa

## *Population Demography*

### ***Seasonal population trends***

Median Fountain Darter density in 2023 was slightly higher in fall (3.00 darters/m$^2$) than spring (2.25 darters/m$^2$) and upper quartiles were similar (~9.00 darters/m$^2$). For both seasons, median density and variability (i.e., interquartile range) in 2023 were slightly higher than 5-year and long-term expectations (Figure 12A). Median catch rates in 2023 decreased from spring (53 darters/p-h) to fall (30 darters/p-h). Median CPUE in spring was slightly higher than historical data, while summer and fall were similar. Upper quartiles and variability in 2023 were lower than historical trends, which can be attributed to lower sample sizes associated with timed dip-netting (Figure 12B). Similar to catch rates, median percent occurrence decreased from spring (43%) to fall (30%). Median percent occurrence approximated 5-year trends across seasons and the upper quartile in fall was notably higher in 2023 (+15%) (Figure 12C).

In summary, population indices met expectations in 2023 and generally aligned with 5-year and long-term data. The only exceptions to this were slightly higher than typical overall density and occurrence in fall which can be attributed to increases of these metrics at City Park and I-35 (see next section). Specifically, darter densities were high within bryophytes which were more prevalent than normal within City Park in 2023. In addition to high densities within species-specific patches, bryophytes were also observed associated with Texas Wild-rice and other taxa, which likely contributed to high darter occurrence in fall. Presence of non-rooted bryophytes within other vegetation taxa such as Texas Wild-rice increased structural complexity of these habitats, thus increasing suitability for Fountain Darters (Alexander and Phillips 2012, Edwards and Bonner 2022).

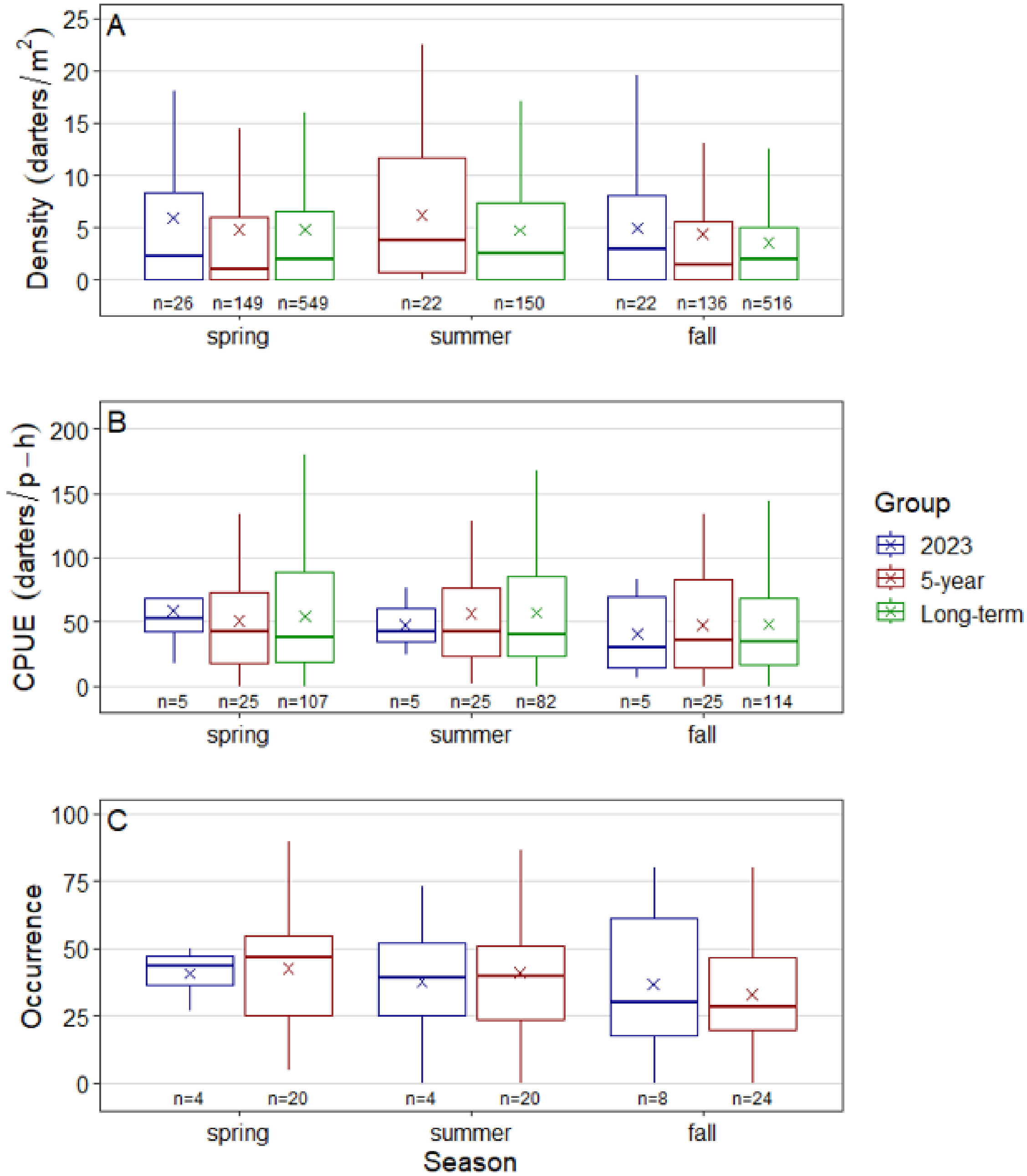


**Figure 12.** **Boxplots comparing Fountain Darter density from drop-net sampling (A), catch-per-unit-effort (CPUE) from timed dip-netting (B), and proportional occurrence from random station dip-netting (C) among seasons in the San Marcos Springs/River. Temporal groups include 2023, 5-year (2019–2023), and long-term (2001–2023) observations. The thick horizontal line in each box is the median, x represents the mean, and the upper/lower bounds of each box represents the interquartile range. Whiskers represent minimum/maximum values up to 1.5 times the interquartile range. The "n" values along the x-axes represent the number of discrete samples per category.**

## ***Drop-net sampling density trends***

Patterns in Fountain Darter density in 2023 differed spatially and in some cases deviated from general seasonal- and reach-specific expectations. Median density at Spring Lake Dam was below the long-term median (1.50 darters/$m^2$) in the spring (0.50 darters/$m^2$) and increased near it in fall (1.00 darters/$m^2$). At City Park, median density increased from spring (4.50 darters/$m^2$) to fall (9.50 darters/$m^2$). Both median and upper quartile estimates in this reach were substantially higher than long-term expectations (2.00 and 6.00 darters/$m^2$, respectively). Median density at I-35 was higher than the long-term upper quartile (5.50 darters/$m^2$) in spring (7.00 darters/$m^2$). The median decreased in fall (3.25 darters/$m^2$), but was still above long-term expectations (2.00 darters/$m^2$) (Figure 13).

Median density the past five years were not strongly correlated ($r < 0.70$) across reaches, suggesting asynchronous trends among reaches. Median and upper quartiles showed an increasing trend overall from 2019–2023 at City Park and I-35 (Figure 13). Positive increases in density at City Park and I-35 in 2023 do not correspond well with patterns in overall coverage of suitable vegetation types or OHSI observed over this time period, as both have decreased. Instead, it appears that density within multiple vegetation types (*Cabomba*, *Hygrophila*, *Ludwigia*, and *Sagittaria*) increased sharply in 2023 (see Figure 15). This increase was most likely related to higher prevalence of bryophytes and algae within these other vegetation types due to lower velocity conditions. Further, bryophyte patches large enough for drop-net sampling established on the stream bottom at City Park in fall, which represents the first opportunity to sample within this taxon in the San Marcos River and best explains the large increase in density observed (See subsequent section for more details on density trends).

Results suggest that extended periods of reduced flows from 2022–2023 did not have an apparent negative effect on Fountain Darter density, and monitoring this year instead indicates increased population densities. Findings in 2022 provided evidence to suggest population resistance to reduced flows may be a function of increased recruitment as documented in other studies of stream fishes (McCargo and Peterson 2010; Katz and Freeman 2015). As stated above, high overall recruitment and substantial increases in density at City Park in 2023 are likely due to increased coverage of bryophytes within other vegetation types. The resulting increase in complexity of benthic habitats occupied by darters has potentially increased carrying capacity, thereby limiting potential density-dependent regulation (i.e., negative feedbacks) (Dennis et al. 2006; Boettiger 2018).

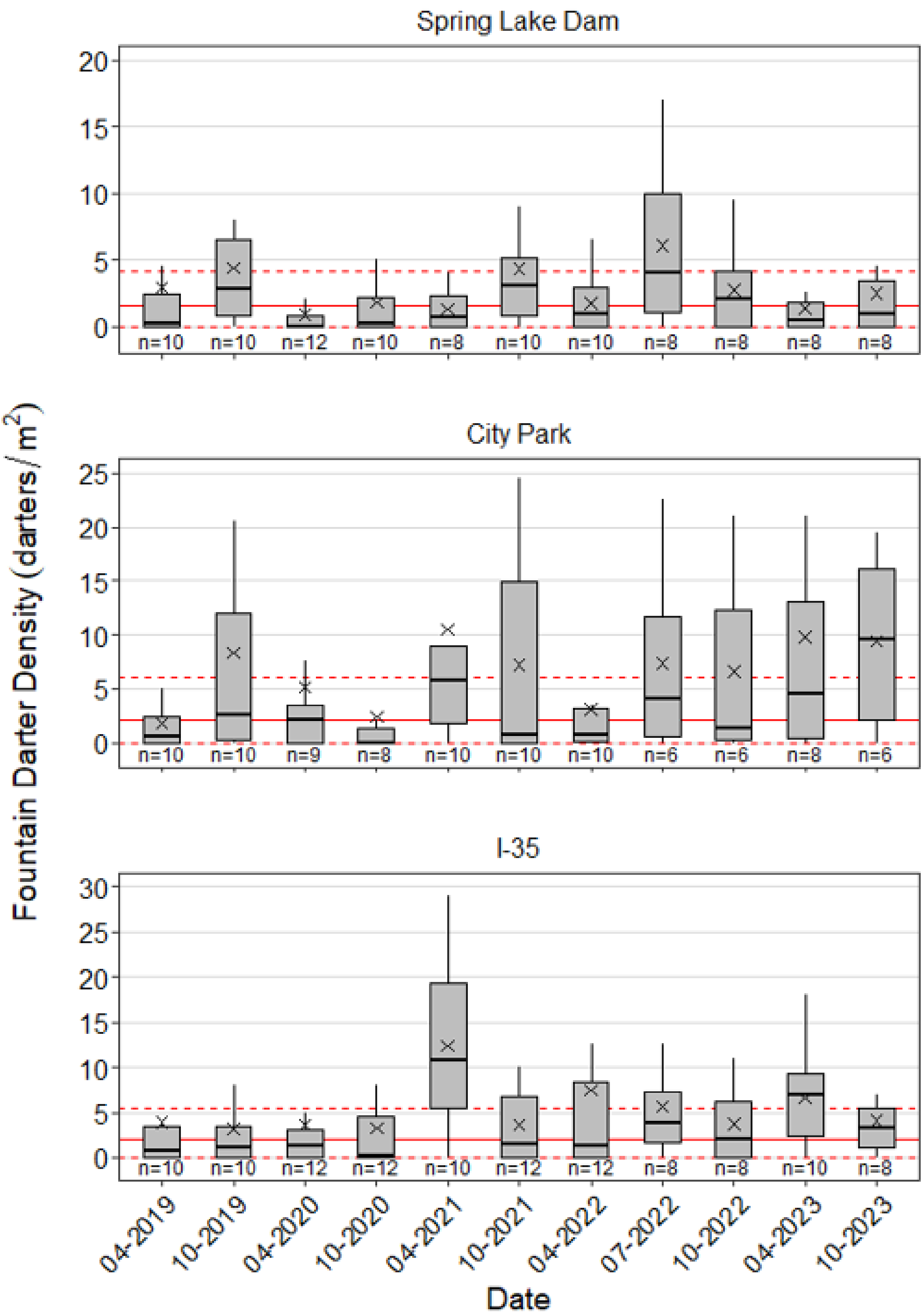


**Figure 13.** **Boxplots displaying temporal trends in Fountain Darter density (darters/m$^2$) among study reaches from 2019–2023 during drop-net sampling in the San Marcos River. The thick horizontal line in each box is the median, x represents the mean, and the upper/lower bounds of each box represents the interquartile range. Whiskers represent minimum/maximum values up to 1.5 times the interquartile range. The "n" values along the x-axes represent the number of drop-net samples in each category. Solid and dashed red lines denote long-term (2001–2023) medians and interquartile ranges, respectively.**

## ***Size structure and recruitment trends***

Five-year trends in Fountain Darter size structure and recruitment displayed consistent patterns among seasons, though event-specific discrepancies were observed within spring and fall events. In general, smaller darters were more frequently observed in spring during the peak reproductive period, as seen by lower median lengths (19–21 mm). Violin plots with distributions that are left-skewed and greater levels of recruitment in spring further support this trend. Patterns in size structure aligned with long-term trends in spring 2023. In recent years, recruitment has been high in spring, being above the 95% confidence interval of historic data in 2019 (61.1%), 2021 (59.5%), and 2022 (57.3%); and similar to the long-term mean in 2020 and 2023 (46.5%). Summer median lengths (25–28 mm) were high with distributions more frequently left-skewed towards larger darters. As such, summer recruitment rates (14.9–26.0%) were lower relative to spring but approximated long-term expectations the past five years. In fall, median lengths (24–29 mm) and recruitment (16.0–39.2%) were mostly comparable to summer. That said, fall recruitment rates in 2019 (31.3%) and 2022 (29.2%) were much higher than expected (Figure 14).

Results do not provide evidence that the continuation of low flows altered size structure or suppressed recruitment of darters. Size structure consistent with previous years suggests Fountain Darter growth was not attenuated in 2023, which conflicts with studies on other riverine darter species and may be influenced by stable water temperatures in this spring-dominated system (Marsh-Matthews and Matthews 2010, Katz and Freeman 2015). Fountain Darter recruitment rates were substantially higher than expected in 2022 and fell back to normal levels in 2023, yet densities increased overall during this time period. This suggests that survival was likely high in 2023. However, survival was not specifically analyzed, and it should be noted that low-flow restrictions on sampling in Texas Wild-rice prevented sampling this taxon in 2023 and this may have influenced overall median densities.

Relative effects of density-independent versus density-dependent factors on population dynamics are currently unknown for Fountain Darters and would help provide a more complete understanding of demographic processes through time (Bellier et al. 2016, Grossman et al. 2017). Regardless, recent trends in recruitment coupled with results from occurrence and abundance indices clearly demonstrate maintaining suitable habitat is important for population persistence (Duncan et al. 2016, Dunn and Angermeier 2019).

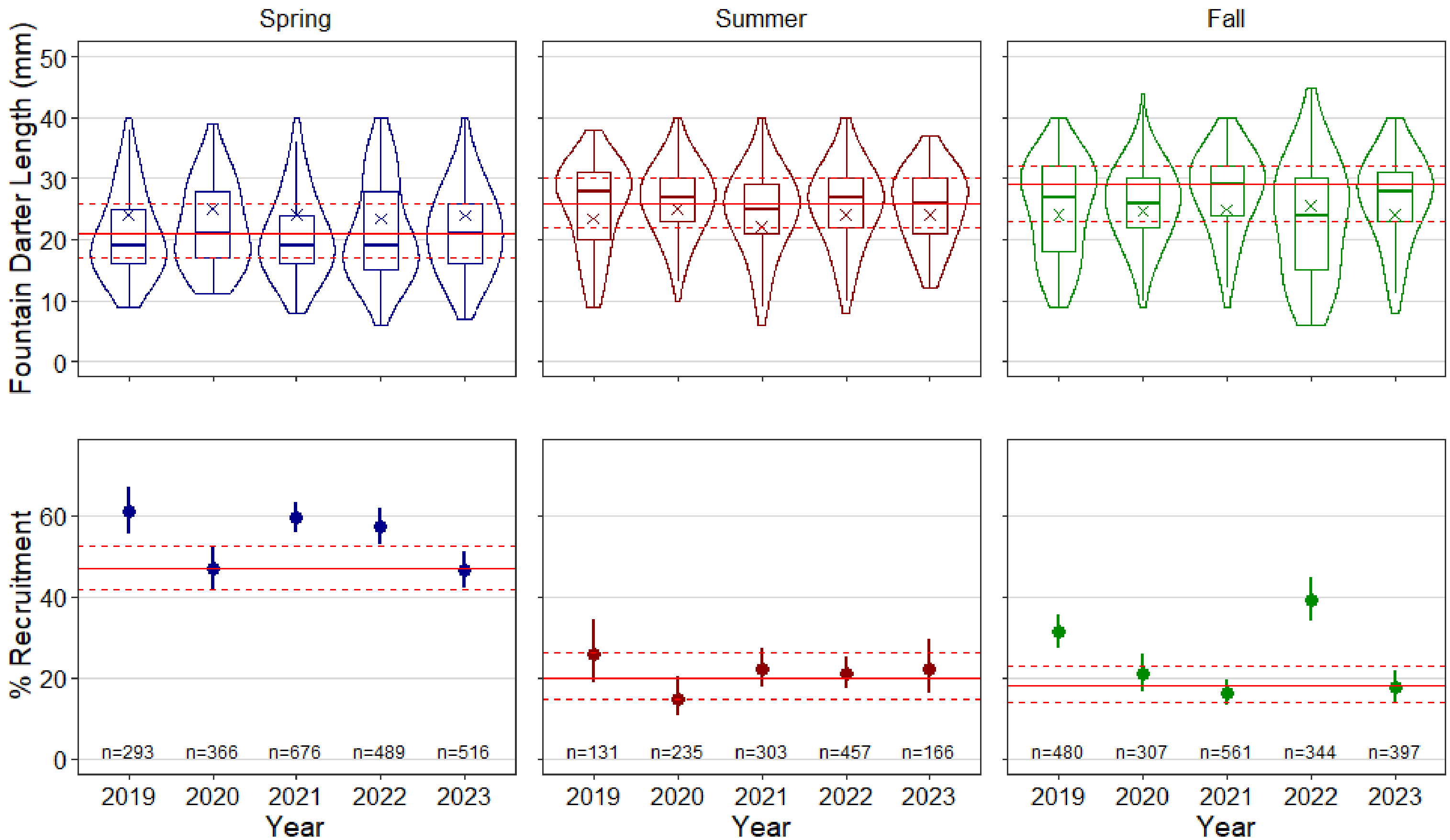


**Figure 14.** **Seasonal trends of Fountain Darter size structure (mm; top row) and percent recruitment (bottom row) in the San Marcos River from 2019–2023. Spring and fall trends are based on drop-net and timed dip-net data in aggregate, whereas summer trends are based on timed dip-net data only. Size structure is displayed with boxplots (median, quartiles, range) and violin plots (probability density; polygons outlining boxplots). The thick horizontal line in each box is the median, x represents the mean, and the upper/lower bounds of each box represents the interquartile range. Whiskers represent minimum/maximum values up to 1.5 times the interquartile range. The "n" values along the x-axis of the top row represent the number of Fountain Darter length measurements in each distribution. Recruitment is the percent relative abundance (± 95% CI) of darters ≤20 mm. Long-term (2001–2023) trends in size structure are represented by median (solid red line) and interquartile range (dashed red lines). Recruitment is compared to the long-term mean percentage (solid red line) and 95% CI (dashed red lines).**

## *Habitat Use and Suitability*

### ***Density trends among vegetation taxa***

Median densities in 2023 were highest in *Cabomba* (15.50 darters/$m^2$) and bryophyte (13.25 darters/$m^2$). Taxa with intermediate median estimates included *Hygrophila* (7.50 darters/$m^2$), and *Ludwigia* (5.25 darters/$m^2$). Fountain Darter densities within *Cabomba*, *Hygrophila*, and *Ludwigia* were substantially higher this year compared to historical data. Patches of bryophyte typically do not persist in the San Marcos River, though establishment of multiple patches in fall 2023 (i.e., City Park) allowed this taxon to be sampled for the first time and high Fountain Darter densities observed closely resembled bryophyte densities in the Comal system (16.50 darters/$m^2$). Median densities were low for the remaining taxa, which included *Sagittaria* (2.50 darters/$m^2$), *Hydrocotyle* (1.75 darters/$m^2$), *Potamogeton* (1.25 darters/$m^2$), and open habitats (0.00 darters/$m^2$). Densities in *Potamogeton* and open habitat aligned with historical expectations, whereas, densities in *Sagittaria* were higher than expected. Median density in *Hydrocotyle* was slightly lower than historical trends, though its upper quartile estimate was much lower (Figure 15).

Current patterns of vegetation use continue to generally support previous research, showing higher Fountain Darter densities occur within ornate vegetation that provides complex structure near the benthos (Schenck and Whiteside 1976; Linam et al. 1993; Alexander and Phillips 2012; Edwards and Bonner 2022). Substantial deviations in taxa-specific densities from historical data for several taxa are possibly due to several factors associated with reduced flows. Higher densities than expected in *Hygrophila*, *Ludwigia*, *Cabomba*, and *Sagittaria* are likely related to increased prevalence of bryophytes within these taxa which creates greater structural complexity (Alexander and Phillips 2012, Edwards and Bonner 2022). Lower current velocities due to persistent low flows have allowed bryophytes to proliferate in riverine areas where they are typically limited under average San Marcos river discharge conditions.

### ***Size structure among vegetation taxa***

Boxplot summary statistics and violin plots showed that Fountain Darter size structure varied among vegetation taxa sampled in 2023. Open was omitted from analysis due to zero counts in this habitat. The lowest median lengths occurred in *Potamogeton* (17 mm) and bryophyte (21 mm), were intermediate in *Hygrophila* (24 mm) and *Cabomba* (24 mm), and highest in *Ludwigia* (27 mm), *Sagittaria* (31 mm), and *Hydrocotyle* (32 mm). Size structure distributions were left-skewed for *Potamogeton*, which differed from previous years' data as this taxon usually harbors larger individuals. This distribution could be influenced by the fact that there were more *Potamogeton* samples in the spring, when recruitment is higher, than in the fall. Bryophyte displayed the strongest left-skewness and was an important habitat for recent recruits in fall 2023. Distributional shape in *Cabomba* was more uniform and aligns with 2022 observations. In contrast, *Ludwigia* displayed an inverse distribution compared to 2022 and yielded a greater proportion of larger adults in 2023. Year-to-year variation in size structure among vegetation taxa such as *Ludwigia*, which can occur in a variety of hydraulic habitats, is potentially related to the depth and velocity conditions present within random drop-net stations. The remaining taxa aligned with observations the past several years (Figure 16; BIO-WEST 2022 and 2023).

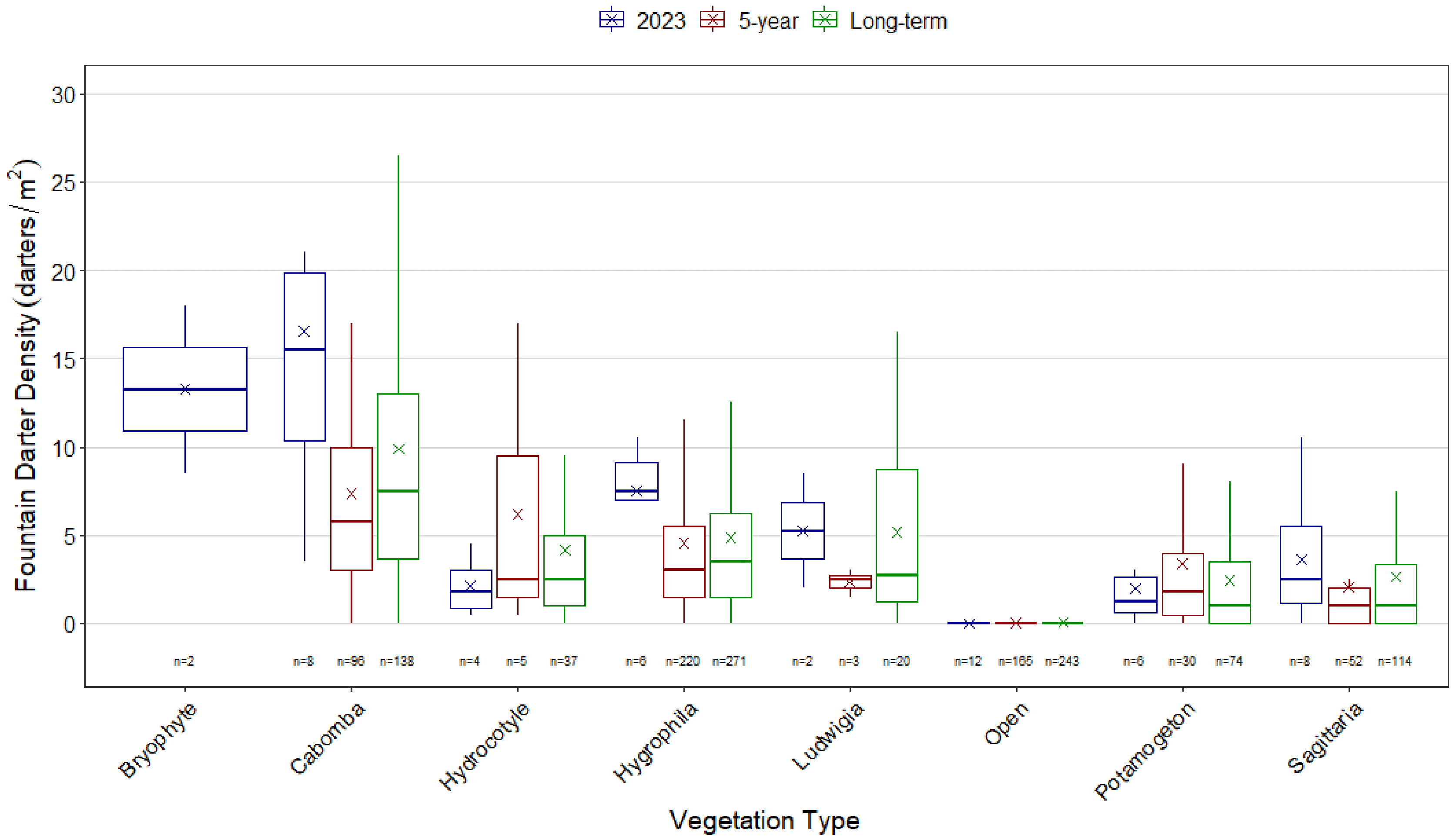


**Figure 15.** **Boxplots displaying 2022, 5-year (2019–2023), and long-term (2001–2023) drop-net Fountain Darter density (darters/m²) among vegetation types in the San Marcos River. The thick horizontal line in each box is the median, x represents the mean, and the upper/lower bounds of each box represents the interquartile range. Whiskers represent minimum/maximum values up to 1.5 times the interquartile range. The "n" values along the x-axes represent drop-net sample sizes per group.**

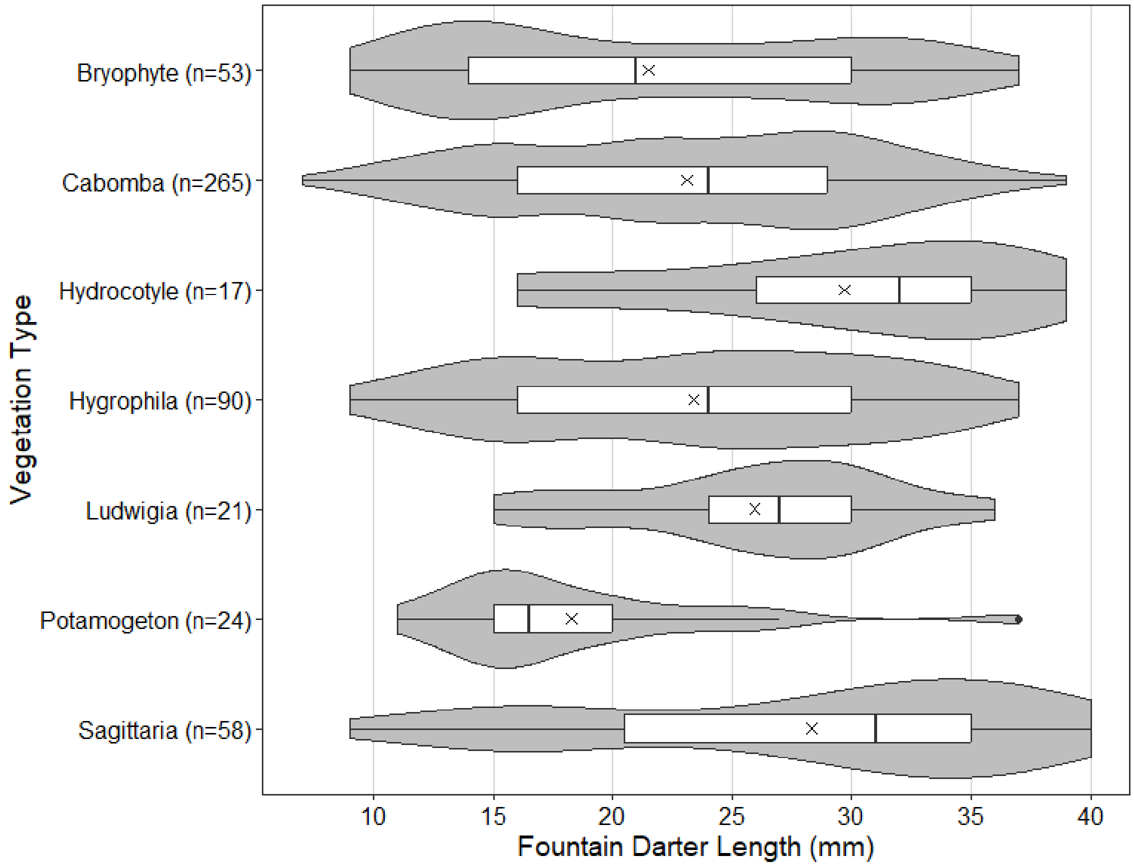


**Figure 16.** **Boxplots and violin plots (grey polygons) displaying Fountain Darter lengths among dominant vegetation types during 2023 drop-net sampling in the San Marcos River. The thick horizontal line in each box is the median, x represents the mean, and the upper/lower bounds of each box represents the interquartile range. Whiskers represent minimum/maximum values up to 1.5 times the interquartile range, and outliers beyond this are designated with solid black circles. The "n" values represent the number of Fountain Darter length measurements per vegetation type.**

### ***Habitat suitability***

Fountain Darter Overall Habitat Suitability Index (OHSI) values at Spring Lake Dam were above the long-term mean from 2019 to spring 2022 (0.12–0.16), whereas habitat suitability fluctuated around the long-term mean from summer 2022 to fall 2023 (0.10–0.15). City Park habitat suitability has remained below the long-term expectations since 2019 and decreased to the lowest level observed over the past five years in 2023. Trends in habitat suitability at I-35 were above the long-term mean from 2019 to spring 2022 (0.12–0.15) and fell below it from summer 2022 to fall 2023 (0.09–0.12) (Figure 17). Decreased OHSI in 2023 was mainly driven by decreases in Texas Wild-rice coverage, which despite having low suitability criteria, is strongly associated with changes in OHSI due to its dominance within study reaches. Although increases in intermixed bryophytes resulted in increased Fountain Darter densities in 2023, this is not captured by the OHSI which assigns long-term taxa-specific density based on dominant vegetation. So, a patch of *Sagittaria* with intermixed bryophytes (and thus high Fountain Darter density) would be assigned the long-term *Sagittaria* density for OHSI calculations. As a result, the current OHSI model does not accurately reflect the increased habitat complexity observed in City Park and I-35 during 2023. Microhabitat conditions (e.g., % bryophyte within, hydraulics) unaccounted for in this analysis also appear to influence habitat conditions and incorporating additional covariates to future HSC models could provide better realizations of overall suitability.

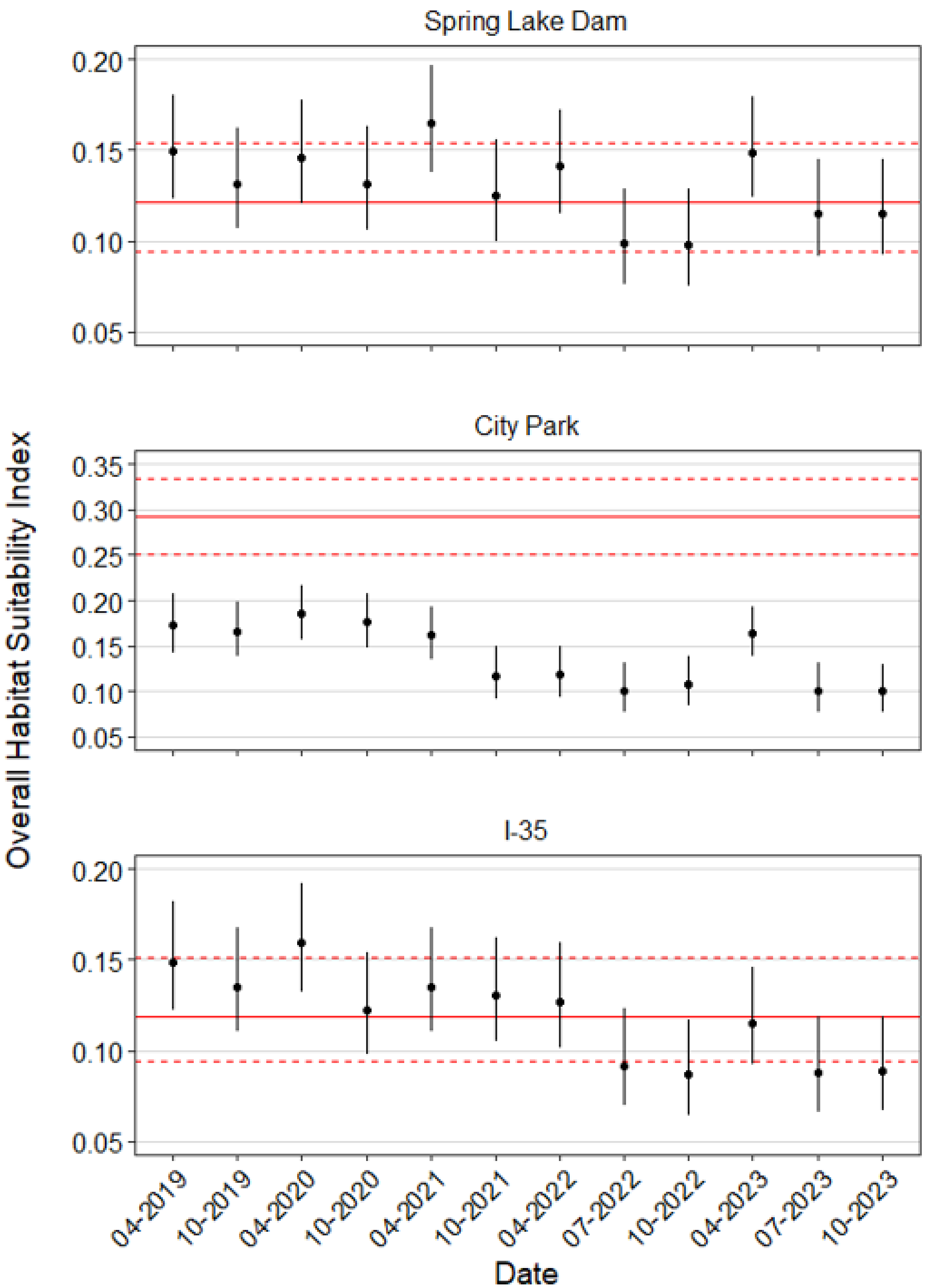


**Figure 17.** **Overall Habitat Suitability Index (OHSI) (±95% CI) from 2019–2023 among study reaches in the San Marcos River. Solid and dashed red lines denote means of long-term (2003–2023) OHSI and 95% CI, respectively.**

Drop-net results demonstrate darters are consistently spatially clustered within smaller patches of more suitable habitat. However, less suitable taxa may still provide important habitat to help fulfill life history requirements, such as dispersal corridors that facilitate connectivity among suitable taxa (Fagan 2002). This in total suggests management strategies should still consider expanding coverages of suitable taxa, in addition to maintaining diverse vegetation assemblages to enhance resistance and resilience potential during and after environmental perturbations (Duncan et al. 2016, Dunn and Angermeier 2018).

## Fish Community

A total of 7,680 fishes represented by 10 families and 30 unique species were observed in the San Marcos Springs system during 2023 sampling. The fish community assemblage showed somewhat discrete spatial patterns shifts in structure (percent relative abundance), particularly between the lower river and upstream segments. At the three most upstream segments, assemblages were dominated by Mexican Tetra (*Astyanax argentatus*; 34.6%), Guadalupe Roundnose Minnow (*Dionda nigrotaeniata*; 15.9–24.6%) or Largespring Gambusia (*Gambusia geiseri*; 53.8%), whereas the Lower River was dominated by Mimic Shiner (*Paranotropis volucellus*; 32.4%) and Texas Shiner (*Notropis amabilis*; 12.1%). Fountain Darter ranked 9th in abundance at Spring Lake (1.6%) and Lower River (2.6%), 4$^{th}$ at Upper River (7.5%), and 5$^{th}$ at Middle River (5.9%) (Appendix E, Table E2).

Trends in species richness and diversity varied between and within study segments. In general, species richness and diversity was highest at Lower River. Species richness was also high at Upper River, though diversity was lower and more similar to that of Spring Lake. Middle River displayed species richness levels similar to Spring Lake while diversity quantities were more intermediate. Five-year trends in species richness and diversity displayed slight increases at Lower River. At the Middle River, diversity until spring 2023 when it sharply declined. Community-based metrics at Spring Lake were lower than other segments and were generally more stable over time (Figure 18).

Trends in spring fishes' species richness and relative density were incongruent with community-level observations. Spring fishes' richness was high and stable at the Upper River and Middle River. Total number of spring fish species was also stable at Spring Lake, though richness did not exceed four species. Spring fishes' richness at Lower River was more variable than upstream river segments. Relative density of spring fishes was high and stable in the upstream reaches of Spring Lake and Upper River. At the Middle River, relative density was also high but more variable than upstream segments. Spring fishes' relative density decreased at Lower River but accounted for 60-80% of the assemblage in fall 2021 and summer 2022 (Figure 19). Decreases in the total species and relative density of spring fishes with increasing distance from springflow influence is well documented (Hubbs 1995; Kollaus and Bonner 2012; Craig et al. 2016).

Temporal trends in Fountain Darter density from 2019–2023 were based on microhabitat sampling data. In 2023, median density was below the long-term median at Spring Lake during spring and fall, which is supported by observations of degraded habitat conditions noted during this timeframe. Variation in density (i.e., interquartile range) has decreased since spring 2022, where the upper quartile was substantially higher. At the Middle River, median density was above the long-term with greater variability in the spring and then dropped to zero in the fall. Reductions in median density documented during fall 2023 may be influenced by a flow pulse that passed immediately before fall fish community sampling and increased river discharge from 85 cfs to over 400 cfs. Lastly, median Fountain Darter density in 2023 at Upper River and Lower River continued to show typical historical patterns with densities at or close to zero (Figure 20).

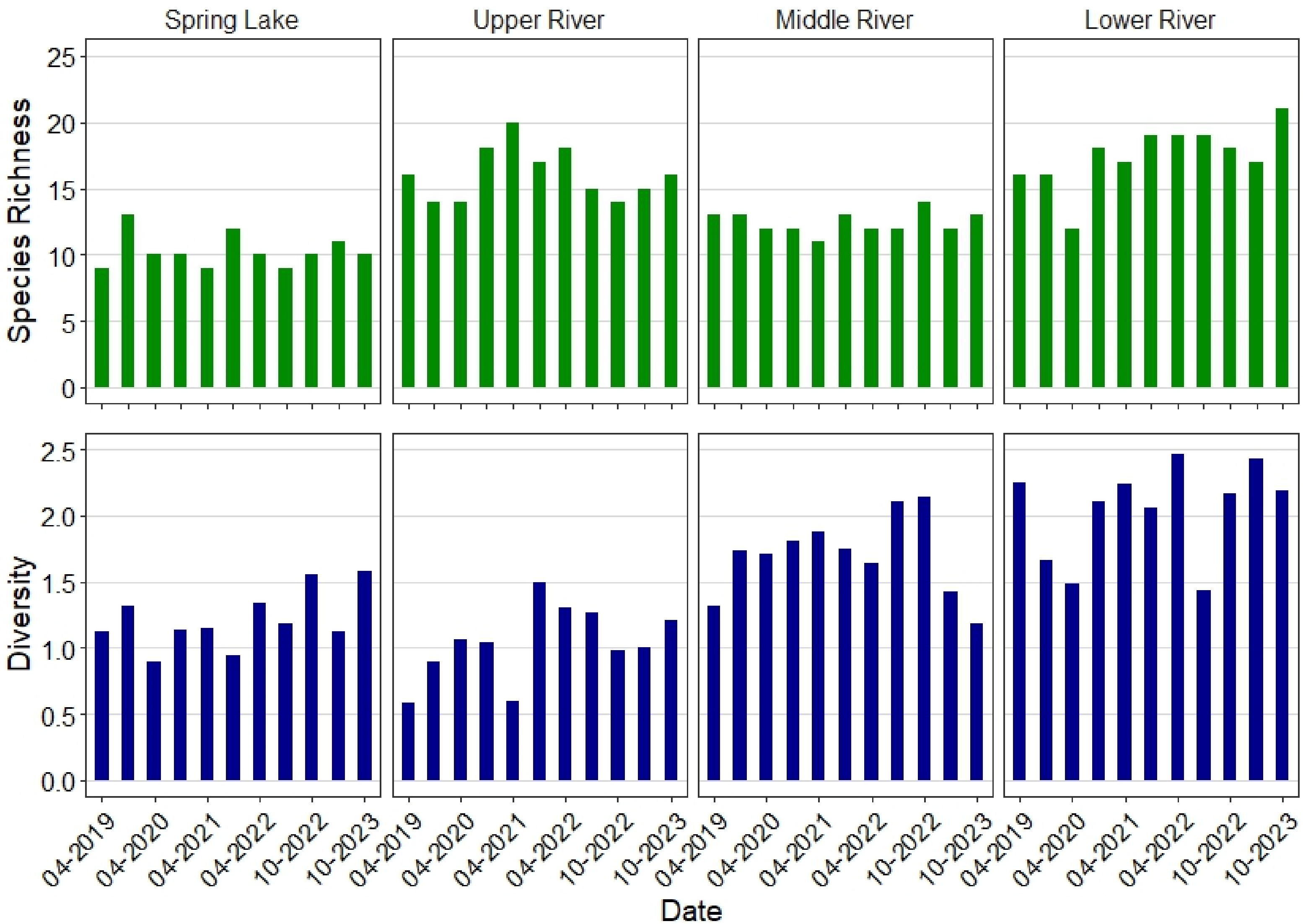


**Figure 18.** **Bar graphs displaying species richness (top row) and diversity (bottom row) from 2019–2023 based on all three fish community sampling methods in the San Marcos Springs/River.**

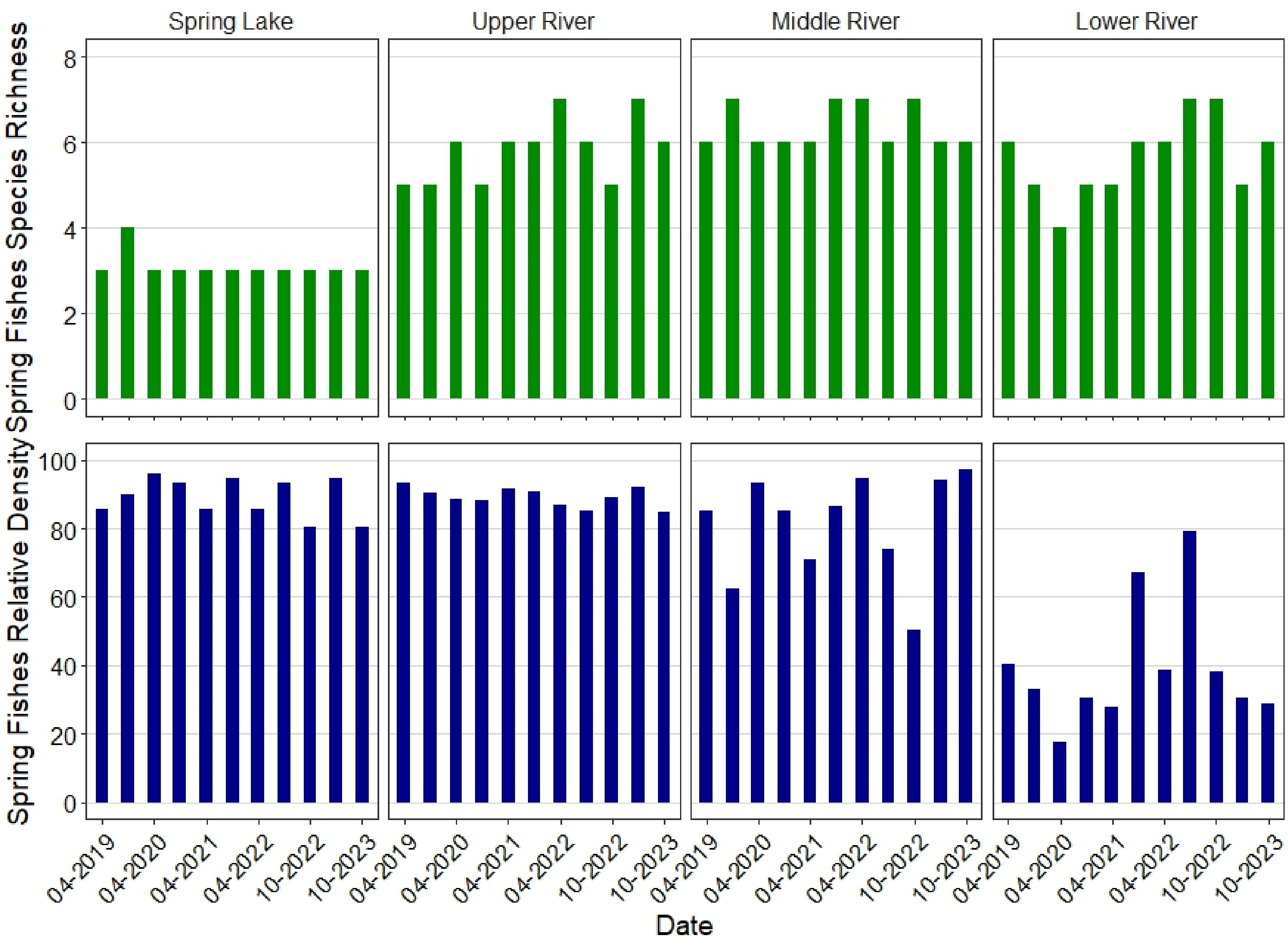


**Figure 19.** **Bar graphs displaying spring fish richness (top row) and relative density (RD; %) (bottom row) from 2019–2023 based on all three fish community sampling methods in the upper San Marcos Springs/River.**

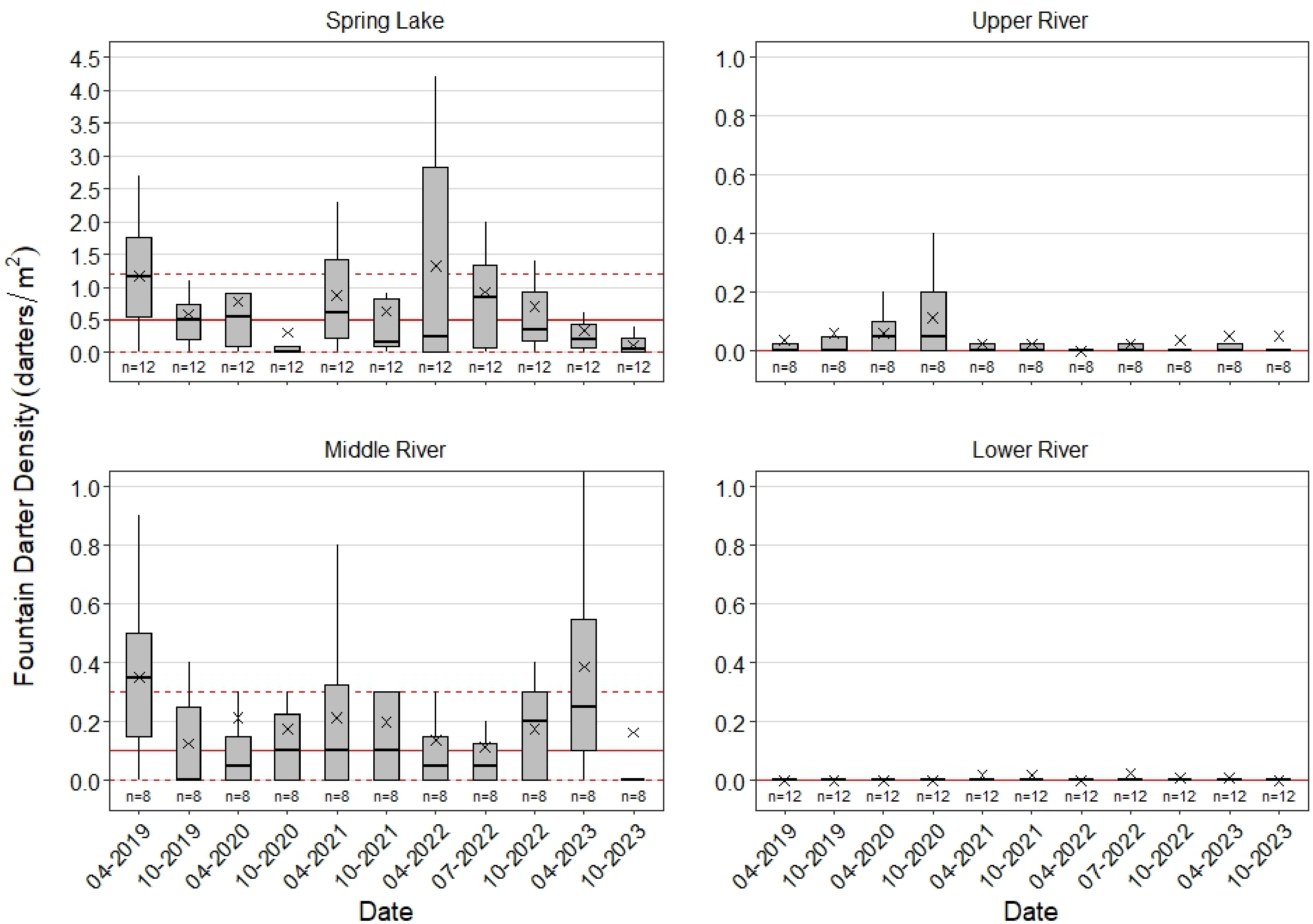


**Figure 20.** **Boxplots displaying temporal trends in Fountain Darter density (darters/m²) among study reaches from 2019–2023 during fish community microhabitat sampling in the San Marcos Springs/River. The thick horizontal line in each box is the median, x represents the mean, and the upper/lower bounds of each box represents the interquartile range. Whiskers represent minimum/maximum values up to 1.5 times the interquartile range. The "n" values along the x-axes represent the number of microhabitat samples per category. Solid and dashed red lines denote long-term (2014–2023) medians and interquartile ranges, respectively.**

## San Marcos Salamander

In 2023, a total of 915 San Marcos salamanders were observed in spring (217 salamanders), three separate low-flow sampling events in the summer / early fall (555 salamanders), and fall (143 salamanders) and densities ranged from 1.51–30.86 salamanders/m$^2$ (Figure 21). At the Hotel Site, salamander densities in 2023 were lower than the long-term average for the spring, species-specific low-flow events, and fall. Fall 2023 density observations at Hotel Site fell outside the confidence interval boundary, suggesting a meaningful difference. San Marcos salamander densities at Riverbed were higher than long-term averages in the spring and low-flow events but were lower in the fall. In spring and fall 2023 densities fell outside the confidence interval boundary. Similar to the Hotel Site, densities at Spring Lake Dam in 2023 were lower than the long-term average for all events, with densities falling outside the confidence intervals in the fall and low-flow events (Figure 21).

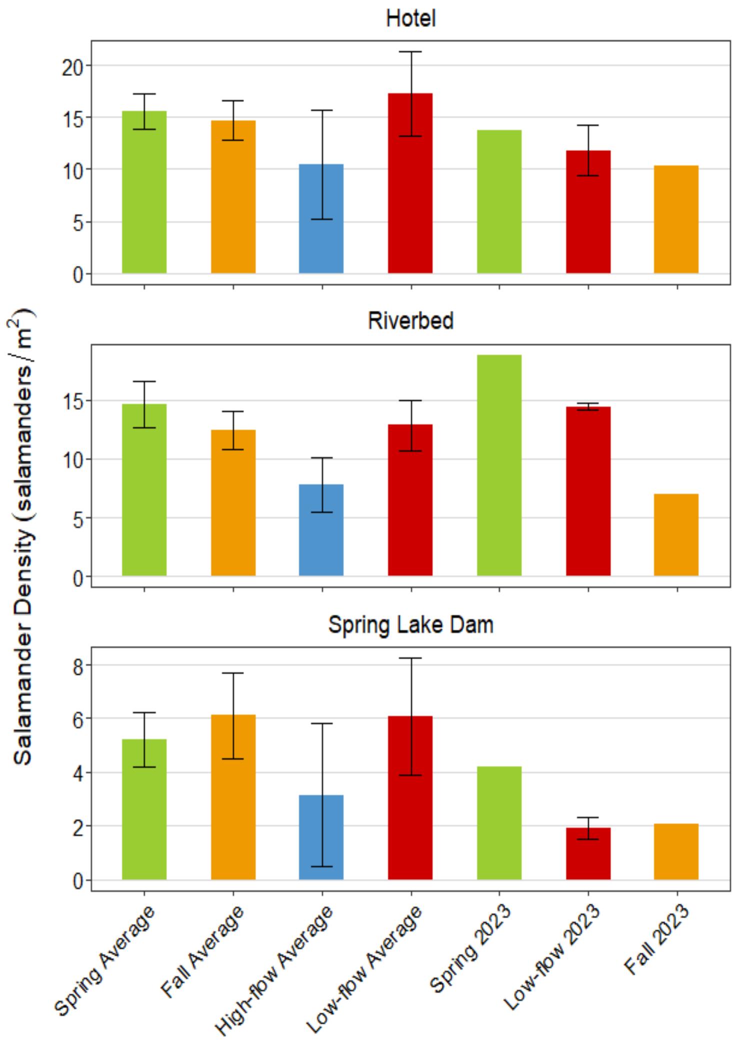


**Figure 21.** **San Marcos Salamander density (salamanders/m$^2$) among sites in 2023, with the long-term (2001–2023) average for each sampling event. Error bars for long-term averages represent 95% confidence intervals.**

Five-year trends at the Hotel Site did not display any distinct patterns in density from 2019 to spring 2022 but a noticeable increase occurred during the last two events in 2022. After this increase, densities in 2023 decreased again and generally remained lower than the previous five years. At the Riverbed Site, density was variable, but the fall 2023 event had the lowest densities observed over the past five years. Density at Spring Lake Dam demonstrated a cyclical but decreasing pattern over the past five years (Figure 22). Subsequent monitoring will help provide insights on how salamander densities change following this low-flow year.

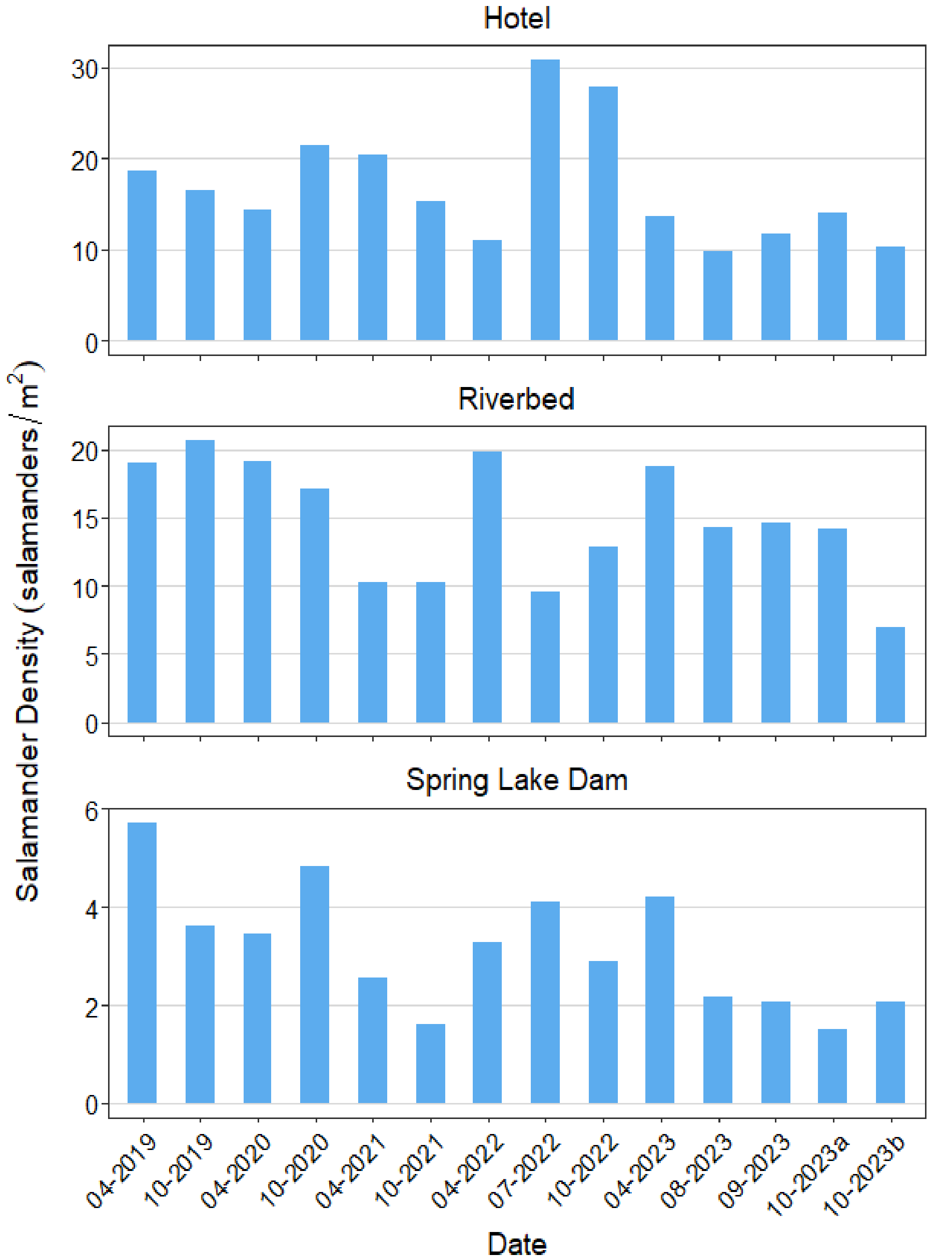


**Figure 22.** **San Marcos Salamander density (salamanders/m$^2$) among sites from 2019–2023 in the San Marcos Springs/River.**

## Macroinvertebrates

### *Benthic Macroinvertebrate Rapid Bioassessment*

Benthic macroinvertebrate rapid bioassessment data was collected during both the spring and fall sampling events in 2023 (raw data presented in Appendix F). At Spring Lake, habitats sampled this year included emergent vegetation, root wads, and sand. Similar habitats were sampled at City Park, with the addition of debris jams. Cobble/gravel habitats were sampled at Spring Lake Dam and I-35 in addition to what was sampled at City Park. No supplemental snag samples were taken. A total of 641 and 648 individual macroinvertebrates, representing 33 and 34 unique taxa were sampled in spring and fall, respectively. Metric scoring criteria for calculating the B-IBI can be found in Table 7. The Cumulative scores and corresponding aquatic-life-use designations are displayed in Figure 23. Altogether, 43 unique taxa were represented among all samples from 2023. Overall scores and aquatic-life-use designations in 2023 generally aligned with four years prior and indicates stable trends. Spring Lake was described as “Intermediate” for both seasons, while Spring Lake Dam and I-35 were described as “High” during both seasons. Aquatic-life-use at City Park was “High” during spring and “Intermediate” during fall (Figure 23).

**Table 7. Metric value scoring ranges for calculating the Texas RBP B-IBI (TCEQ 2014).**

| METRIC | SCORING CRITERIA | | | |
|---|---|---|---|---|
| | 4 | 3 | 2 | 1 |
| Taxa richness | >21 | 15–21 | 8–14 | <8 |
| EPT taxa abundance | >9 | 7–9 | 4–6 | <4 |
| Biotic index (HBI) | <3.77 | 3.77–4.52 | 4.56–5.27 | >5.27 |
| % Chironomidae | 0.79–4.10 | 4.11–9.48 | 9.49–16.19 | <0.79 or >16.19 |
| % Dominant taxon | <22.15 | 22.15–31.01 | 31.02–39.88 | >39.88 |
| % Dominant FFG | <36.50 | 36.50–45.30 | 45.31–54.12 | >54.12 |
| % Predators | 4.73–15.20 | 15.21–25.67 | 25.68–36.14 | <4.73 or >36.14 |
| Ratio of intolerant: tolerant taxa | >4.79 | 3.21–4.79 | 1.63–3.20 | <1.63 |
| % of total Trichoptera as Hydropsychidae | <25.50 | 25.51–50.50 | 50.51–75.50 | >75.50 or no Trichoptera |
| # of non–insect taxa | >5 | 4–5 | 2–3 | <2 |
| % Collector–gatherers | 8.00–19.23 | 19.24–30.46 | 30.47–41.68 | <8.00 or >41.68 |
| % of total number as Elmidae | 0.88–10.04 | 10.05–20.08 | 20.09–30.12 | <0.88 or >30.12 |

Spring Lake and City Park scored lower than the other sites, likely due to differences in available habitats. Lower scores were expected at Spring Lake as these lentic communities are naturally different compared to swift flowing “least-disturbed reference streams”. It is interesting that Aquatic-life-use at City Park in spring was described as “High”, which only occurred one other time (i.e., 2020) during the past five years. At City Park, lower scores in fall compared to Spring Lake Dam and I-35 were also not surprising. Lotic habitats at City Park consists of runs, while the other riverine sites of Spring Lake Dam and I-35 display riffles with cobble and gravel substrates more similar to reference streams. As such, higher scores at Spring Lake Dam and I-35 are best explained by greater prevalence of fluvial specialists, resulting in greater taxa diversity overall. It should also be noted that most reference streams do not exhibit the stenothermal conditions present within the upper San Marcos River and this may result in differing community composition. Based on this, the level of score is less important in the spring-fed San Marcos River sample reaches than the consistency or trends in results per reach over time. Additional monitoring will yield a robust reference dataset and allow for the development of scoring criteria specific to this unique ecosystem, providing a more accurate realization of ecological health through time.

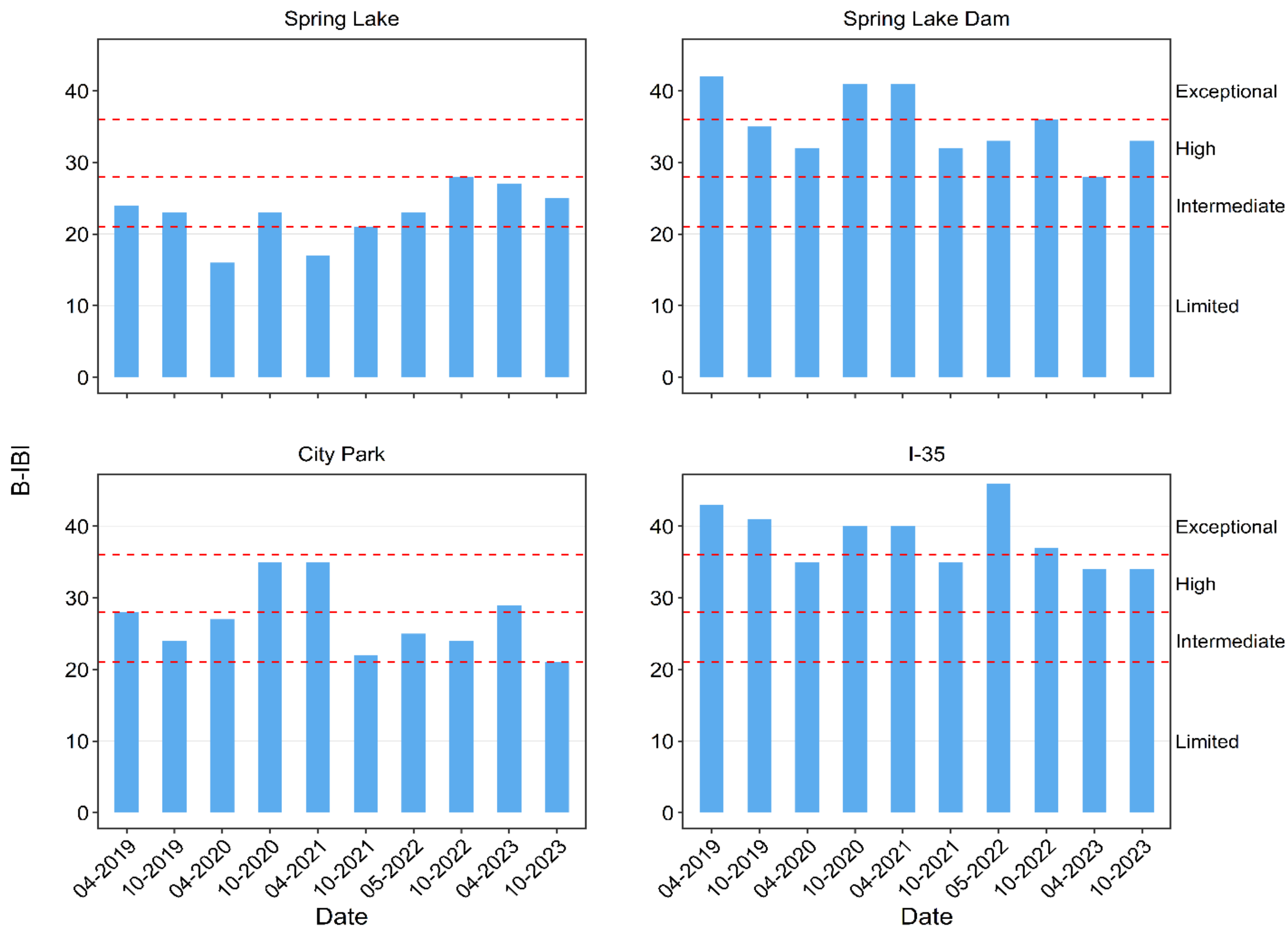


**Figure 23.** **Benthic macroinvertebrate Index of Biotic Integrity (B-IBI) scores and aquatic-life-use point-score ranges from 2019–2023 in the San Marcos Springs/River.**

# CONCLUSION

Results from the 2023 biological monitoring in the San Marcos Springs/River system indicated overall declining trends in discharge and variable trends in Covered Species population metrics. Based on monthly analysis of daily mean discharge, the system was near or below 10$^{th}$ percentile flow conditions for the duration of the year, resulting in the lowest flow conditions observed in 23 years of biological monitoring. Low variation in water temperature continued to occur at more stable reaches closer to springs (i.e., Spring Lake), whereas higher variation occurred at less stable reaches farther from springs (i.e., Wastewater Treatment Plant). Although exceedance frequency and duration of Fountain Darter larval and egg production thresholds increased throughout the summer, habitat conditions appear to have had a more direct impact on Fountain Darter populations.

Habitat evaluations during low-flow events in the summer demonstrated slightly degraded habitat conditions for the Covered Species. Low water levels at Spring Lake and Spring Lake Dam increased siltation and algae build up, influencing habitat conditions for both San Marcos Salamanders and Fountain Darters. Habitat condition in downstream riverine reaches also declined slightly as wetted width of the river channel was reduced and aquatic vegetation coverage decreased. This led to reductions in Texas Wild-rice coverage and habitat availability for Fountain Darters. No temporal trends in fish community diversity/richness or macroinvertebrate bioassessment scores were apparent, suggesting that sustained flows in 2023 did not degrade the ecological health of the San Marcos system.

Total aquatic vegetation coverage declined from spring to fall across all study reaches with ubiquitous declines mainly attributed to decreased coverage of Texas Wild-rice due to low flows and recreation. Although Texas Wild-rice dominated assemblage structure throughout the upper reaches of the system, the species declined to its lowest coverage observed since 2016 and was the Covered Species most impacted by reduced flows. Reduced river discharge led to some Texas Wild-rice becoming dewatered and stranded on islands or along bank habitats. Unlike previous low-flow years, stranded Texas Wild-rice eventually perished and gave way to terrestrial vegetation. Vegetation varied at City Park as bryophytes increased in abundance for the first time observed in the biological monitoring program. Fountain Darter density and occurrence were higher at City Park due to enhanced suitable habitat provided by bryophytes intermixed with other vegetation types. However, overall habitat suitability indices did not pick up on this observed habitat improvement, since they are based on dominant vegetation type. Reductions in wetted habitat altered the river channel and the vegetation assemblage mainly within the I-35 reach. Amphibious species (e.g., *Hygrophila* and *Sagittaria*) that could survive as emergent outcompeted other taxa. Trends in San Marcos Salamander densities were variable among sites in 2023 and over the past five years. However, all sites showed relatively low densities in fall 2023, and low-flow impacts (e.g., siltation) to salamander habitats were observed in Spring Lake.

Overall, 2023 biological monitoring captured the response of the San Marcos Springs/River aquatic community to the lowest flow conditions observed since 1956. Results indicated that the San Marcos Springs/River was resilient to the sustained low-flow conditions in 2023. Texas Wild-rice coverage remains well above pre-HCP levels despite reduced wetted habitat and substantial declines in coverage since the beginning of the year. Vegetation coverage varied throughout the system, yet low flows allowed bryophytes to establish throughout rooted vegetation and along the benthos. This increased benthic habitat complexity provided by bryophytes positively impacted Fountain Darter populations as observed in the higher densities over the past two years. Fountain Darter catch rates and percent occurrence were comparable to previous years. No obvious trends in salamanders, fish assemblage composition, spring fishes, or macroinvertebrates were noted. Despite declines in Covered Species habitats from low flows, populations persist and are expected to rebound when typical flows return. Subsequent monitoring efforts will provide opportunities to better understand the dynamics of this complex ecological system and how it responds to future hydrologic conditions.

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# Appendix G4 | **Permit Renewal Work Plan**

| EAHCP Work Plan Versioning Table | | |
|---|---|---|
| Version # | Date | Summary of Changes |
| 1.0 | 07/19/2022 | First draft |
| 2.0 | 1/24/2023 | Updated Figure 2-1 (org chart) and Figure 4-1 (project schedule). Revisions to address EAHCP staff comments. |
| 3.0 | 4/26/2023 | Updated Figure 2-1 and removed Subtask 5.4, Foreseeable Future and Climate Vulnerability Assessment. Analyses regarding the foreseeable future (e.g., future groundwater pumping projections) and climate conditions (e.g., temperature, precipitation) will be conducted as part of Task 6, Modeling Projections. |
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# WORK PLAN

# PERMIT RENEWAL FOR THE EDWARDS AQUIFER HABITAT CONSERVATION PLAN

**PREPARED FOR:**

Edwards Aquifer Authority

**PREPARED BY:**

ICF

**April 2023**

# Contents

# Tables and Figures

# Chapter 1
# Introduction

## 1.1 Program Overview

In 1996, the Texas Legislature passed the Edwards Aquifer Authority Act, which created the Edwards Aquifer Authority (EAA) to regulate pumping from the aquifer and pursue a program “to ensure that the continuous minimum springflows of the Comal Springs and the San Marcos Springs are maintained to protect endangered and threatened species to the extent required by federal law” (EAA Act § 1.14). The Texas Legislature amended the EAA Act in 2007 to form the Edwards Aquifer Recovery Implementation Program (EARIP) and directed the EARIP to work with the U.S. Fish and Wildlife Service (USFWS) to prepare the *Edwards Aquifer Recovery Implementation Program Habitat Conservation Plan* (EAHCP or Plan). The EARIP process, including years of negotiations among the eventual Permittees and with many stakeholders, led to the completion of the EAHCP in 2013.

The EAHCP has been highly effective in conserving the Covered Species and the ecosystems on which they depend. Activities covered include groundwater pumping from the Edwards Aquifer, surface water management, aquatic and riparian habitat management, and recreational use in the aboveground springs fed by the aquifer in the Cities of New Braunfels and San Marcos. Its implementation has greatly expanded what is understood about the life histories of many of its Covered Species. The EAHCP’s committees—formed during the EARIP process—have also demonstrated the ability to use the Plan’s adaptive management process to make necessary and important changes to Conservation Measures to improve their overall feasibility and effectiveness.

The EAHCP has a relatively short permit term (15 years), expiring on March 31, 2028. The Permittees are now looking ahead to the end of the permit term and are proceeding with an Incidental Take Permit (ITP) renewal process to continue the program beyond 2028. The primary goal of this renewal process is extending the duration of ITP, but in the process the Permittees will also look to improve the EAHCP to set the stage for its long-term success.

**There are three comprehensive goals for the permit renewal of the EAHCP.** These goals pertain to the renewal process, renewed permit, and implementation and are as follows:

1. Renewal Process: To have an efficient and transparent permit renewal process that considers stakeholder input and results in an ITP renewal prior to the expiration of the current permit in 2028.
2. Renewed Permit: Renew the permit in ways that will continue to set up the plan for long-term success by reinforcing the plan’s many accomplishments and adjusting what has not worked well.
3. Implementation: Enhance the flexibility and clarity of the plan to make implementation easier, more efficient, and more cost-effective for the long term.

The EAA began identifying potential changes to the EAHCP through the Permit Options Report, which ICF completed in 2020. Potential changes identified to be considered by the Permittees included the following:

- Add Covered Species or Covered Activities.
- Restructure biological goals and objectives for listed Covered Species and add biological goals and objectives for unlisted Covered Species.
- Adjust Conservation Measures and monitoring to improve implementation and effectiveness tracking.
- Separate the EAHCP and the Funding and Management Agreement.
- Simplify processes for administrative and adaptive management changes.
- Evaluate the potential effects of climate change and extend the duration of the ITP well beyond 2028.

Many of these changes would require an amendment to the EAHCP, which will be part of the ITP renewal process. This amendment would require National Environmental Policy Act (NEPA) review by the USFWS through an environmental assessment (EA) or environmental impact statement (EIS). The program under which these efforts will be completed is termed the *Permit Renewal for the Edwards Aquifer Habitat Conservation Plan* (PREAHCP).

## 1.2 Work Plan Overview

This document will guide the work to be conducted as part of the PREAHCP. It covers the following:

- **Team Organization and Communication.** Identifies team members and roles and specifies communication protocols.
- **Tasks and Quality Control.** Describes each task to be conducted as part of the PREAHCP, including deliverables and assumptions, and summarizes ICF's process for quality control.
- **Schedule.** Outlines the phases of the PREAHCP, based on a detailed project schedule.
- **Amended EAHCP Outline.** Summarizes the organization of the Amended EAHCP.

This work plan is intended to be flexible to respond to new issues and will be modified upon agreement with EAHCP staff.

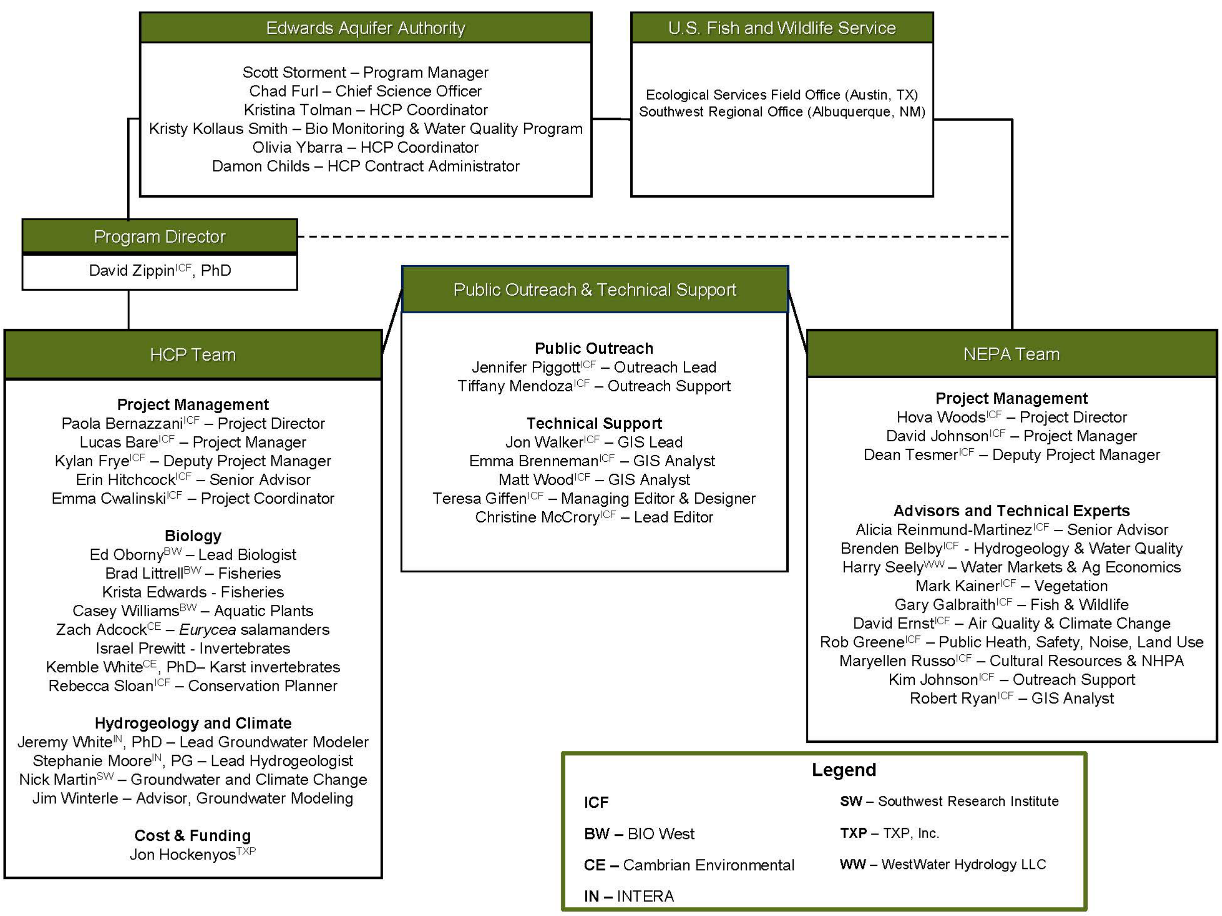
## Chapter 2
# Team Organization and Communication

Effective organization and communication will be key to the success of the PREAHCP. Shared understanding of roles and responsibilities and clear communication throughout the life of the project will be critical to completing project deliverables on schedule and within budget. The following sections describe the team's organization and communication protocols.

## 2.1 Team Organization

Figure 2-1 illustrates the PREAHCP team organization, including EAHCP staff, the HCP team, and the NEPA team. EAHCP staff will direct the work of the HCP team. The U.S. Fish and Wildlife Service (USFWS) will direct the work of the NEPA team. ICF's program director serves as the connection between the HCP team and the NEPA team for contract and management purposes.

**Figure 2-1. Organizational Chart**



# 2.2 Communication

A detailed list of all staff, roles, and contact information will be housed in the project's document library accessible to the EAHCP staff and ICF team and provided by ICF upon request.

The HCP team will communicate directly with EAHCP staff, while the NEPA team will communicate directly with USFWS and with EAHCP staff and the HCP team as authorized by USFWS. Regularly scheduled meetings will serve as a primary communication means for the PREAHCP. HCP team meetings are described below in Section 3.2, Task 2: Meetings. NEPA team meetings are described under the respective NEPA tasks in Sections 3.8, 3.10, 3.11, and 3.13.

Below is a list of communication best practices that will ensure appropriate information is being communicated to the right parties:

- **Include the ICF HCP or NEPA project manager and on all communications**. The relevant project manager should be copied on every message related to the project to facilitate progress tracking, resolution of issues, and escalation of concerns as needed.
- **Precede email subject lines with "PREACHP**." Email communication will have in the subject line "PREAHCP – [email subject]" in order to easily identify communication for this project.
- **Keep decision makers informed**. Identifying and keeping the appropriate decision-making authorities informed throughout the project duration will be critical to its success.
- **Maintain action item list**. ICF will track action items and will read them at the end of each meeting to establish and confirm common understanding of responsibilities and expectations.
- **Communicate meeting objectives**. Prior to beginning meetings, ICF and EAA should clearly state the objectives for each meeting and the end-goal, so participants have a common understanding of what needs to be achieved.
- **Coordinate in advance on deliverables**. Prior to starting work on each deliverable, ICF will coordinate with EAA regarding the outline, content, and format to ensure common understanding of the work product and establish expectations. When submitting each deliverable, ICF will provide written directions to reviewers about how they should comment (see Section 3.14, "Quality Control," for more procedures related to deliverables).
- **GIS**. EAA and ICF will agree to an approach to delivery of EAA GIS data to ICF.
- **External stakeholder engagement**. EAHCP staff will be responsible for all external written communication, including with EAHCP committees, the public, and the USFWS. The HCP team will conduct external communication only as directed by EAHCP staff.

# 2.3 SharePoint

Microsoft SharePoint will be used to store and share all project files. ICF will maintain the SharePoint site. ICF will establish separate document libraries to organize files and administer appropriate permissions to share files with various users. Master project files, including working versions of all documents, should be stored on the project SharePoint site at all times to avoid version control issues. If master documents are to be downloaded and "checked out" of SharePoint the user must notify the ICF Project Manager. The following are best practices when using SharePoint:

- Do NOT "check out" the document. This will prevent others from simultaneously editing and will create version control issues.
- Use current version of Microsoft Word when possible and always save as a .docx.
- Click on the link and enable the edit function (open in the traditional MS Word software and NOT the web app).
- Activate track changes.
- Use “AutoSave” or save frequently when editing in SharePoint, and always save and exit the document when you leave your computer (even for a brief break).
- If you see sections where others are reviewing, SharePoint will prevent two reviewers from editing the same paragraph at any one time. Return to these sections later or communicate with the other reviewer to discuss.
- Do not accept track changes when multiple users are in the file.
- Do not attempt major formatting for the document.
- Do not make any changes to the entire text (i.e., changing the font using CTRL+A).
- Do not do a global Find and Replace.
- Co-authoring works best where there are at most five people in the document at a given time.

# Chapter 3
# Tasks and Quality Control

Below are the tasks to be performed under the PREAHCP effort. ICF will work with the EAHCP staff to avoid unnecessary delays in the project due to requested changes, and ICF will not perform work outside the current contract scope of work without written authorization from EAA.

## 3.1 Task 1: Program Management

### 3.1.1 Task Description

ICF will be responsible for managing all ICF staff and subcontractor staff in the execution of the scope of work over the period of performance. ICF will manage different teams for development of the HCP and NEPA documents and will provide technical expertise to perform studies to renew the ITP. The HCP will be developed for the ITP Permittees, and the NEPA document will be developed for the USFWS.

ICF will draft a project work plan and schedule to complete the Amended HCP to discuss at the kickoff meeting (Task 2). We will update the project work plan and schedule as needed through the period of performance to complete the ITP renewal process. The work plan will address the preparation of the NEPA documents generally, acknowledging that more specific planning will be conducted in coordination with the USFWS at the appropriate time, as part of Task 8. ICF will also set up an electronic file sharing site to be maintained and updated through the period of performance.

ICF will create, manage, and distribute any necessary templates in Microsoft Word and PowerPoint and will maintain a list of terms and abbreviations to ensure consistency across all contract deliverables. ICF will also develop an ITP renewal process logo for branding purposes. Templates, the logo, and list of terms and abbreviations will be used for all contract deliverables by the ICF team.

The ICF program director, David, will oversee the HCP and NEPA project directors, Paola and Hova, respectively. The program and project directors will be responsible for setting the tone and approach for the program, guiding the schedule and technical analyses, troubleshooting difficult stakeholder and technical issues, and performing senior review. The project managers, supported by HCP and NEPA deputy project managers, respectively, will oversee authors and technical analyses, be responsible for managing the deliverable and meeting schedule, perform senior review, and serve as the point of contact for EAA, including for invoicing and contractual purposes.

### 3.1.2 Deliverables

- Draft work plan
- Draft schedule
- Updated work plan as needed

- Updated schedule as needed
- Draft electronic file sharing site
- Updated electronic file sharing site as needed
- Draft Microsoft Word and PowerPoint templates
- Second draft Microsoft Word and PowerPoint templates
- Final Microsoft Word and PowerPoint templates
- Draft PREAHCP logo
- Second draft PREAHCP logo
- Final PREAHCP logo
- List of terms and abbreviations
- Updated list of terms and abbreviations as needed
- Monthly invoices

### 3.1.3 Assumptions

- SharePoint will be used for all document storage/sharing.
- Microsoft Project will be used to create and maintain a detailed project schedule.
- ICF will update the work plan, schedule, and list of terms and abbreviations periodically throughout the life of the project as needed.

## 3.2 Task 2: Meetings

### 3.2.1 Task Description

Meetings are the framework within which important decisions will be made throughout the permit renewal process. The management approach and meeting breakdown described in this section will support work under all HCP tasks. NEPA meeting tasks are described under Tasks 8, 10, 11, and 13.

The following components outline the ICF team's plan for conducting meetings.

- **Regularly scheduled meetings**. We will use regularly scheduled or standing meetings whenever possible.
- **Attendees**. The HCP project manager and HCP deputy project manager will plan to attend all coordination meetings for continuity. Additional ICF team staff will attend meetings on an as-needed basis depending on active project tasks and necessary technical or strategic expertise, determined in coordination with EAHCP staff.
- **Agendas and agenda management.** The ICF team will propose an agenda prior to each coordination meeting. Having an agenda for each meeting is key to ensuring that meetings achieve their intended objectives and that all topics needing discussion and decisions are addressed.

- **Screen sharing**. Screen sharing during meetings is a valuable tool to bolster engagement and understanding of issues being discussed and to facilitate reaching consensus efficiently. Sharing notes and tasks on screen ensures they are correct and limits the need for post-meeting corrections.
- **Review material**. The ICF team will distribute review material to be discussed in meetings in advance of the meeting when feasible.
- **Notes, decisions, and action items**. The ICF team will distribute notes after each meeting. Distributing notes post-meeting ensures everyone on the team concurs with the meeting outcome. ICF will track key decisions and action items for ease of reference. These tools capture the evolution of the project and can be particularly important on longer projects where there may be staff turnover. Assigning action items to individuals or organizations, providing due dates, and then following up with reminders are all tactics the ICF team will use to facilitate accountability and ensure the project stays on schedule.

In addition to the project kickoff meeting, the project will consist of four other meeting types: regularly scheduled coordination meetings (approximately 1 hour), in-person meetings (approximately a full workday), virtual meetings (approximately a half workday), and virtual presentations at the request of the EAHCP management team (likely corresponding with committee or EAA board meetings). Coordination meetings every 2 weeks will be used to track decisions and technical tasks, prepare for upcoming deliverables, debrief from past meetings, plan for future meetings, and check in on program status with respect to the schedule. **Table 3-1** lists the meetings planned to support all HCP tasks, including those allocated under other tasks. Specifically, the table approximates how the 34 in-person and virtual meetings will be allocated amongst HCP development tasks.

ICF will be responsible for meeting coordination and will work with EAHCP staff to identify attendees, set agendas, and manage meeting notes and the decision record.

**Table 3-1. HCP Team Meetings[1] by Task in Support of the Permit Renewal for the EAHCP**

| Task | In-Person Meetings | Virtual Meetings | Virtual Presentations[2] | Regular Coordination Meetings[3] |
|---|---|---|---|---|
| Task 2, Kickoff Meeting | 1 | -- | -- | -- |
| Task 3, Listen and Learn | See Task 3[4] | -- | 1 | 16 |
| Task 4, Operating Agreements | -- | 2 | -- | 2 |
| Task 5, HCP Planning and Alternative Development | 6 | 10 | 10 | 42 |
| Task 6, Modeling | 2 | 2 | 1 | 12 |
| Task 7, Draft HCP | 2 | 6 | 1 | 18 |
| Task 8, Draft NEPA | NEPA Team Meetings Funded Under Task 8 | | | |
| Task 9, ITP Application | -- | -- | -- | 2 |
| Task 10, Public Scoping | NEPA Team Meetings Funded Under Task 10 | | | |
| Task 11, Draft EIS Public Meetings | NEPA Team Meetings Funded Under Task 11 | | | |

| Task | In-Person Meetings | Virtual Meetings | Virtual Presentations[2] | Regular Coordination Meetings[3] |
|---|---|---|---|---|
| Task 12, Final HCP | 1 | 2 | 1 | 8 |
| Task 13, Final NEPA Document | NEPA Team Meetings Funded Under Task 16 | | | |
| **Total Meetings Funded Under Task 2** | **12** | **22** | **14** | **116** |

[1]NEPA team meetings are not included in Task 2, but are included in the NEPA Tasks 8, 10, 11, and 13 to facilitate a separation of the HCP and NEPA teams (i.e., NEPA team staff and HCP team staff work should be conducted on separate tasks).

[2]Assumes that the ICF team would be requested to provide up to 20 virtual presentations over the course of the ITP renewal process.

[3]Assumes regularly scheduled coordination meetings between the HCP team and EAHCP staff approximately twice per month. The number of these meetings for each task is approximated based on the estimated task duration.

[4]Listen and Learn in-person workshops are allocated under Task 3. Coordination meetings and virtual presentations that may occur during this phase of the project are included under Task 2.

### 3.2.2 Deliverables

- Kickoff meeting agenda
- Coordination of regularly scheduled status meetings
- Attendance and/or facilitation at up to 12 in-person meetings
- Attendance and/or facilitation at up to 22 virtual meetings
- Virtual presentations at the request of the EAHCP project manager

### 3.2.3 Assumptions

- Up to 4 ICF team members will attend up to 12 in-person meetings and facilitate up to 22 virtual meetings.
- The ICF team will be requested to provide up to 14 virtual presentations over the course of the ITP renewal process.
- In-person meetings will be up to 8 hours in duration.
- Virtual meetings will be up to 4 hours in duration.
- Virtual meetings will be conducted via Microsoft Teams.

## 3.3 Task 3: Listen and Learn Workshops

### 3.3.1 Task Description

The HCP team will prepare, conduct, and facilitate four 1-day workshops to get input and data sources from community stakeholders. EAHCP staff will collaborate with the HCP team to focus the content for each workshop. An open-house style meeting will be held for each topic, with each meeting lasting up to 8 hours in duration.

Designing and implementing a successful Listen and Learn workshop process requires strong public meeting design skills, clear intent, and a well-constructed plan for incorporating information gathered from the workshops into the permit renewal process. The HCP team and ICF's public outreach staff will work closely with EAHCP staff and the HCP management team to set goals for the Listen and Learn workshops, outline the best approach for interfacing with stakeholders, and create a list of proposed workshop materials.

Up to four HCP team and public outreach staff persons will attend each workshop. Feedback will be collected on the topic and requests for existing data on the topic will be made electronically before and after each workshop and in-person at each workshop. The outcome of each workshop will be a summary of all the feedback received. EAHCP staff will collaborate with the ICF team in advance to identify stakeholders not yet on the EAHCP mailing list to include on future communications and to invite to the workshops. The four workshop topics to be conducted are outlined below.

#### 3.3.1.1 Workshop 1: Recommended ITP Approach

The purpose of this workshop is to collect feedback on the following items:

- Permit renewal options
    - Covered Activities
    - Covered Species
    - Mitigation and Management Measures
    - Other ITP conditions
- Length of the permit term
- Administrative changes

#### 3.3.1.2 Workshop 2: Biological Goals and Objectives

The purpose of this workshop is to collect feedback on the biological goals and objectives of the EAHCP:

- Define goals for species, habitat, or ecosystems
- What the new goals and objectives might be
- How objectives define success
- What tools may help evaluate success

#### 3.3.1.3 Workshop 3: Climate Change and System Vulnerabilities

Climate is a fundamental component to the future management of the conservation measures implemented in the EAHCP. Understanding the direction/focus of the biological goals and objectives will help to refine a climate vulnerability assessment. Building on the outcome of the first two workshops, the purpose of this workshop is to collect feedback on the following topics regarding climate change.

- The effect of climate change on covered species, habitat, or ecosystem
- The sensitivity, exposure, and adaptive capacity of the spring systems and the Edwards Aquifer

#### 3.3.1.4 Workshop 4: Conservation Measures

The EAHCP defines measures to conserve federally listed species that live in the Edwards Aquifer and the Comal and San Marcos springs through implementation of Minimization and Mitigation Measures (Conservation Measures). The activities defined in the EAHCP have changed via adaptive management or due to the lack of necessity. The purpose of this workshop is to collect feedback on the EAHCP Conservation Measures and determine if changes should be made to the following items.

- Details of the Conservation Measures
- Implementation efforts
- Funding

ICF will be responsible for the following Listen and Learn workshop components.

- Workshop logistics
- Meeting materials (presentations, brochures, fact sheets, display boards, comment forms, and/or sign-in sheets)
- Participation at meetings
- Collecting public comments using various methods (paper forms and electronic)

ICF will conduct a dry run of the first workshop for the EAHCP staff and Permittees 12 days prior to the first workshop. After the four workshops have been conducted, ICF will summarize the feedback received in a draft and final report for EAHCP staff. ICF will coordinate with EAHCP staff to develop recommendations for next steps based on the data received.

## 3.3.2 Deliverables

- Attendance at up to five in-person meetings
- Draft workshop materials (electronic for each workshop)
- Administrative draft workshop materials (electronic for each workshop)
- Administrative draft workshop materials (printed for dry run)
- Final electronic and printed workshop materials (for each workshop)
- Draft Listen and Learn Workshop Report
- Final Listen and Learn Workshop Report

## 3.3.3 Assumptions

- To reduce travel costs, ICF will conduct the dry run of the first workshop on the same trip as Workshop 1 (e.g., 1–2 days prior to Workshop 1).
- Up to four ICF team members will attend each Listen and Learn workshop.
- EAHCP staff will be responsible for maintaining the mailing list or public notice of workshops.

# 3.4 Task 4: Operating Agreements

## 3.4.1 Task Description

The HCP team management and program director will review existing operating agreements and make recommendations for future changes. This task may require interviewing EAHCP staff, Permittees, and other Committee members. The HCP team will conduct interviews virtually unless conducted concurrently with other in-person meetings under Task 2. ICF will make recommendations for changes to the following documents.

- *Funding and Management Agreement*
- *Operational Procedures of the Implementing Committee of the Edwards Aquifer Habitat Conservation Plan Program* (March 2012)
- *Parliamentary Rules of Conduct of the Implementing Committee of the Edwards Aquifer Habitat Conservation Plan Program* (March 2012)
- *Program Operational Rules for EAHCP Program Adaptive Management Stakeholder Committee Members and Participants* (October 2012)
- *Operational Procedures of the Science Committee of the Edwards Aquifer Habitat Conservation Plan Program* (April 2014).

As part of this task, the HCP team will conduct a thorough review of all relevant operating agreements listed above to answer the following questions.

- Do any provisions of these agreements need to change to align to the proposed amendments to the EAHCP?
- Should any provisions of these agreements be changed to improve the efficiency and effectiveness of EAHCP implementation?
- Can any of these agreements be separated from the EAHCP and ITP to provide the Permittees with more flexibility in implementation?

## 3.4.2 Deliverables

- Recommended tracked change revisions to the following.
    - *The Funding and Management Agreement*
    - *Operational Procedures of the Implementing Committee of the Edwards Aquifer Habitat Conservation Plan Program* (March 2012)
    - *Parliamentary Rules of Conduct of the Implementing Committee of the Edwards Aquifer Habitat Conservation Plan Program* (March 2012)
    - *Program Operational Rules for EAHCP Program Adaptive Management Stakeholder Committee Members and Participants* (October 2012)
    - *Operational Procedures of the Science Committee of the Edwards Aquifer Habitat Conservation Plan Program* (April 2014)

- Documented justification for recommended changes provided in a memorandum format and/or in comments in the reviewed documents.

### 3.4.3 Assumptions

- The HCP team will conduct interviews with EAHCP staff, Permittees, and other Committee members to obtain information on recommendations for operating agreement changes virtually unless conducted concurrently with other in-person meetings under Task 2.
- The HCP team will provide documented justification for required recommended changes to operating agreements in a memorandum format and/or in comments in the reviewed documents.

## 3.5 Task 5: HCP Planning and Alternative Development

### 3.5.1 Task Description

The HCP team will perform planning and technical studies to support the permit renewal for the EAHCP. The HCP team may also use these studies to identify data gaps and additional studies, if any, are needed to inform development of the HCP. These analyses should include the projected level of effort in both cost and time needed for proposed studies. The ICF team will provide any resource tools (i.e., Geographic Information System files, spreadsheets, etc.) created in the development of their work.

This task includes much of the essential content that will make up Chapters 2–7 of the HCP Amendment described under Task 7 (**Figure 3-1**). As with all writing tasks, the ICF team will begin with existing HCP text where useful and relevant. Subtasks 5.4, Define Biological Goals and Objectives, through 5.9, Monitoring Plan, will be informed by Task 6, Modeling Projections. All subtask deliverables will be overseen by the HCP team management staff, drawing on the HCP team's technical experts as noted below.

Technical memos or short technical reports will be used as the way to solicit early feedback from EAHCP staff and the USFWS on the foundational elements of the HCP. Two or three versions of each memo will be developed with review from EAHCP staff, the USFWS, and the Stakeholder and Implementing committees. We will coordinate with EAHCP staff to determine a draft development and review process for each memo, but **Table 3-2** provides the assumed approach to deliverables under this task.

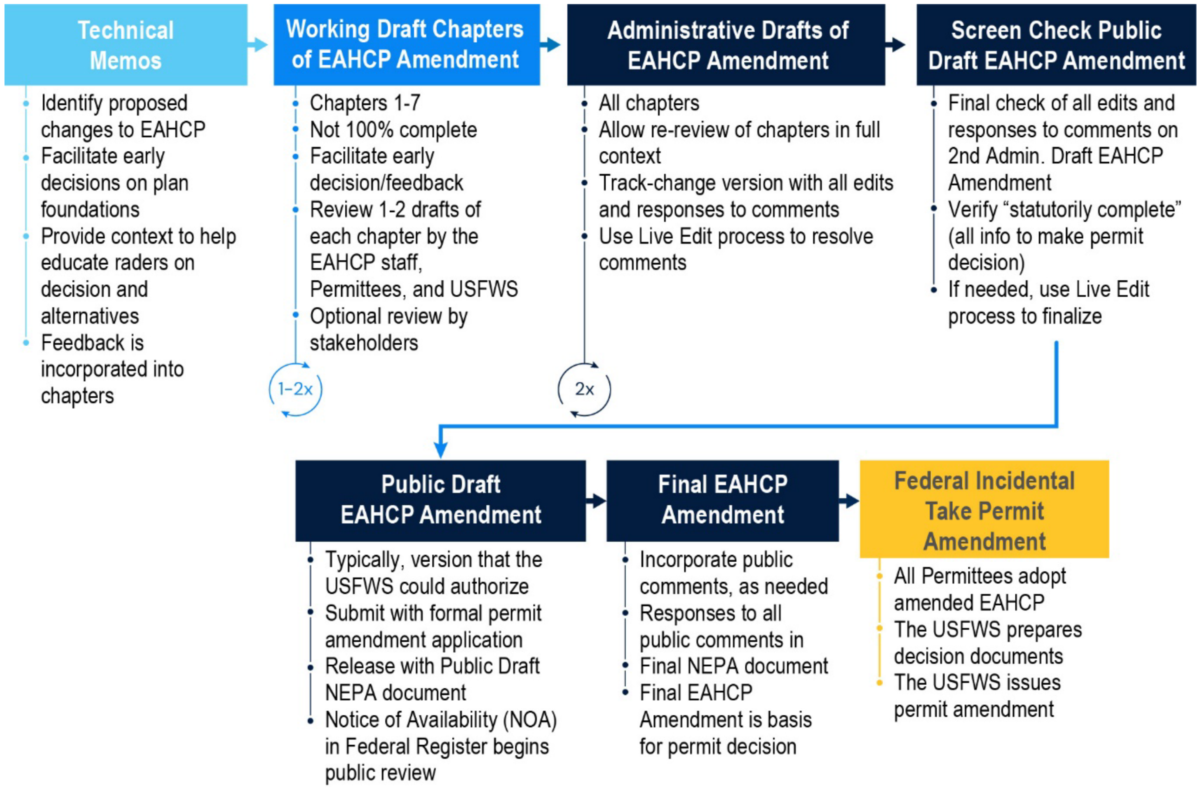
**Table 3-2. Task 5 Deliverables**

| Deliverable | | # of Drafts | Notes and Next Steps |
|---|---|---|---|
| 1a-c | Draft Covered Species Memo | 3[a] | Incorporate into Amended HCP Chapter 3, "Existing Conditions," and HCP appendix to document covered species selection process (Task 7) |
| 2a-c | Draft Covered Activities Memo | 3[a] | Incorporate into Amended HCP Chapter 2, "Covered Activities" (Task 7) |

| Deliverable | | # of Drafts | Notes and Next Steps |
|---|---|---|---|
| 3a-c | Update to Environmental Setting and Baseline Conditions Chapter | 3[a] | Update to EAHCP Chapter 3 |
| 4a | Draft Biological Goals and Objectives Memo | 1 | Follows workshop on this topic with the USFWS; edits incorporated into revised memo |
| 4b-c | Revised Draft Biological Goals and Objectives Memos | 2[a] | Incorporate into Amended HCP Chapter 5, “Conservation Strategy” (Task 7) |
| 5a-c | Draft Preliminary Conservation Strategy Changes Memo | 3[a] | Incorporate into Amended HCP Chapter 5, “Conservation Strategy” (Task 7) |
| 6a-c | Draft Habitat Suitability Analysis | 3[a] | Incorporate into Amended HCP Chapter 5, “Conservation Strategy.” Final document as EAHCP appendix (Task 7) |
| 7a | Effects Analysis and Take Assessment Memo (methods only) | 1 | Precursor topic to performing the effects analysis; important to gain buy-in on methods before we apply them |
| 7b-c | Effects Analysis and Take Assessment Memo | 2[a] | Incorporate into Amended HCP Chapter 4, “Effects Analysis” (Task 7) |
| 8a-b | Draft Monitoring Plan Updates Memo | 2[a] | Incorporate into Amended HCP Chapter 6, Sections 6.2 and 6.3 (Task 7) |
| 9a-c | Draft Preliminary Costs Memo | 3[a] | Incorporate into Amended HCP Chapter 7, “Cost and Funding” (Task 7) |
| | Total | 29 | |

[a] Assumes first draft reviewed by EAHCP staff, second draft reviewed by the USFWS and stakeholders, and third draft reviewed and approved by the Implementing Committee. Exceptions are the Biological Goals and Objectives and Effects Analysis and Take Assessment memos, which will have the first draft reviewed by both EAHCP staff and the USFWS simultaneously. It is assumed that the Effects Analysis and Take Assessment Memo and Draft Monitoring Plan Updates Memo will not require Implementing Committee approval at this stage, so only two drafts will be prepared.

**Figure 3-1. Document Review Process**




Once approved by the Implementing Committee, most technical memos would be applied to the first draft of the relevant Amended HCP chapter (Task 7) (exceptions to this, where a technical memo is assumed to be an appendix to the HCP, are noted in **Figure 3-1**). It is important that material be maintained as a "working draft" up until the Public Draft Amended HCP. The technical memo format helps to convey the working draft status. In cases where the technical material will become an appendix to the HCP, a standalone report is appropriate. In other cases, avoiding a report or memo altogether is preferrable so that reviews can be focused on the Amended HCP chapters.

In all cases, technical memos and technical reports in this task will assess and identify important data gaps that may be relevant to the Amended HCP. For each data gap we will identify the following.

- Relevance or importance to completing the Amended HCP
- Risk to the Amended HCP of not addressing the data gap
- Analysis or study required to address the data gap and estimated time and cost (if necessary, analysis to completely address the data gap is unknown, a scoping phase will be described)
- Options to address the data gap during HCP implementation should it not be addressed during the Amended HCP

The following subtasks will be conducted under this task.

#### 3.5.1.1 Subtask 5.1: Define Covered Species

The HCP team will use information collected during workshops and the results of previous deliverables to recommend what Covered Species should be included in the renewed ITP. ICF will coordinate closely with EAHCP staff in finalizing recommendations presented to Permittees. This work plan assumes up to two additional Covered Species added to the EAHCP and the removal of the San Marcos gambusia (proposed extinct).

The HCP team's technical staff will carefully evaluate species for coverage. ICF uses the following criteria to evaluate whether a species should be covered under an HCP.

- **Listing status.** Is the species currently listed as threatened or endangered? If not, considering its status and threats to the species, what is the likelihood that the species will be listed during the permit term?
- **Range.** Is the species known to occur or expected to occur within the Plan Area based on best available data and professional expertise? If not currently known or expected to occur, is it expected to move into the Plan Area during the permit term?
- **Impact.** Will the species or its habitat be affected by Covered Activities at a level that may result in take?
- **Species data.** Is there sufficient scientific data on the species life history, habitat requirements, and occurrence in the Plan Area to allow for adequate evaluation of impacts on the species and the development of Conservation Measures to mitigate those impacts?

Detailed information on the following topics will be included for the species recommended for coverage: listing status, historical and current range, habitat description, habitat extent in the Plan Area, presence in the Plan Area, and threats. Covered Species reports are typically captured, in full, as an appendix to Chapter 3, "Environmental Setting and Baseline Conditions," described under Task 7. The report for each species, often referred to as a species account or species profile, will be authored by an ICF team biology technical expert.

#### 3.5.1.2 Subtask 5.2: Define Covered Activities

The HCP team will use information collected during Listen and Learn workshops, the results of previous deliverables, text in the existing HCP, and information from annual reports documenting the HCP's Conservation Measures, to recommend what Covered Activities should be included in the renewed ITP. We will coordinate closely with EAHCP staff in finalizing recommendations presented to Permittees.

The HCP team will use the following criteria as a starting point to evaluate whether activities warrant coverage, which can be adapted as needed.

- **Location.** The project and/or activity occurs in the Plan Area.
- **Timing.** Construction of the project or operational or maintenance activities will occur during the permit term.
- **Impact.** The project or activity has a reasonable potential or likelihood to result in take of a Covered Species.

- **Definition.** The location, size, and other relevant aspects of the project or activity can be defined sufficiently such that direct and indirect impacts on Covered Species can be evaluated and Conservation Measures developed to mitigate those impacts.
- **Practicability.** Inclusion of the project and/or activity as a Covered Activity will not result in undue delays or substantial additional cost to HCP development and permitting processes relative to the benefit of including the project, activity, or service in the permit. In other words, it will be more cost-effective to provide endangered species permits for the project, activity, or service through the HCP rather than separately. Impractical Covered Activities include ones that, on their own, would add additional Covered Species, generate substantial controversy, or significantly complicate the impact analysis.

#### 3.5.1.3 Subtask 5.3: Existing Conditions

The HCP team will use information collected during workshops and the existing EAHCP Chapter 3, "Environmental Setting and Baseline Conditions," to evaluate how the chapter needs to be updated given what conditions have changed since the EAHCP was approved.

Updated existing conditions is an important input to the permit renewal process that will inform the EAHCP effects analysis, conservation strategy, and monitoring and adaptive management plan. The HCP team will start with the existing EAHCP Chapter 3, "Environmental Setting and Baseline Conditions," and evaluate how the chapter needs to be updated given what conditions have changed since the EAHCP was approved and amended last. We will also consider which changes might be considered for the EAHCP, drawing from the *EAHCP Permit Options Report* and information gathered in the Listen and Learn phase, and determine whether additional analysis of existing conditions on any topics or resource areas that were not addressed in the original EAHCP is required. Sources for information will include the EAHCP and its annual reports and biological monitoring reports, *Review of the Edwards Aquifer Habitat Conservation Plan, Report 3* and the *EAHCP Permit Options Report*. In particular, this subtask will focus on the topics necessary to inform the Amended HCP, including the following.

- Climate, including temperature, precipitation, and drought projections
- Hydrology, including the Edwards Aquifer and aquifer-fed springs in the Plan Area
- Updates to species data for each Covered Species, including new data for Covered Species added to the EAHCP

All relevant text from the EAHCP will be used whenever possible. Some content in Chapter 3 of the EAHCP may need to be updated after completing the remaining Task 5 subtasks. These updates will be made in the Draft HCP (Task 7).

#### 3.5.1.4 Subtask 5.4: Define Biological Goals and Objectives

The HCP team will use information collected during workshops, historical data and studies, and the results of previous deliverables to recommend the biological goals and objectives that should be included in the renewed ITP. The HCP team will coordinate closely with EAHCP staff in finalizing recommendations presented to Permittees.

The existing biological goals and objectives for EAHCP Covered Species will serve as a starting point for the biological goals and objectives to be included in the Amended HCP. New biological goals and objectives will need to be developed for added Covered Species (we assume up to two species will be added). The HCP team will use a collaborative approach to develop biological goals and objectives, including a workshop with USFWS staff, Permittees, the HCP management team, and species experts. Species experts are crucial to informing the discussion on what are and are not reasonable expectations for species outcomes, which helps frame the discussion with the USFWS to reach biological goals and objectives that result in beneficial conservation outcomes for species while also driving practicable Conservation Measures.

#### 3.5.1.5 Subtask 5.5: Preliminary Conservation Strategy Changes

The HCP team will use information collected during workshops to recommend the mitigation and minimization measures to be included in the renewed ITP. The HCP team and EAHCP staff will coordinate closely in finalizing recommendations presented to Permittees.

This subtask will focus on identifying the options available to update the minimization and mitigation measures in the EAHCP (Chapter 5). The technical memo delivered under this task will identify the important changes to the conservation strategy that will involve deletions, additions, or major changes to existing Conservation Measures based on the following information.

- Adaptive management changes implemented by the EAA so far
- Recommendations of the *Review of the Edwards Aquifer Habitat Conservation Plan, Report 3*
- Recommendations of the *EAHCP Permit Options Report*
- Additional Covered Species that may be added to the EAHCP (e.g., if existing Conservation Measures are insufficient to address the mitigation needs of these new species)
- New information that suggests new or different Conservation Measures will be more effective than existing measures
- Updated Biological Goals and Objectives
- Updated Effects Analysis and Take Assessment

Conservation Measures identified in the approved technical memo will be incorporated into a revised Amended EAHCP Chapter 5 (Task 7).

#### 3.5.1.6 Subtask 5.6: Habitat Suitability Analysis

The HCP Team will use available tools to perform the habitat suitability analysis (HSI). Springflow, the output from MODFLOW, will be fed into the existing HSI structure for each of the modeled scenarios. The HCP team will need to review and update available tools as needed to perform the analysis. The HCP team will conduct habitat suitability analyses for fountain darter, Texas wild-rice, San Marcos salamander, Comal salamander, and Comal Springs riffle beetle. Habitat suitability analyses for other Covered Species are not included in this scope of work.

BIO-WEST will lead the habitat suitability analysis with oversight from ICF's HCP management team and technical assistance, as needed, from Cambrian. Data and analytical tools related to habitat, water quality, and springflow are available to support habitat suitability analyses for fountain darter, Texas wild-rice, San Marcos salamander, Comal salamander, and Comal Springs riffle beetle. Updated projections from Task 6 would also inform the springflow parameter for the analyses. The Comal Springs Riffle Beetle Population Assessment that BIO-WEST is conducting over 2022 and

2023 should also inform the habitat suitability analysis for the riffle beetle, but uncertainty in the beetle's use of subsurface habitat remains. Life history data for the Comal Springs dryopid beetle, Peck's cave amphipod, and other deep aquifer Covered Species remains insufficient to conduct habitat suitability analyses for these species. More data may be available for these species at the time this task is initiated, and the ICF team will coordinate with the EAA to determine the feasibility of habitat suitability analyses for deep aquifer Covered Species.

#### 3.5.1.7 Subtask 5.7: HCP Effects Analysis and Take Assessment

The HCP team will document the effects analysis and take assessment for each Covered Species. The effects analyses and take assessment methods will be updated consistent with the updated Covered Species list, the revised Covered Activity description, and changes to the biological goals and objectives. The effects analysis and take assessment methods will also be updated, as needed, to include any new or revised approaches to the adaptive management program. The effects analysis and take assessment methods will be provided to EAHCP staff and the USFWS for review prior to completing the full analysis and memo.

This subtask will document the proposed changes to the effects analysis and take assessment for each Covered Species. The effects analyses and take assessment methods will be updated consistent with the updated Covered Species list, the revised Covered Activity description, and changes to the biological goals and objectives. The effects analysis and take assessment methods will also be updated, as needed, to include any new or revised approaches to the adaptive management program (that address uncertainties in the effects analysis). The effects analysis and take assessment methods will be provided to EAHCP staff and the USFWS for review prior to completing the full analysis and memo.

#### 3.5.1.8 Subtask 5.8: Monitoring Plan

The HCP team will coordinate closely with EAHCP staff to establish and document a monitoring plan that will evaluate the effectiveness of Conservation Measures.

This subtask will focus on proposed changes to the monitoring program in Sections 6.2 and 6.3 of the EAHCP. The monitoring plan will be updated primarily in response to changes to the Conservation Measures and the adaptive management program. Stakeholder input and lessons learned from implementation of the original HCP are also expected to inform the plan.  For example, requirements for monitoring and management requirements for gill parasites may change. Or changes to performance standards for riparian restoration may lead to changes in monitoring approach or frequency. BIO-WEST will lead the development of the monitoring plan updates memo with oversight from the HCP management team. The memo will propose additions, deletions, and changes to the long-term monitoring program and explain the rationale for these changes. Once approved, the revisions to monitoring will be incorporated into a revised monitoring chapter in Task 7.

#### 3.5.1.9 Subtask 5.9: Preliminary Costs

The HCP team will coordinate with EAHCP staff to establish and document costs and funding analysis consistent with USFWS guidance for inclusion in the Draft HCP.

The preliminary cost memo will identify expected cost changes because of the recommended changes to the Covered Activities, Covered Species, biological goals and objectives, Conservation

Measures, and monitoring activities. ICF will use the existing EAHCP budget as a starting point for the costs analysis. The costs report may also consider changes to HCP administration as these changes could lead to adjustments in costs, specifically decreases in cost because of gained efficiency. Jon Hockenyos, HCP economic/financial analyst, will lead the preliminary costs memo.

## Deliverables

Table 3-2 summarizes the deliverables under Task 5.

- Draft Covered Species Memo
- Draft Covered Activities Memo
- Update to Environmental Setting and Baseline Conditions chapter
- Draft Biological Goals and Objectives Memo
- Revised Draft Biological Goals and Objectives Memos
- Draft Habitat Suitability Analysis
- Effects Analysis and Take Assessment Memo (methods only)
- Effects Analysis and Take Assessment Memo
- Draft Preliminary Conservation Strategy Changes Memo
- Draft Monitoring Plan Updates Memo
- Draft Preliminary Costs Memo

## Assumptions

- ICF will remove the San Marcos gambusia (proposed extinct) from the list of Covered Species and therefore not analyze it in the Amended HCP.
- ICF will add up to two additional Covered Species to the list of Covered Species in the Amended HCP.
- ICF will conduct habitat suitability analyses for fountain darter, Texas wild-rice, San Marcos salamander, Comal salamander, and Comal Springs riffle beetle. Habitat suitability analyses for other Covered Species are not included in this work plan.
- ICF will develop draft technical memos for Task 5 for EAHCP staff, USFWS and stakeholders, and Implementing Committees to review, totaling up to three versions of each memo. ICF will address Implementing Committee comments on the revised draft technical memos in Chapters 1–7 of the Amended HCP. Refer to **Table 3-2** for details.

# 3.6 Task 6: Modeling Projections

## 3.6.1 Task Description

The HCP team will work closely with EAA technical staff in the development of study design and execution for each of the subtasks described below. The EAA MODFLOW model will be provided along with technical assistance in completing various model scenario runs.

The estimation of springflow response to changes in climate and water use is a critical element of the Amended HCP. Changes in springflow quantity are one of the primary impact mechanisms to the Covered Species. Maintaining minimum springflow during droughts is a key Conservation Measure of the EAHCP that will be maintained in the Amended HCP. Accordingly, this analysis must be robust, transparent, and reproducible so that the USFWS, Permittees, and stakeholders have confidence in the results and corresponding requirements.

Projections for future surface water and groundwater conditions will be developed and evaluated during this task to assess the adequacy of current minimum springflow commitments in the EAHCP in the face of climate change. Work completed during this task provides the basis for analysis and prediction of future aquatic habitat as required to inform Task 5.

Drawing on the skills and system knowledge of EAA staff, we will implement a risk-based workflow to project future springflow outcomes under a range of possible future climate and water-use conditions. This workflow requires linking existing EAA models and analysis into a bespoke workflow, as shown in **Figure 3-2**. We will use approaches that the EAA and the project team have implemented successfully and efficiently in the past. Jeremy White, PhD, of INTERA will lead the modeling workflow. Nick Martin (SwRI) and Jim Winterle (independent consultant) will provide advice, consultation, and assistance with analyses as needed.

Forecasts of future springflow patterns will be developed probabilistically using the existing EAA models, climate analyses, and pumping and permit data to represent possible future springflow patterns, as well as to estimate uncertainty in this important HCP quantity. Our team will use a probabilistic approach to address and explicitly describe the uncertainty inherent in forecasted future springflow (**Figure 3-2**). This approach will allow the EAHCP staff, Permittees, and the USFWS to evaluate the efficacy of the springflow protection measures to reduce the risk to aquatic habitat for the Covered Species from the most likely future conditions. We will adopt a scripting-driven workflow approach to increase efficiency, transparency, and reproducibly. This will also increase the quality of the final product and increase stakeholder acceptance.

Throughout the proposed linked-modeling workflow (see below), we note explicit assumptions related to the availability of datasets or models. We will update these assumptions in coordination with EAA at the initiation of Task 6 and as needed throughout its completion. We understand that EAA technical staff with be available throughout the proposed linked-modeling analysis to collaborate with and assist our team as needed. Below is a summary of the deliverables and assumptions identified for this task. Additional detail regarding work to be completed and associated assumptions are provided further below in following sections.

### Deliverables

- Draft Temperature and Rainfall Scenarios Report

- Final Temperature and Rainfall Scenarios Report
- Draft Recharge Rates, Pumping Scenarios, and MODFLOW Springflow Projections Report
- Final Recharge Rates, Pumping Scenarios, and MODFLOW Springflow Projections Report

### Assumptions

- EAA technical staff will be available throughout the proposed linked-modeling analysis to collaborate with and assist the ICF team as needed.
- ICF will include the Final Temperature and Rainfall Scenarios Report and the Final Recharge Rates, Pumping Scenarios, and MODFLOW Springflow Projections report as appendices to the Amended HCP, and the USFWS will review them during its review of the Amended HCP.
- Detailed assumptions on methods for Task 6 will be developed by the ICF Team and approved by EAHCP staff and EAA modeling staff and appended to this work plan prior to initiating work on Task 6.

#### 3.6.1.2 Subtask 6.1: Temperature and Rainfall Scenarios

EAA staff will deliver their preferred set of downscaled future climate scenarios for more than one concentration pathway, which will already include the comparisons of the recent decadal hindcasts to measured weather. The HCP team will use the existing EAA preferred downscaled future climate scenarios. The HCP team will compare the future predicted temperature and rainfall scenarios to measured temperature and rainfall during the drought of record and other recorded significant drought periods to better understand the temporal and spatial characteristics of the predicted temperature and rainfall scenarios.

The projections of future temperature and rainfall provided by the EAA will be inputs to the modeling efforts in Subtasks 6.2, 6.3, and 6.4 (**Figure 3-2**). Analysis of future recharge in Subtask 6.2 will require temperature and rainfall inputs, as will the pumping scenario development in Subtask 6.3 and the future spring discharge estimates in Subtask 6.4.

We recognize that EAA technical staff have developed downscaled and bias-corrected estimates of future precipitation and temperature conditions from CMIP5[1] for more than one concentration pathway; we also recognize that EAA technical staff have developed approaches for estimating future potential evapotranspiration conditions. If these are the preferred future climate conditions, we will rely on these estimates directly, assuming they will be supplied by EAA technical staff. Our assumption is that the climate analyses that are currently being implemented by the EAA technical staff will include and address the following requirements.

- EAA technical staff has implemented a novel downscaling method that they deem the best available for the study region to produce downscaled CMIP5 projections of temperature and rainfall across the Edwards Aquifer Region (EAR). The EAA technical staff has already judged that this approach is recommended based on reasonably matching historical climate.

[1]CMIP = Combined Model Intercomparison Project version 5. We understand that EAA staff are working towards a transition to CMIP6, but peer review and validation is expected to take another 2 years, which may not be in time to incorporate into the HCP renewal process.

- The ICF team will use the downscaled projections produced by EAA technical staff in the analyses under the assumption that they are the EAA's preferred approach and that the EAA has implemented all comparisons that it deems necessary to validate this approach.
- The downscaled CMIP5 projections of temperature and rainfall, produced by the EAA staff with their preferred downscaling method, will incorporate CMIP5 simulations results for more than one Representative Concentration Pathway (RCP) through 2078 across the EAR.
- The project team will produce an ensemble of temperature and rainfall time histories through 2078 across the EAR from the downscaled CMIP5 projections for more than one RCP that cover the entire EAR as produced by EAA technical staff.

The project team will document the future predicted temperature and rainfall scenarios produced for this task in a report (see *Deliverables* above). This approach uses all available EAA science teamwork products and requires extensive collaboration among the ICF team and the EAA science team.

#### 3.6.1.3 Subtask 6.2 Recharge Rates

The HCP team will develop a parallel track approach to addressing recharge rate. The first approach will focus on using first-order correlation analyses to estimate the relation between temperature, rainfall, and recharge from the historic datasets available. The second approach will be to use the watershed model Hydrologic Simulation Program in FORTRAN (HSPF) for each of the contributing basins. The HCP team will re-train HSPF models to produce an HSPF-based recharge estimation tool that is an advanced semi-physical analogue of the USGS recharge estimation method. The HSPF-based recharge estimation tools will focus on the following.

- Estimation and reproduction of historical stream discharge at the upstream border of the Edwards (Balcones Fault Zone, or BFZ)
- Estimation and reproduction of historical stream discharge at the downstream border of the BFZ Edwards Recharge Zone
- Estimation stream seepage losses within the BFZ Edwards Recharge Zone

The HSPF-based recharge estimation tools will estimate runoff contributions from recharge zone subbasins and diffuse recharge from deep percolation through the soil column within the recharge zone to provide a complete water balance–based recharge estimator. This ensemble can then be used with the climate scenarios to account for uncertainty in the transformation from future precipitation and temperature to future estimated recharge.

To estimate predicted future Edwards Aquifer recharge, we will rely on historical USGS estimates of recharge, measured historical temperature and rainfall, and the future predicted temperature and rainfall scenarios developed from Task 6.1. In recognition of the importance of the recharge estimation process and the complexity that it entails, we are proposing a parallel track approach leading to a decision point by mid 2023. One parallel track will focus on using first-order correlation analyses to estimate the relation between temperature, rainfall, and recharge from the historical datasets available. Conceptually, this approach will focus on matching short-duration future precipitation and recharge patterns to historical analogues. For example, we may use a 3-month forward-in-time window for each future precipitation and temperature scenario, matching the climatic quantities within each 3-month window to the most similar 3-month historical period. In essence, this approach will use a correlation-based, pattern-matching engine.

While the historical analogue approach is being developed, we will explore repurposing the existing HSPF models as recharge estimators. The goal of this approach is to re-train the HSPF basin models to reproduce the USGS recharge estimates, using the "Puente Method"[2], over the historical period. Conceptually, our approach to re-training HSPF models is to produce an HSPF-based tool that is an advanced analogue of the USGS recharge estimation method, which uses water balance methods in conjunction with stream gauges upstream and downstream of the BFZ Edwards Recharge zone. Additionally, we will incorporate "new" stream gauge data, where available, into the HSPF-based tool training process. There are several locations where stream gauges have been installed on either the upstream or downstream border of the BFZ Edwards Recharge Zone in the last 15 years, after formulation of the EAA's HSPF models.

The ICF team does not plan to "recalibrate" the HSPF models to the myriad available observations to be improved simulators of basin watershed dynamics across the BFZ Edwards Contributing and Recharge zones. Instead, we will train these models to be quasi-physical transform functions, ones that take precipitation and temperature inputs and yield recharge estimates. Conceptually, the HSPF-based recharge estimation tools are solely for BFZ Edwards recharge estimation under the hypothesis that focused recharge from streams, rivers, and karst features in the BFZ Edwards Recharge Zone is significantly more important than diffuse recharge. Consequently, the HSPF-based recharge estimation tools will focus on (1) estimation and reproduction of historical stream discharge at the upstream border of the BFZ Edwards Recharge Zone; (2) estimation and reproduction of historical stream discharge at the downstream border of the BFZ Edwards Recharge Zone; and (3) estimation of stream seepage losses within the BFZ Edwards Recharge Zone. HSPF provides a "lumped"—rather than a "discrete feature"—representation. Simulated stream seepage losses will be extended conceptually within this representation to represent all focused recharge within the recharge zone. The HSPF-based recharge estimation tools will also estimate runoff contributions from recharge zone subbasins and diffuse recharge from deep percolation through the soil column within the recharge zone to provide a complete water balance–based recharge estimator.

As a result of the proposed approach, the retrained HSPF models may include parameter values of decreased physical plausibility in the contributing zone because the HSPF-based representation of regions upstream of the BFZ Edwards Recharge Zone will be lumped, aggregated, and optimized to reproduce stream discharge at the border of the recharge zone. However, the HSPF-based recharge estimation tools may produce a representation of focused BFZ Edwards recharge that has increased physical plausibility because of the inherent focus on this mechanism. We anticipate using the tool PESTPP-IES (White 2018; White et al. 2020)[3] for this training because it is highly efficient in high-dimensional spaces and yields an ensemble of HSPF model inputs. If successful, this approach will contain unique HSPF parameter values that all reproduce the historic USGS recharge estimates and available gauge data. This ensemble of HSPF models, which will describe the inherent uncertainty in the physical watershed representation embodied within HSPF, can then be used with the climate

[2] Puente, C., 1978, Method of Estimating Natural Recharge to the Edwards Aquifer in the San Antonio Area, Texas, U.S. Geological Survey WRI 78-10. 34p.

[3] White, J.T. 2018. A model-independent iterative ensemble smoother for history matching and uncertainty quantification in very high dimensions. Environmental Modeling and Software; and White, J.T., Hunt, R.J., Fienen, M.N., and Doherty, J.E., 2020, Approaches to Highly Parameterized Inversion: PEST++ Version 5, a Software Suite for Parameter Estimation, Uncertainty Analysis, Management Optimization and Sensitivity Analysis: U.S. Geological Survey Techniques and Methods 7C26, 52 p., https://doi.org/10.3133/tm7C26.

scenarios to account for uncertainty in the transformation from future precipitation and temperature to future estimated recharge.

We see the HSPF-based recharge estimators as the best potential approach to estimating future recharge rates. However, the efficacy of the proposed approach is unknown and contains many unforeseen opportunities for hardship. Therefore, we propose to test the proposed HSPF approach on two representative HSPF basin models. Representative HSPF basin models will be selected in consultation with EAA science staff. If the results of this testing are deemed successful and fit for the purpose of recharge estimation, then we will proceed with completing the re-training for the remaining HSPF basin models. However, if the two-basin test is not successful, we will rely on the historical analogue approach. We anticipate working closely with EAA science staff during this task, especially during the HSPF testing analysis.

#### 3.6.1.4 Subtask 6.3: Pumping Scenarios

The HCP team will develop a set of pumping scenarios through 2078 based on prior pumping, rainfall, and temperature records and informed by future temperature and rainfall scenarios recommended in Task 6.1 (**Figure 3-2**).

Developing an ensemble of appropriate future water-use scenarios requires several important considerations. First, the scenarios should be at least partially coherent with future population projections and expected future agricultural water-use patterns. At the same time, the water-use scenarios must be compatible with the existing specialized version of MODFLOW that is needed to simulate the EAA stage restrictions and EAHCP springflow protection measures requirements. To cope with this complexity, our water-use scenarios will be based on the drought of record water-use patterns and will introduce stochasticity by varying water-use categories within an expected range of plausible future water-use demands. The introduced stochastic water-use component will be coherent with the stochastic future temperature and precipitation projections developed during Subtask 6.1 on a realization-by-realization basis. This will result in a pumping scenario that respects and is aligned with temperature and precipitation quantities (and resulting recharge estimate).

We recognize that previous EAHCP modeling focused on simulating the maximum permitted groundwater use quantities during the 1950s drought of record period, as this is a conservative approach. We will consult with EAHCP staff and EAA technical staff to determine the preferred approach to representing future water-use demands to produce reasonable pumping scenarios as inputs into the MODFLOW model to best assess future water-use conditions (and uncertainty) in the linked-modeling workflow (**Figure 3-2**).

#### 3.6.1.5 Subtask 6.4: MODFLOW Springflow Projections

The HCP team will develop a set of MODFLOW springflow projections combining pumping and recharge scenarios from Subtasks 6.2 and 6.3, including EAA stage restrictions and EAHCP springflow protection measures. The HCP team may be required to update the EAA MODFLOW model and run scenarios to estimate an ensemble of possible future springflow outcomes. These springflow outcomes will be used to evaluate the performance of the EAA stage restrictions and EAHCP springflow protection measures under varying future forcing conditions, including the effects of climate change.

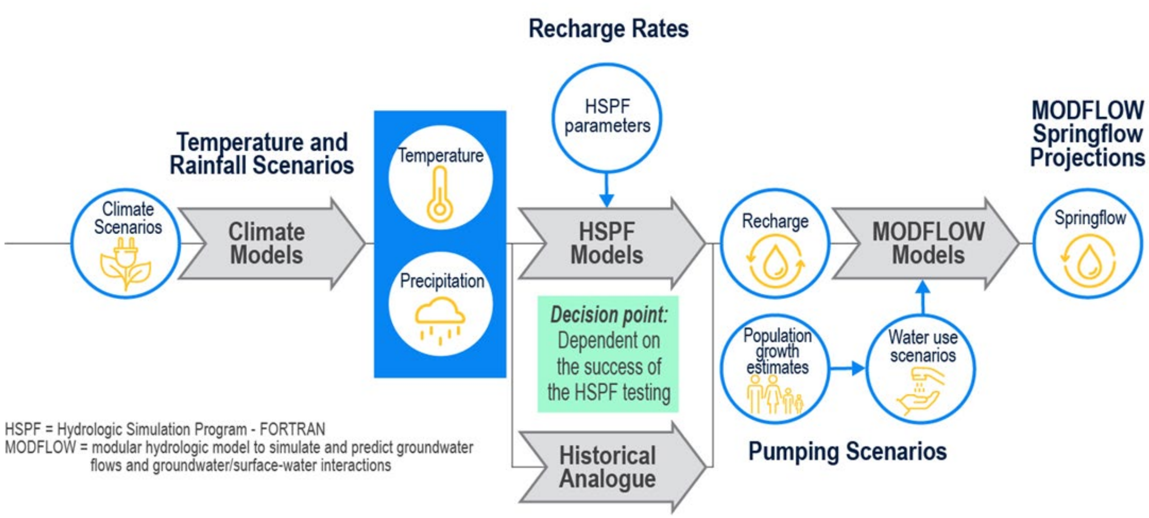
We anticipate that the statistical recharge estimation analysis steps (Subtask 6.2) can be completed in parallel to and in concert with the water-use scenario development process (Subtask 6.3; **Figure**

**3-2**). This parallel approach will provide schedule and cost efficiencies. Once these two analyses are completed, the resulting water-use scenario ensembles and recharge ensembles will be combined into a joint ensemble. The joint ensemble will be propagated through the MODFLOW model to estimate an ensemble of possible future springflow outcomes. These springflow outcomes will be used to evaluate the performance of the EAA stage restrictions and EAHCP springflow protection measures under varying future forcing conditions, including the effects of climate change. We expect the outcome of this advanced analysis to provide substantial risk-based guidance to inform the HCP renewal process.

We assume the EAA MODFLOW model will be fully configured for deployment to a future conditions analysis and that the coding processes and functions needed to simulate springflow protection measures can be deployed to inform the HCP Planning and Alternative Development tasks including the Habitat Suitability Analysis, Biological Goals and Objectives, and Effects Analysis. We understand the MODFLOW model has not been updated since spring 2019.

We understand the importance of evaluating and explicitly accounting for model input uncertainty in both the HSPF and MODFLOW models. We believe uncertainty in the model inputs will likely increase uncertainty in the simulated future springflows. This uncertainty may also interact with uncertainty in the future precipitation, temperature, and recharge estimates in nonlinear ways to affect the simulation of future springflow. This may, in turn, affect the efficacy of the springflow protection measures. If necessary, the ICF team can quantify and account for these additional uncertainties within the proposed linked-model workflow by drawing on previous experience with the HSPF and MODFLOW models, and through use of the Parameter Estimation (PEST) code model interface. Jeremy White, PhD, will lead this task with technical support from INTERA staff and technical oversight by Jim Winterle.

**Figure 3-2. Task 6 Modeling Projections Workflow**




### 3.6.1.6 Subtask 6.5: Modeling Workshop

The HCP team will design and conduct a half-day workshop to facilitate increased understanding of ensemble-based modeling workflows for EAA staff and stakeholders. At the request of the EAHCP project manager, the HCP team will present a summary of ensemble-based modeling workflows to a joint meeting of EAHCP committees (see **Table 3-1**).

#### 3.6.1.7 Subtask 6.6: Modeling Database

Task 6 will generate many complex spatially and temporally distributed datasets. It is important that these datasets are archived appropriately for transparency and reproducibility, to increase stakeholder acceptance and use during EAHCP implementation. The database should include inputs to and simulation results from each modeling run. The HCP team will develop a cloud-based database to be used to control the versions of the many complex spatially and temporally distributed datasets used across the Task 6 analyses. The datasets will be archived appropriately for transparency and reproducibility to increase stakeholder acceptance and use during EAHCP implementation. The database will include inputs to and simulation results from each modeling run. The database will also serve as the final archive of the datasets.

# 3.7 Task 7: Draft HCP

## 3.7.1 Task Description

The HCP team will develop a Draft HCP consistent with USFWS guidelines in accordance with Section 10(a)(1)(B) of the ESA of 1973, as amended. The HCP team will work closely with the EAHCP staff and Permittees to document the proposed Covered Activities, environmental setting, an analysis of Covered Species, the mitigation and minimization measures, approach to adaptive management, costs and funding assurances, changed circumstances and no surprises, permit administration, and other applicable sections. The HCP team will rely on materials developed through other tasks on this contract as well as the best available data. The Amended HCP will be based on the outline included in this work plan. Draft HCP deliverables are listed below under *Deliverables*. The Implementing Committee will review and sign-off on the Final Draft HCP prior to submittal to USFWS. The HCP team will distribute electronic copies of the Final Draft HCP to the public and applicable agencies and, if requested by EAHCP staff, will produce up to 20 hardcopies of the main HCP document with appendices included as electronic files.

The Draft HCP represents the culmination of all previous efforts on the amendment from the Listen and Learn workshops to numerous meetings, assessments, drafts, and individual chapters. This task encompasses internal coordination, QA/QC, the integration of previous comments, formatting, editing, and—critically—a stepwise process for reviewing and resolving input. At the end of this task, a publication-ready Draft HCP will be released to the public (the NEPA document will be released at the same time as per Task 11) for a mandatory public review period in accordance with USFWS policy for review of draft NEPA and HCP documents.

The Amended Draft EAHCP will be assembled from all the elements developed in Tasks 3 through 6. **Table 3-3** summarizes the chapters composing the Amended HCP. A detailed Amended HCP outline is housed in the project's document library here: HCP Outline. This outline will be updated as needed throughout the analysis phase of the permit renewal process.

**Table 3-3. Chapters of in the Amended HCP**

| Amended HCP Chapter | Original EAHCP Chapter | Corresponding Task |
|---|---|---|
| Chapter 1, "Introduction" | Same | Variety of sources, including Task 3 and Final Listen and Learn Session Report to summarize outreach process, and several Task 5 technical memos |
| Chapter 2, "Covered Activities" | Same | Task 5 and Draft Covered Activities Memo (incorporated into chapter) |
| Chapter 3, "Environmental Setting and Baseline Conditions" | Same | Task 5 and Update to EAHCP Chapter 3 |
| Chapter 4, "Effects Analysis" | Same | Task 5 and Draft Effects Analysis and Take Assessment Methods Memo (incorporated into chapter), and modeling results of Task 6 |
| Chapter 5, "Conservation Strategy" | Same | Task 5 and revised conservation strategy to address effects in Chapter 4, considering future conditions defined in Tasks 5 and 6 |
| Chapter 6, "Monitoring and Adaptive Management" | Same | Task 5, Monitoring Plan Revisions Memo |
| Chapter 7, "Plan Implementation" | 8 and 9 | Task 4 and relevant future conditions for changed circumstances |
| Chapter 8, "Costs and Funding" | 7 | Task 5, Preliminary Cost Memo and updated funding plan |
| Chapter 9, "Preparers and Contributors" | 10 | Completed as part of Task 7 |
| Chapter 10, "Literature Cited" | 12 | Updated from original HCP |
| Appendix A: Abbreviations and Acronyms | 11 | Updated from original HCP |
| Appendix B: Glossary | New | Updated from Annual Report |
| Appendix C: Covered Species Memo | New | Task 5 |
| Appendix D: Habitat Suitability Analysis | New | Task 5 |
| Appendix E: Temperature and Rainfall Scenarios Report | New | Task 6 |
| Appendix F: Recharge Rates, Pumping Scenarios, and MODFLOW Springflow Projections Report | New | Task 6 |

We will make full use of the original EAHCP by adopting its clear organization[4] and any text that still applies to the Amended HCP. However, to make it clear that the HCP is revised and updated to support a new permit application, we will update the format of the document, including font, headers, footers, the and a different cover. We will clearly indicate in the Draft HCP document and/or a summary table the changes relative to the original HCP. This approach will make clear to all reviewers, including the USFWS, what has been changed and which sections are completely new.

[4] The one exception to this organization is to combine Chapter 8, "Changed Circumstances, Unforeseen Circumstances, No Surprises, and Other Federal Commitments," and Chapter 9, "Permit Administration," into one chapter called "Plan Implementation" (Table 3-1).

As an amendment, it is as important to show what has not changed from the original HCP as it is to show what has changed.

During this task, close coordination and collaboration with the USFWS will be critical to rapid progress and successful completion of the Public Draft HCP. The ICF team will use several approaches to ensure productive discussion and negotiation between the EAA and the USFWS, including the following.

- Review, sort, and prioritize all comments; code comments that need discussion for ICF's proven live-edit meeting (coded comments are simply prioritized comments tagged with a key word to quickly move through a document)
- Hold in-person live-edit meetings to systematically discuss and resolve all coded comments and, when possible, edit the document on screen to reach agreement on revisions
- Clearly document all decisions made during this process to prevent renegotiating by new USFWS staff
- For comments not adopted, explain why in the comment response
- Hold follow-up meetings as needed to resolve all comments and produce the next draft

## Deliverables

- Draft Amended HCP Chapters 1–7 (see **Table 3-3**) reviewed by EAHCP staff
- Revised Draft amended HCP Chapter 1-7 reviewed by Committees and USFWS
- First Administrative Draft Amended HCP reviewed by EAHCP staff and Implementing Committee
- Second Administrative Draft Amended HCP reviewed by Committees and USFWS
- Screen-check Draft Amended HCP reviewed by EAHCP staff and Implementing Committee
- Final Draft Amended HCP for Implementing Committee Review and Sign-off
- Up to 20 hardcopies of the public draft Amended HCP with electronic appendices for distribution

## Assumptions

- The ICF team will assemble the Amended HCP from all the elements developed in Tasks 3–6. We assume that compiling the Amended HCP under this task will not require any new substantive analysis in addition to what is already completed under Tasks 3–6.
- The existing EAHCP will serve as the basis for the Amended HCP. Any text that still applies will be adopted in the Amended HCP.

# 3.8 Task 8: Draft NEPA

## 3.8.1 Task Description

The USFWS's renewal of the ITP and approval of the HCP Amendment constitutes a federal action subject to compliance with NEPA. The USFWS (as the NEPA lead agency) has two important considerations for the NEPA document at the outset of the NEPA process. First, the scope of the environmental document will be based on the scope of the Amended HCP and the potential impacts of its implementation. To keep the environmental analysis focused, it will be critical for ICF to work with the USFWS to clearly define the scope of the amendment and develop a clear proposed action under NEPA. Second, it will be important to determine the level of NEPA review. As the lead federal agency responsible for NEPA compliance, the USFWS will determine whether the NEPA document will be an EA or an EIS. If the USFWS anticipates potential significant effects to the human environment due to the implementation of the HCP amendment, it may require the development of an EIS. If this is the case, the USFWS will also determine whether to prepare a supplemental EIS instead of a new EIS. This work plan assumes that USFWS will determine that an EIS is necessary. However, this work plan will be updated at the start of this task to reflect the level of NEPA review determined by USFWS, if necessary.

At the direction of the USFWS, the NEPA team will draft an EIS consistent with USFWS guidance and pursuant to provisions of NEPA (Title 42 of the United States Code (USC) Section 4321 et seq., implemented by Council on Environmental Quality Regulations). To help define project expectations and roles, the NEPA team will develop a memorandum of understanding (MOU) to outline the roles and responsibilities of EAHCP staff, the USFWS, and the NEPA team for the NEPA process. In addition, the NEPA team will develop a clear communications protocol to maintain a firewall between the HCP and NEPA teams. The NEPA team will work with the USFWS regarding any data needs from or questions directed to the HCP team, EAHCP staff, and/or Permittees per the established firewall protocol. The NEPA team will prepare a NEPA schedule with task assignments and milestones and will be responsible for meeting agendas, notetaking, and dissemination of relevant materials. The NEPA team will hold a kickoff meeting with the USFWS and regularly scheduled (approximately twice-monthly) meetings until the public draft NEPA document is completed. The NEPA team will work with USFWS to establish the administrative record protocol and begin implementation at the start of the project, although it will not be submitted in its entirety until the end of the project. The NEPA team will work closely with the USFWS, and EAHCP staff and Permittees as applicable, to document the purpose and need, alternatives considered and those not considered, the affected environment, and environmental consequences. The NEPA team will rely on materials developed through other tasks on this contract as well as the best available data. The NEPA team will perform the necessary steps to develop a Public Draft EIS.

- Submit EIS draft Chapter 1, "Purpose and Need," and Chapter 2, "Description of the Proposed Action and Alternatives," for USFWS review. The description of the proposed action will incorporate the HCP's description of the permit area, permit term, Covered Species, Covered Activities, and conservation strategy.
- Following USFWS review of EIS Chapters 1 and 2, prepare revised versions of the chapters for USFWS approval.
- Following USFWS approval of EIS Chapters 1 and 2, prepare a First Administrative Draft EIS for USFWS review.

- Address USFWS comments and prepare a Second Administrative Draft EIS for USFWS review including the USFWS Regional office and DOI Solicitor's office as appropriate.
- Address USFWS comments and prepare a Third Administrative Draft EIS (camera ready) for concurrence and approval for publication.
- Submit the Public Draft EIS to the USFWS for distribution and filing with the U.S. Environmental Protection Agency.

The ICF team will obtain data and information to characterize baseline conditions for the resource areas from publicly available data, the HCP, the previous EAHCP EIS, and the results of Tasks 5 and 6. The USFWS will ultimately determine which resources to evaluate in detail and which could be informed by early public engagement; however, based on the previous EIS, ICF's experience with similar NEPA documents, and our knowledge of the EAHCP project, we anticipate analyzing the following resources will be analyzed in detail.

- Air quality and climate
- Geology and soils
- Water resources (surface water and groundwater)
- Biological resources, including Covered Species, non-listed species in the area, and wildlife, aquatic, and vegetation
- Socioeconomics
- Environmental justice
- Land use
- Cultural and historic resources

NEPA project director, project manager, and deputy project manager will lead this task. The NEPA project director will be responsible for strategic planning and senior review, as well as ensuring the ICF NEPA team has the necessary resources to adhere to the project's schedule, scope, and budget. The NEPA project manager will be the primary point of contact with the USFWS for the EIS and overseeing the technical quality of the analyses, document preparation, project status reports, and schedule. The NEPA project manager, with the deputy project manager's assistance, will also be responsible for coordinating subject matter experts from the NEPA project team.

### Deliverables

- Draft MOU
- Final MOU for execution
- Draft administrative record protocol
- Draft description of the proposed action and alternatives
- Final description of the proposed action and alternatives
- First Administrative Draft EIS
- Second Administrative Draft EIS
- Third Administrative Draft EIS

- Public Draft EIS

### Assumptions

- Meetings between the NEPA team and the USFWS assume a kickoff meeting (virtual) and approximately twice-monthly coordination meetings (virtual) through the duration of the task.
- ICF will prepare a draft and final MOU to outline the roles and responsibilities of EAHCP staff, the USFWS, and the NEPA team for the NEPA process.
- The USFWS will compile and reconcile comments on the first and second administrative drafts from all reviewers in a single document.
- ICF will prepare the Draft EIS in electronic form. No hard copies will be necessary.

# 3.9 Task 9: ITP Application

## 3.9.1 Task Description

The HCP team will prepare the ITP application package and all supporting documents for submission to USFWS. EAHCP staff will coordinate with the Implementing Committee for review and sign-off of the application prior to submittal.

The ICF team will use the new online application process provided by the USFWS. This application process is expected to evolve throughout the ITP renewal process as the USFWS aims to create a better integrated approach that initiates at start-up and continues through permitting and project implementation.

The ITP application for the ITP renewal will include the draft Amended HCP, and the online application will address the following information.

- All required reports prepared under the existing valid permit
- A list of Covered Species that will be added or removed as part of the renewal, as applicable
- A description of any changes to Covered Activities and/or conservation activities, as applicable
- A description of the change in location of any proposed Covered Activities, as applicable
- A description of any additional changes or revisions to the ITP and HCP

We acknowledge that given the breadth of the changes being considered to the EAHCP, close coordination with the USFWS will be needed to ensure the ITP application meets all the agency's issuance needs.

### Deliverables

- ITP application form for an ESA 10(a)(1)(b) ITP amendment.

### Assumptions

- EAHCP staff will coordinate Permittee signatures and application fees.

# 3.10 Task 10: Public Scoping

### 3.10.1.1 Task Description

If an EIS is required by the USFWS, public scoping meetings will need to be held by the NEPA team. Up to six public scoping meetings will be needed throughout the Plan Area. The NEPA team will conduct a dry run of the public meeting for the USFWS, EAHCP staff, and Permittees. The NEPA team will be responsible for the following duties, which will be planned and executed in consultation with USFWS.

- Meeting logistics
- Published meeting notifications in newspapers
- Draft Notice of Intent (NOI) content for USFWS to publish in the Federal Register
- Meeting materials (presentations, brochures, fact sheets, display boards, comment forms, and/or sign-in sheets)
- Participation at meetings by up to two NEPA team staff persons
- Collect public comments using various methods (paper forms, electronic, and/or court reporters)
- Summarize public comments and the scoping process in a draft and final public scoping report

Public scoping is a required part of the EIS process that provides the opportunity for the public to be informed about the project and provide input on the scope of issues and alternatives to be considered in the NEPA analysis. Public scoping is required for an EIS; however, it is at the discretion of the USFWS to determine the level of public engagement (e.g., the number of public scoping meetings and their format).

The ICF team's Public Outreach specialists will lead the public scoping task and they will coordinate the task with the NEPA project manager and the USFWS. ICF will prepare a public scoping plan in close coordination with the USFWS to determine the right level of engagement based on stakeholder needs and public sentiment. This plan will include ICF's approach to meetings, preparation of meeting materials, preparation of the NOI for the federal register, and collection and summarization of public comments. This plan will ensure an efficient and effective public scoping process and a consistent message when engaging audiences.

#### Deliverables

- Attendance at up to six in-person public meetings and one dry run
- Draft Public Scoping Plan
- Final Public Scoping Plan
- Draft newspaper meeting notification
- Final newspaper meeting notification
- Publication in up to eight newspapers
- Draft NOI

- Administrative draft meeting materials as electronic files
- Administrative draft meeting materials for dry run
- Final printed and electronic meeting materials
- Draft scoping report
- Final scoping report

### Assumptions

- Scoping meetings will consist of six in-person meetings and one in-person dry-run meeting. ICF will hold the six in-person meetings within 2 consecutive work weeks. Up to two staff persons, 1 based locally and one who may need to travel from out of state, will attend in-person meetings.
- Meetings would occur approximately twice-monthly coordination virtual meetings through the duration of the task.
- Meeting materials will include three drafts: administrative draft meeting materials as electronic files, administrative draft meeting materials for "dry run," and final printed and electronic meeting materials.
- The scoping report will include two versions: draft and final.

# 3.11 Task 11: Draft EIS Public Meetings

## 3.11.1 Task Description

If an EIS is required by the USFWS, the work plan assumes that up to six public meetings will need to be held during the Draft EIS public comment period. The NEPA team will conduct a dry run of the public meeting for the USFWS, EAHCP staff, and Permittees. The NEPA team will be responsible for the following duties, which will be planned and executed in consultation with USFWS:

- Meeting logistics
- Published meeting notifications in newspapers
- Draft Notice of Availability content for USFWS to publish in the Federal Register
- Meeting materials (presentations, brochures, fact sheets, display boards, comment forms, and/or sign-in sheets)
- Participation at meetings by up to two NEPA team staff persons

Public meetings during the NEPA process provide the opportunity for the public to hear directly from the lead federal agency and provide comments on the Draft EIS and HCP. ICF's proposed approach to the public meeting tasks will follow the same approach as Task 10, Public Scoping. ICF will prepare meeting materials and facilitate meetings. ICF's public outreach lead will lead the task and coordinate with the NEPA project manager and the USFWS.

The USFWS will make the final decision on the number of meetings on the Draft EIS and whether they will be held in person or virtually. This work plan assumes seven in-person scoping meetings during the public comment period (one dry run and six public meetings).

### Deliverables

- Published meeting notifications in newspapers
- Draft Notice of Availability content for USFWS to publish in the Federal Register
- Meeting materials (presentations, brochures, fact sheets, display boards, comment forms, and/or sign-in sheets)
- Participation at meetings by up to two NEPA team staff persons

### Assumptions

- Draft EIS public meetings will consist of six in-person meetings and one in-person dry-run meeting. ICF will hold the six in-person meetings within 2 consecutive work weeks. Up to two staff persons, one based locally and one who may need to travel from out of state, will attend in-person meetings.
- Meeting would occur approximately twice-monthly coordination virtual meetings through the duration of the task.
- Meeting materials will include three drafts: administrative draft meeting materials as electronic files, administrative draft meeting materials for "dry run," and final printed and electronic meeting materials.
- Public comments will be submitted directly to the USFWS. The USFWS will provide ICF with a public comment matrix and all copies of comments received.

# 3.12 Task 12: Final HCP

## 3.12.1 Task Description

The HCP team will address any changes to the Draft HCP based on comments received during the public comment period to produce a Final HCP. The HCP team will work closely with the USFWS, and EAHCP staff and Permittees as applicable, to address comments received on the Draft HCP. The HCP team will facilitate a live-edit meeting with the USFWS, EAHCP staff, and the HCP management team. The HCP team will also support USFWS, at their request, in responding to comments on the draft NEPA document. Once responses to comments have been approved by the EAHCP staff, the HCP team will update the Draft HCP as an Administrative Final HCP with appendices for delivery to the EAHCP staff. Once the Implementing Committee approves the document revisions the HCP team will produce a Final HCP for distribution. The HCP team will provide an electronic copy of the Final HCP to EAHCP staff and the USFWS and may be required to produce up to 20 hardcopies of the main report with appendices included as electronic files.

Managing the Final HCP task requires an understanding of (1) how to provide efficient and substantive responses to comments, (2) how to coordinate the response process with the NEPA team as comments on both the HCP and the NEPA documents are received together, and (3) how to adjust the HCP document without triggering recirculation of the public draft files. The HCP management team and technical experts will work closely with the USFWS, EAHCP staff, and Permittees, as applicable, to revise the HCP in response to comments. ICF will also support the USFWS in responding to comments related to the HCP from the draft NEPA document.

The ICF team will use the following approach for responding to comments and creating the Final HCP. The NEPA team will assign HCP-specific comments to the HCP team and provide a format—approved by the USFWS—for numbering and responding to individual comments, grouped comments, or comment subcomponents (see Task 13 for NEPA team responsibilities). Once the comment response document is complete and all reviewers agree on final changes to the HCP, the ICF HCP team will prepare the Final HCP. ICF will hold a screen-check meeting with the USFWS to create the Final HCP (as described below). Both EAHCP staff and the USFWS must approve all proposed changes to the HCP. Once they approve those changes, ICF will produce a Final HCP for publication.

### Deliverables

- Response to comments on Draft HCP
- Administrative Final HCP document with appendices
- Final HCP with appendices for electronic distribution
- Up to 20 hardcopies of the Final HCP with electronic appendices for distribution

### Assumptions

- ICF will complete and approve revisions to the Final HCP through a live-edit meeting with the USFWS, EAHCP staff, and the HCP management team.

# 3.13 Task 13: Final NEPA Document

## 3.13.1 Task Description

The NEPA team will address any changes to the EIS document based on comments received during the public comment period to produce a Final EIS. The NEPA team will perform the necessary steps to develop a Public Final EIS:

- The NEPA team will process public comments received during the public comment period. At the direction of the USFWS, the NEPA team will identify which comments are related to the HCP and provide the comments that require input from EAHCP staff. USFWS will coordinate with EAHCP staff to develop responses to comments related to the HCP, for inclusion in the Final EIS. If needed, the NEPA team and the USFWS will meet with EAHCP staff to discuss the comments and responses. The HCP consultant team may also assist EAHCP staff in providing input for responses to public comments.
- The NEPA team will draft responses to public comments on the Draft EIS (including agency comments) and submit them to the USFWS for review. The NEPA team will make any revisions to the responses based on USFWS review.
- Following the USFWS's approval of response to comments, the NEPA team will prepare the Administrative Final EIS (with appendices) for USFWS review.
- Following USFWS review, the NEPA team will address final USFWS comments and prepare a Final EIS for electronic distribution.

- Once completed, the NEPA team will provide a draft Record of Decision (ROD) document to USFWS.

### Deliverables

- Categorized comments received during the comment period on the Draft EIS and HCP
- Response to comments on the Draft EIS and HCP
- Administrative Final EIS document with appendices
- Public Final EIS document with appendices for electronic distribution
- Final electronic administrative record provided to USFWS and, with USFWS's approval, to EAHCP staff
- Draft language for the Record of Decision (ROD)

### Assumptions

- Meetings would occur approximately twice-monthly coordination virtual meetings through the duration of the task.
- ICF will prepare the Final EA in electronic form. No hard copies will be necessary.
- ICF will prepare the Administrative Record and the ROD as part of this task.

# 3.14 Quality Control

ICF's HCP team will directly oversee all HCP tasks to ensure deliverables meet the EAHCP Program Manager's expectations and the USFWS's permit issuance criteria. The HCP team will use the following process throughout the project to ensure high-quality work products that are delivered on schedule and within budget.

- The HCP project manager and HCP project director or program director discuss each task and deliverable with EAHCP staff to establish a mutual understanding of the scope, schedule, and technical expertise that may be needed. For tasks of a more technical nature, the ICF team's technical staff may need to be involved in these early discussions to help refine the scope.
- The HCP project manager and deputy project manager develop an outline of the deliverable. The outline is reviewed by the project director or program director and then provided to EAHCP staff for review.
- EAHCP staff provide comments on the outline, and the HCP project manager and deputy project manager meet with EAHCP staff to resolve comments. The project director or program director may also be involved in this meeting, depending on the nature of the comments to resolve.
- The HCP project manager and HCP deputy project manager communicate to technical experts assignments for the deliverable, including the outline with any additional guidance, writing assignments, and schedule.
- Technical experts draft the content of the deliverable.
- The HCP deputy project manager, lead conservation planner, or QA/QC and senior regulatory advisor review the initial drafts and provide comments back to technical experts, if needed.

Once the first round of internal comments is addressed, the HCP project manager reviews the deliverable and provides comments back to the deputy project manager, lead conservation planner, and/or technical experts to address.

- Once the second round of internal comments is addressed, the HCP project director or program director reviews the deliverable and provides comments back to the project manager and/or technical experts to address.
- Once the third round of internal comments is addressed, the deliverable is provided to the managing editor and designer for final technical edit and format.
- The HCP project manager resolves any comments with the managing editor and submits the deliverable to EAHCP staff and Permittees for review.

A similar process to that described above will also occur for any NEPA deliverables to the USFWS, involving the NEPA project director, NEPA project manager, NEPA deputy project manager, NEPA QA/QC and senior advisor, and subject matter experts.

# Chapter 4
# Schedule

The ICF team will maintain a detailed project schedule in the project's document library.

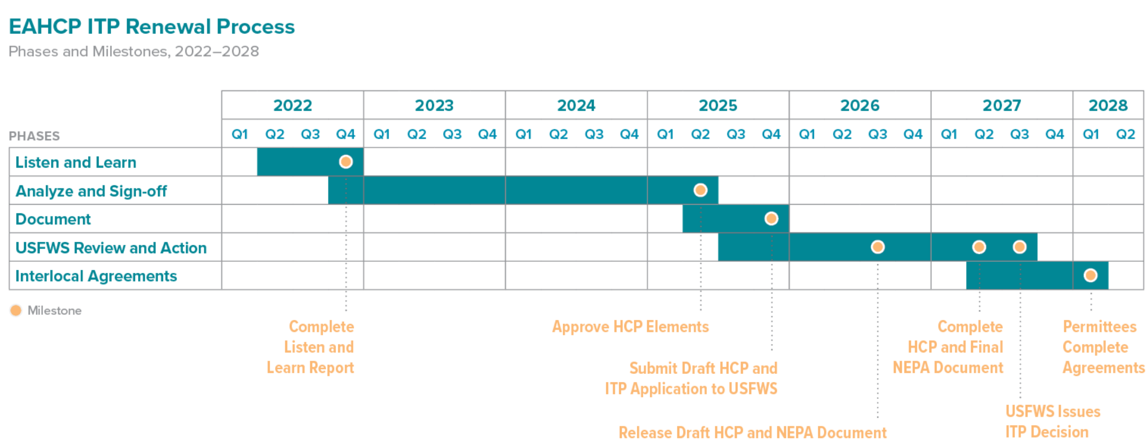
The detailed schedule includes timelines for all tasks and review periods for EAHCP staff, committees, and the USFWS. The schedule also includes the final step in 2027 of review and approval of Inter-Local Agreements with Permittees before implementation of the renewed permit can begin. Figure 4-1 provides a high-level summary schedule, based on the detailed schedule, of the permit renewal process by phase.

The detailed project schedule will be maintained in Microsoft Project throughout the permit renewal process and will be updated periodically. The ICF HCP and NEPA project managers will monitor all factors with potential to cause deviations from the approved schedule.  The causes of potential schedule deviations may include changes to the scope of work that are requested by EAHCP Program Manager, factors that affect critical milestones such as granted requests for shortened or extended review periods, or delays in Federal Register publications.  Such factors potentially could either shorten or lengthen either the overall schedule, or components within the schedule.

Upon recognition that the need for deviation from the approved schedule is foreseen, the ICF project manager will take the following steps:

1. Identify the proposed deviation from the schedule.
2. Discuss proposed deviation from the schedule with the EAHCP or USFWS staff including rationale, alternative approaches considered, and project implications.
3. EAHCP Program Manager decides whether to accept the proposed schedule deviation.
4. ICF addresses any related scope of work changes that may result from schedule deviations.

**Figure 4-1. Permit Renewal Phase Timelines by Quarter**



# Chapter 5
# Amended EAHCP Outline

Below is a summary outline of the Amended EAHCP. This outline will be updated periodically throughout the permit renewal process, including during Phase 1 and after the completion of Task 5 prior to initiating Phase 3, Documentation.

1. Introduction
    1.1. Background
    1.2. Permit Area
    1.3. Permit Holders and Permit Duration
    1.4. Species Proposed for Coverage under the Permit
    1.5. Regulatory Framework
    1.6. Alternatives Considered during the Development of the HCP
    1.7. Public Involvement
2. Covered Activities
    2.1. Covered Activities
    2.2. Edwards Aquifer Authority
    2.3. City of New Braunfels
    2.4. City of San Marcos
    2.5. Texas State University
    2.6. San Antonio Water System
    2.7. Texas Parks and Wildlife Department
    2.8. Adaptive Management Process
3. Environmental Setting and Baseline Conditions
    3.1. Climate
    3.2. Aquifer-fed Springs
    3.3. Edwards Aquifer
    3.4. The Edwards Aquifer, Comal Springs, and San Marcos Springs
    3.5. Covered Species
4. Effects Analysis
    4.1. Introduction
    4.2. Potential Impacts to and Incidental Take of Covered Species
5. Conservation Strategy
    5.1. Introduction
    5.2. Biological Goals and Objectives
    5.3. Minimization and Mitigation Measures
6. Monitoring and Adaptive Management
    6.1. Adaptive Management Process
    6.2. Monitoring
    6.3. Core Adaptive Management Actions
7. Plan Implementation
    7.1. Governance
    7.2. Permit Amendments
    7.3. Annual Reporting

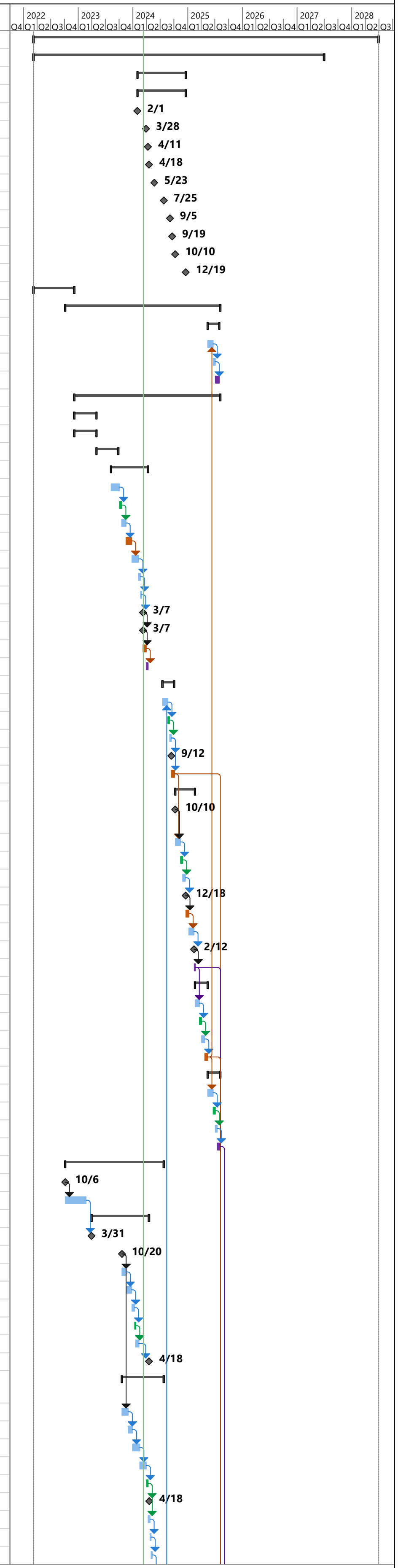
- 7.4. Changed Circumstances
- 7.5. Unforeseen Circumstances

8. Costs and Funding
   - 8.1. Cost and Benefit of the EAHCP
   - 8.2. Purpose of Cost Estimate and Annual EAHCP Implementation Budget
   - 8.3. EAHCP Cost Estimate
   - 8.4. Cost Estimate Methodology
   - 8.5. Funding Sources and Assurances
   - 8.6. EAHCP Benefits
9. Preparers and Contributors
10. Literature Cited

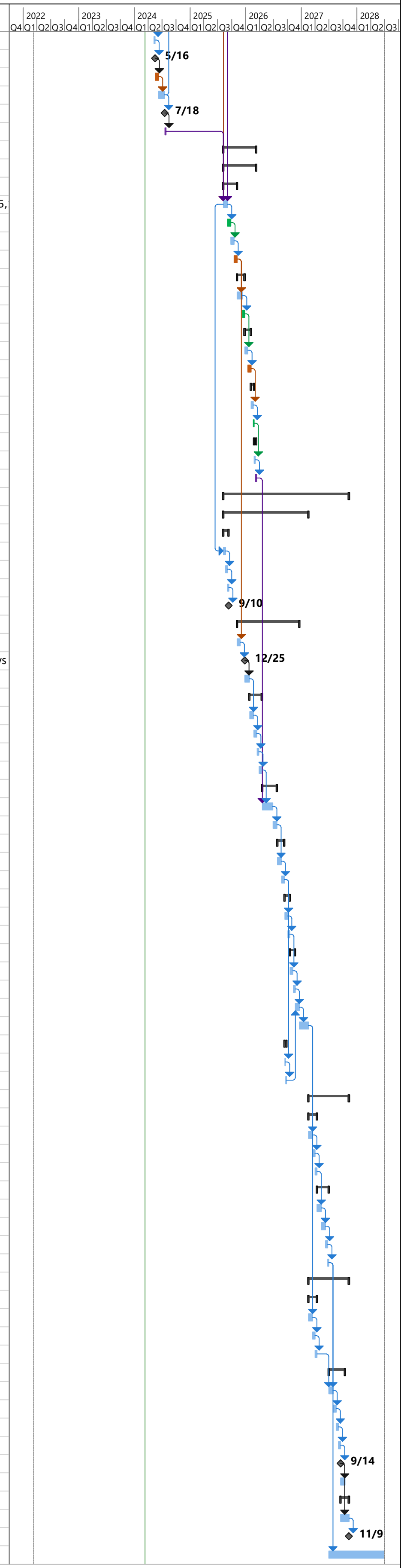
Appendix A: Abbreviations and Acronyms
Appendix B: Glossary
Appendix C: Covered Species
Appendix D: Habitat Suitability Analysis
Appendix E: Temperature and Rainfall Scenarios Report
Appendix F: Recharge Rates, Pumping Scenarios, and MODFLOW Springflow Projections Report

# Appendix G5 | **Permit Renewal Detailed Schedule**

| ID | Task Mode | Task Name | Duration | Start | Finish | Predecessors |
|---|---|---|---|---|---|---|
| 1 | | **Permit Renewal for the EAHCP** | **1643 days** | **Wed 3/9/22** | **Wed 6/28/28** | |
| 2 | | **1. Program Management** | **1383 days** | **Wed 3/9/22** | **Wed 6/30/27** | |
| 18 | | **2. Meetings** | **230 days** | **Thu 2/1/24** | **Thu 12/19/24** | |
| 19 | | **2024 Committee Meetings** | **230 days** | **Thu 2/1/24** | **Thu 12/19/24** | |
| 20 | | Joint Stakeholder and Implementing Committee | 0 days | Thu 2/1/24 | Thu 2/1/24 | |
| 21 | | Joint Stakeholder and Implementing Committee | 0 days | Thu 3/28/24 | Thu 3/28/24 | |
| 22 | | Implementing Committee | 0 days | Thu 4/11/24 | Thu 4/11/24 | |
| 23 | | Science Committee | 0 days | Thu 4/18/24 | Thu 4/18/24 | |
| 24 | | Implementing Committee | 0 days | Thu 5/23/24 | Thu 5/23/24 | |
| 25 | | Joint Stakeholder and Implementing Committee | 0 days | Thu 7/25/24 | Thu 7/25/24 | |
| 26 | | Science Committee | 0 days | Thu 9/5/24 | Thu 9/5/24 | |
| 27 | | Implementing Committee | 0 days | Thu 9/19/24 | Thu 9/19/24 | |
| 28 | | Implementing Committee | 0 days | Thu 10/10/24 | Thu 10/10/24 | |
| 29 | | Join Stakeholder, Science, Implementing Committee | 0 days | Thu 12/19/24 | Thu 12/19/24 | |
| 30 | | **Phase 1: Listen and Learn** | **191 days** | **Wed 3/9/22** | **Mon 12/5/22** | |
| 80 | | **Phase 2: Analyze and Sign-off** | **740 days** | **Thu 10/6/22** | **Wed 8/6/25** | |
| 81 | | **4. Operating Agreements** | **55 days** | **Thu 5/15/25** | **Wed 7/30/25** | |
| 82 | | ICF Prepare Redlined Agreements & Justification | 25 days | Thu 5/15/25 | Wed 6/18/25 | 145 |
| 83 | | EAHCP Staff Review | 10 days | Thu 6/19/25 | Wed 7/2/25 | 82 |
| 84 | | EAHCP Permittees Review Redlined Agreements | 20 days | Thu 7/3/25 | Wed 7/30/25 | 83 |
| 85 | | **5. HCP Planning and Analysis** | **697 days** | **Tue 12/6/22** | **Wed 8/6/25** | |
| 86 | | **5.1. Define Covered Species** | **107 days** | **Tue 12/6/22** | **Wed 5/3/23** | |
| 97 | | **5.2. Define Covered Activities** | **107 days** | **Tue 12/6/22** | **Wed 5/3/23** | |
| 106 | | **5.3. Existing Conditions** | **103 days** | **Thu 5/4/23** | **Mon 9/25/23** | |
| 113 | | **5.4. Define Biological Goals and Objectives** | **177 days** | **Wed 8/9/23** | **Thu 4/11/24** | |
| 114 | | ICF Prepare Draft Memo | 40 days | Wed 8/9/23 | Tue 10/3/23 | 110 |
| 115 | | EAHCP Staff Review | 10 days | Wed 10/4/23 | Tue 10/17/23 | 114 |
| 116 | | ICF Prepare Revised Draft Biological Goals and Objectives Memo | 21 days | Wed 10/18/23 | Wed 11/15/23 | 115 |
| 117 | | Committees & USFWS Review | 27 days | Thu 11/16/23 | Fri 12/22/23 | 116 |
| 118 | | ICF Team Address Comments | 34 days | Mon 12/25/23 | Thu 2/8/24 | 117 |
| 119 | | ICF Prepare Draft Final Memo w/ Comment Responses | 8 days | Fri 2/9/24 | Tue 2/20/24 | 118 |
| 120 | | EAHCP Staff Review Draft Final Memo | 5 days | Wed 2/21/24 | Tue 2/27/24 | 119 |
| 121 | | EAHCP Staff Distribute to Committees | 0 days | Thu 3/7/24 | Thu 3/7/24 | 120FS+7 days |
| 122 | | ICF Team Present to Science Committee | 0 days | Thu 3/7/24 | Thu 3/7/24 | 121 |
| 123 | | Science Committee Review BGOs memo and provide response memo | 15 days | Fri 3/8/24 | Thu 3/28/24 | 122 |
| 124 | | IC Final Review & Directive to Proceed | 10 days | Fri 3/29/24 | Thu 4/11/24 | 123 |
| 125 | | **5.6 & 5.7. Habitat Suitability Analysis & Take Assessment** | **57 days** | **Wed 7/17/24** | **Thu 10/3/24** | |
| 126 | | ICF Prepare Draft Memo | 25 days | Wed 7/17/24 | Tue 8/20/24 | 176 |
| 127 | | EAHCP Staff Review | 8 days | Wed 8/21/24 | Fri 8/30/24 | 126 |
| 128 | | ICF Prepare Revised Draft Memo | 9 days | Mon 9/2/24 | Thu 9/12/24 | 127 |
| 129 | | Present to Implementing Committee | 0 days | Thu 9/12/24 | Thu 9/12/24 | 128 |
| 130 | | Committees & USFWS Review | 15 days | Fri 9/13/24 | Thu 10/3/24 | 128 |
| 131 | | **5.5 Preliminary Conservation Strategy Changes** | **95 days** | **Thu 10/10/24** | **Wed 2/19/25** | |
| 132 | | ICF Team Receive Conservation Measures Subcommittee Recommendations | 0 days | Thu 10/10/24 | Thu 10/10/24 | |
| 133 | | ICF Prepare Draft Memo | 25 days | Thu 10/10/24 | Wed 11/13/24 | 130,132 |
| 134 | | EAHCP Staff Review | 10 days | Thu 11/14/24 | Wed 11/27/24 | 133 |
| 135 | | ICF Prepare Revised Memo | 13 days | Thu 11/28/24 | Mon 12/16/24 | 134 |
| 136 | | EAHCP Staff Distribute to Committees & USFWS | 0 days | Wed 12/18/24 | Wed 12/18/24 | 135FS+2 days |
| 137 | | Committees & USFWS Review | 15 days | Thu 12/19/24 | Wed 1/8/25 | 136 |
| 138 | | ICF & EAHCP Staff Address Comments | 23 days | Thu 1/9/25 | Mon 2/10/25 | 137 |
| 139 | | EAHCP Staff Distribute to Committees and USFWS | 0 days | Wed 2/12/25 | Wed 2/12/25 | 138FS+2 days |
| 140 | | IC Final Review & Directive to Proceed | 5 days | Thu 2/13/25 | Wed 2/19/25 | 139 |
| 141 | | **5.8. Monitoring Plan** | **60 days** | **Thu 2/20/25** | **Wed 5/14/25** | |
| 142 | | ICF Prepare Draft Monitoring Plan Memo | 20 days | Thu 2/20/25 | Wed 3/19/25 | 140 |
| 143 | | EAHCP Staff Review | 10 days | Thu 3/20/25 | Wed 4/2/25 | 142 |
| 144 | | ICF Prepare Revised Draft Monitoring Plan Memo | 15 days | Thu 4/3/25 | Wed 4/23/25 | 143 |
| 145 | | Committees & USFWS Review | 15 days | Thu 4/24/25 | Wed 5/14/25 | 144 |
| 146 | | **5.9. Preliminary Costs** | **60 days** | **Thu 5/15/25** | **Wed 8/6/25** | |
| 147 | | ICF Prepare Draft Preliminary Costs | 25 days | Thu 5/15/25 | Wed 6/18/25 | 145 |
| 148 | | EAHCP Staff Review | 10 days | Thu 6/19/25 | Wed 7/2/25 | 147 |
| 149 | | ICF Prepare Revised Draft Memo | 10 days | Thu 7/3/25 | Wed 7/16/25 | 148 |
| 150 | | Permittees Review | 15 days | Thu 7/17/25 | Wed 8/6/25 | 149 |
| 151 | | **6. Modeling Projections** | **471 days** | **Thu 10/6/22** | **Thu 7/25/24** | |
| 152 | | Task Kickoff Meeting | 0 days | Thu 10/6/22 | Thu 10/6/22 | |
| 153 | | ICF Team Establish Workflow and Prep Models | 100 days | Thu 10/6/22 | Wed 2/22/23 | 152 |
| 154 | | **6.1. Temperature and Precipitation Projections** | **274 days** | **Fri 3/31/23** | **Thu 4/18/24** | |
| 155 | | EAA Provide Downscaled Climate Scenarios | 0 days | Fri 3/31/23 | Fri 3/31/23 | 153 |
| 156 | | EAA Provides Downscaling Report | 0 days | Fri 10/20/23 | Fri 10/20/23 | |
| 157 | | ICF Climate Team EAA Data Infrastructure Setup | 21 days | Fri 10/20/23 | Fri 11/17/23 | 156 |
| 158 | | ICF Climate Team Develop Drought Scenarios | 25 days | Mon 11/20/23 | Fri 12/22/23 | 157 |
| 159 | | ICF Prepare Draft Report | 14 days | Mon 12/25/23 | Thu 1/11/24 | 158 |
| 160 | | EAA Staff Review | 5 days | Fri 1/12/24 | Thu 1/18/24 | 159 |
| 161 | | ICF Prepare Revised Report | 16 days | Fri 1/19/24 | Fri 2/9/24 | 160 |
| 162 | | EAHCP Staff Distribute Draft Report to Committees & USFWS | 0 days | Thu 4/18/24 | Thu 4/18/24 | 161FS+4 days |
| 163 | | **6.2. Recharge Rates, Pumping Scenarios, MODFLOW Springflow Projections** | **200 days** | **Fri 10/20/23** | **Thu 7/25/24** | |
| 164 | | Recharge Estimates | 30 days | Fri 10/20/23 | Thu 11/30/23 | 156 |
| 165 | | Initial MODFLOW Results | 20 days | Fri 12/1/23 | Thu 12/28/23 | 164 |
| 166 | | Model Simulations for Climate Models | 35 days | Fri 12/29/23 | Thu 2/15/24 | 165 |
| 167 | | EAA Complete Analysis | 31 days | Fri 2/16/24 | Fri 3/29/24 | 166 |
| 168 | | EAHCP Staff & ICF Review Analysis Results | 8 days | Mon 4/1/24 | Wed 4/10/24 | 167 |
| 169 | | Modeling Workshop | 0 days | Thu 4/18/24 | Thu 4/18/24 | 168FS+6 days |
| 170 | | EAA Completes Content for Draft Report | 9 days | Thu 4/11/24 | Tue 4/23/24 | 168 |
| 171 | | ICF Produces Draft Report | 5 days | Wed 4/24/24 | Tue 4/30/24 | 170 |
| 172 | | EAA Review Draft Report | 5 days | Wed 5/1/24 | Tue 5/7/24 | 171 |



| ID | Task Mode | Task Name | Duration | Start | Finish | Predecessors |
|---|---|---|---|---|---|---|
| 173 | | ICF Address EAA Comments | 5 days | Wed 5/8/24 | Tue 5/14/24 | 172 |
| 174 | | EAHCP Staff Distribute to Committees & USFWS | 0 days | Thu 5/16/24 | Thu 5/16/24 | 173FS+2 days |
| 175 | | Committees & USFWS Review | 15 days | Fri 5/17/24 | Thu 6/6/24 | 174 |
| 176 | | ICF & EAHCP Staff Address Comments | 28 days | Fri 6/7/24 | Tue 7/16/24 | 175 |
| 177 | | EAHCP Staff Distribute to Committees & USFWS | 0 days | Thu 7/18/24 | Thu 7/18/24 | 176FS+2 days |
| 178 | | IC Final Review & Directive to Proceed | 5 days | Fri 7/19/24 | Thu 7/25/24 | 177 |
| 179 | | **Phase 3: Document** | **155 days** | **Thu 8/7/25** | **Wed 3/11/26** | |
| 180 | | **7. Draft HCP** | **155 days** | **Thu 8/7/25** | **Wed 3/11/26** | |
| 181 | | **Draft HCP Ch. 1-7** | **65 days** | **Thu 8/7/25** | **Wed 11/5/25** | |
| 182 | | ICF Prepare Draft Amended HCP Ch. 1-7 | 20 days | Thu 8/7/25 | Wed 9/3/25 | 112,150,96,105, |
| 183 | | EAHCP Staff Review | 15 days | Thu 9/4/25 | Wed 9/24/25 | 182 |
| 184 | | ICF Revise Draft Amended HCP Ch. 1-7 | 15 days | Thu 9/25/25 | Wed 10/15/25 | 183 |
| 185 | | Committees and USFWS Review Draft HCP Ch. 1-7 | 15 days | Thu 10/16/25 | Wed 11/5/25 | 184 |
| 186 | | **First Administrative Draft HCP** | **35 days** | **Thu 11/6/25** | **Wed 12/24/25** | |
| 187 | | ICF Prepare First Admin Draft HCP | 25 days | Thu 11/6/25 | Wed 12/10/25 | 185 |
| 188 | | EAHCP Staff & Implementing Committee Review | 10 days | Thu 12/11/25 | Wed 12/24/25 | 187 |
| 189 | | **Second Administrative Draft HCP** | **30 days** | **Thu 12/25/25** | **Wed 2/4/26** | |
| 190 | | ICF Prepare Second Admin Draft | 15 days | Thu 12/25/25 | Wed 1/14/26 | 188 |
| 191 | | Committees and USFWS Review | 15 days | Thu 1/15/26 | Wed 2/4/26 | 190 |
| 192 | | **Screen Check Draft HCP** | **15 days** | **Thu 2/5/26** | **Wed 2/25/26** | |
| 193 | | ICF Prepare Screen Check Draft | 10 days | Thu 2/5/26 | Wed 2/18/26 | 191 |
| 194 | | EAHCP Staff & Implementing Committee Review | 5 days | Thu 2/19/26 | Wed 2/25/26 | 193 |
| 195 | | **Final Draft HCP** | **10 days** | **Thu 2/26/26** | **Wed 3/11/26** | |
| 196 | | ICF Prepare Final Draft HCP | 5 days | Thu 2/26/26 | Wed 3/4/26 | 194 |
| 197 | | Implementing Committee Review and Sign-off | 5 days | Thu 3/5/26 | Wed 3/11/26 | 196 |
| 198 | | **Phase 4: USFWS Review and Decision** | **589 days** | **Thu 8/7/25** | **Tue 11/9/27** | |
| 199 | | **8. Draft NEPA** | **399 days** | **Thu 8/7/25** | **Tue 2/16/27** | |
| 200 | | **Memorandum of Understanding** | **25 days** | **Thu 8/7/25** | **Wed 9/10/25** | |
| 201 | | Draft MOU | 10 days | Thu 8/7/25 | Wed 8/20/25 | 182SS |
| 202 | | EAHCP and USFWS Review | 10 days | Thu 8/21/25 | Wed 9/3/25 | 201 |
| 203 | | Final MOU | 5 days | Thu 9/4/25 | Wed 9/10/25 | 202 |
| 204 | | MOU Execution | 0 days | Wed 9/10/25 | Wed 9/10/25 | 203 |
| 205 | | **Draft EIS** | **292 days** | **Thu 11/6/25** | **Fri 12/18/26** | |
| 206 | | Prepare Notice of Intent | 14 days | Thu 11/6/25 | Tue 11/25/25 | 185 |
| 207 | | Publish Notice of Intent in Federal Register | 0 days | Thu 12/25/25 | Thu 12/25/25 | 206FS+30 edays |
| 208 | | Public Scoping | 30 edays | Thu 12/25/25 | Sat 1/24/26 | 207 |
| 209 | | **Proposed Action & Alternatives** | **60 days** | **Mon 1/26/26** | **Fri 4/17/26** | |
| 210 | | Draft Description of Proposed Action and Alternatives | 20 days | Mon 1/26/26 | Fri 2/20/26 | 208 |
| 211 | | USFWS Review | 15 days | Mon 2/23/26 | Fri 3/13/26 | 210 |
| 212 | | Final Description of Proposed Action and Alternatives | 10 days | Mon 3/16/26 | Fri 3/27/26 | 211 |
| 213 | | USFWS Review | 15 days | Mon 3/30/26 | Fri 4/17/26 | 212 |
| 214 | | **First Admin Draft EIS** | **70 days** | **Mon 4/20/26** | **Fri 7/24/26** | |
| 215 | | Prepare First Draft EIS | 50 days | Mon 4/20/26 | Fri 6/26/26 | 213,197 |
| 216 | | USFWS Review | 20 days | Mon 6/29/26 | Fri 7/24/26 | 215 |
| 217 | | **Second Admin Draft EIS** | **35 days** | **Mon 7/27/26** | **Fri 9/11/26** | |
| 218 | | Prepare Second Draft EIS | 20 days | Mon 7/27/26 | Fri 8/21/26 | 216 |
| 219 | | USFWS Review | 15 days | Mon 8/24/26 | Fri 9/11/26 | 218 |
| 220 | | **Third Admin Draft EIS** | **25 days** | **Mon 9/14/26** | **Fri 10/16/26** | |
| 221 | | Prepare Third Draft EIS | 15 days | Mon 9/14/26 | Fri 10/2/26 | 219 |
| 222 | | USFWS Review | 10 days | Mon 10/5/26 | Fri 10/16/26 | 221 |
| 223 | | **Public Draft EIS** | **25 days** | **Mon 10/19/26** | **Fri 11/20/26** | |
| 224 | | Draft EIS | 15 days | Mon 10/19/26 | Fri 11/6/26 | 222 |
| 225 | | USFWS Review | 10 days | Mon 11/9/26 | Fri 11/20/26 | 224 |
| 226 | | Final Public Draft EIS and NOA in Federal Register | 20 days | Mon 11/23/26 | Fri 12/18/26 | 225,230 |
| 227 | | Public Comment Period (60 days) | 60 edays | Fri 12/18/26 | Tue 2/16/27 | 226 |
| 228 | | **9. ITP Application** | **10 days** | **Mon 9/14/26** | **Fri 9/25/26** | |
| 229 | | ICF Prepare ITP Application | 5 days | Mon 9/14/26 | Fri 9/18/26 | 219 |
| 230 | | EAHCP Review and Submit to USFWS | 5 days | Mon 9/21/26 | Fri 9/25/26 | 229 |
| 231 | | **12. Final HCP** | **190 days** | **Wed 2/17/27** | **Tue 11/9/27** | |
| 232 | | **Response to Comments** | **40 days** | **Wed 2/17/27** | **Tue 4/13/27** | |
| 233 | | ICF Prepare Draft Response to Comments on HCP | 20 days | Wed 2/17/27 | Tue 3/16/27 | 227 |
| 234 | | EAHCP Staff Review | 10 days | Wed 3/17/27 | Tue 3/30/27 | 233 |
| 235 | | Final Response to Comments to USFWS | 10 days | Wed 3/31/27 | Tue 4/13/27 | 234 |
| 236 | | **Final HCP** | **55 days** | **Wed 4/14/27** | **Tue 6/29/27** | |
| 237 | | ICF Prepare Admin Final HCP | 20 days | Wed 4/14/27 | Tue 5/11/27 | 235 |
| 238 | | EAHCP Permittees Review | 20 days | Wed 5/12/27 | Tue 6/8/27 | 237 |
| 239 | | ICF Prepare Final HCP | 10 days | Wed 6/9/27 | Tue 6/22/27 | 238 |
| 240 | | Implementing Committee Review & Sign-Off | 5 days | Wed 6/23/27 | Tue 6/29/27 | 239 |
| 241 | | **13. Final NEPA** | **190 days** | **Wed 2/17/27** | **Tue 11/9/27** | |
| 242 | | **Response to Comments** | **40 days** | **Wed 2/17/27** | **Tue 4/13/27** | |
| 243 | | ICF Prepare Draft Responses to Comments on EIS | 20 days | Wed 2/17/27 | Tue 3/16/27 | 227 |
| 244 | | USFWS Review all Responses to Comments | 10 days | Wed 3/17/27 | Tue 3/30/27 | 243 |
| 245 | | ICF Prepare Final Responses to Comments | 10 days | Wed 3/31/27 | Tue 4/13/27 | 244 |
| 246 | | **Final EIS and Draft Record of Decision** | **77 days** | **Wed 6/30/27** | **Thu 10/14/27** | |
| 247 | | ICF Prepare Admin Final EIS | 20 days | Wed 6/30/27 | Tue 7/27/27 | 245,240 |
| 248 | | USFWS Review | 15 days | Wed 7/28/27 | Tue 8/17/27 | 247 |
| 249 | | ICF Prepare Final EIS | 10 days | Wed 8/18/27 | Tue 8/31/27 | 248 |
| 250 | | USFWS Review Final EIS | 10 days | Wed 9/1/27 | Tue 9/14/27 | 249 |
| 251 | | Publish Final EIS | 0 days | Tue 9/14/27 | Tue 9/14/27 | 250 |
| 252 | | 30-day Period | 30 edays | Tue 9/14/27 | Thu 10/14/27 | 251 |
| 253 | | **Findings, ROD, and Permit** | **40 days** | **Wed 9/15/27** | **Tue 11/9/27** | |
| 254 | | ESA Findings, Biological Opinion, and ROD | 8 wks | Wed 9/15/27 | Tue 11/9/27 | 251 |
| 255 | | **Permit Issuance** | **0 days** | **Tue 11/9/27** | **Tue 11/9/27** | **254** |
| 256 | | Phase 6: Inter-Local Agreements | 365 edays | Tue 6/29/27 | Wed 6/28/28 | 240 |



# Appendix G6 | **Covered Activities Memorandum**

# Memorandum

| | |
|---|---|
| **To:** | Scott Storment, EAHCP Program Manager |
| **From:** | Lucas Bare, Kylan Frye, and Erin Hitchcock, ICF |
| **Date:** | April 26, 2023 |
| **Re:** | **Recommended Changes to EAHCP Covered Activities for the Permit Renewal** |

# 1. Introduction

The purpose of this memo is to identify recommended changes to the activities covered under the Edwards Aquifer Habitat Conservation Plan (EAHCP) in the planning process to renew the EAHCP incidental take permit. This is the first of several memos and reports for the Analyze and Sign-off Phase of the permit renewal process, which will examine the major components of the EAHCP (e.g., Covered Activities, Covered Species, Conservation Measures) and identify potential changes to the EAHCP and incidental take permit to be considered by voting members of the Implementing Committee.[1] Changes identified herein will be presented to the Implementing Committee for concurrence by voting members and then will be carried forward in the permit renewal process. This permit renewal process will result in a draft amended EAHCP to the governing bodies of the permittees for final approval and authorization to submit to the U.S. Fish and Wildlife Service (USFWS). The final draft amended EAHCP will be submitted to USFWS with the incidental take permit amendment application. For more information about the EAHCP permit renewal process, including a detailed work plan, refer to eahcprenewal.org.

The EAHCP permit renewal is a multi-year and iterative planning process. The anticipated timeline for submitting the draft amended EAHCP and incidental take permit amendment application to the USFWS is the end of 2025. Throughout the planning process to identify changes to the EAHCP, components of the plan may need to be re-examined should circumstances change (e.g., identification of new scientific data or changes in regulatory status of species). As such, this memo serves as a check point to identify changes to Covered Activities to carry forward in the permit

[1] The Implementing Committee, as defined on page 35 of the Funding and Management Agreement, is composed of voting members from each of the five permittees and the Guadalupe-Blanco River Authority, a non-voting member. The governing bodies of the ITP Permittees will ultimately approve the final draft HCP.

renewal, but other changes to Covered Activities may still need to be considered later in the planning process. These changes will be documented through additional technical memoranda or draft EAHCP chapters and reviewed by EAHCP stakeholders, USFWS, and Permittees.

This memo describes the process for identifying changes to the Covered Activities and summarizes all changes evaluated, which are categorized as either recommended changes, changes considered but not recommended, or changes needing further evaluation.. The proposed specific edits to the Covered Activities chapter of the EAHCP are detailed in ***Attachment 1: Edwards Aquifer Habitat Conservation Plan Excerpted Chapter 2 with Proposed Changes.*** This memo only addresses the Covered Activities for which take is authorized by the incidental take permit, which is described in Chapter 2 of the EAHCP. It does not address Conservation Measures, including avoidance and minimization measures for new Covered Activities, which will be covered in a subsequent memo.

# 2. Evaluation of Covered Activities

Covered Activities encompass all actions that the EAHCP Permittees may conduct for which take is authorized by the incidental take permit. Covered Activities must be under the direct control[2] of the Permittees. The following sections describe the evaluation of the EAHCP's Covered Activities for the permit renewal process.

## 2.1 Process for Evaluating Covered Activities

The process for identifying potential changes to the EAHCP's Covered Activities started with the 2020 *Permit Options Report*.[3] The *Permit Options Report* describes how Permittees may make changes to the EAHCP and the incidental take permit. To inform the report, EAHCP program staff and Permittees were interviewed to identify issues that could be addressed through various permit options, including potential changes to Covered Activities.

Feedback on the EAHCP's Covered Activities was also requested during the Listen and Learn Phase of this permit renewal process. At Workshop 1, the following question was posed: "During the permit renewal process, what activities should be removed or considered for coverage that are not already covered?" The feedback received was then summarized in the 2022 *Listen and Learn Report*.[4]

Following the completion of the Listen and Learn Phase, further evaluation of potential changes to Covered Activities was conducted as follows:

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[2] *Direct control* is defined at 50 Code of Federal Regulations 13.25(d) to include any person who is under the direct control of the permittee, a person employed by the permittee, or person under contract to the permittee for purposes authorized by the permit.

[3] Available here: https://www.edwardsaquifer.org/wp-content/uploads/2020/09/EAHCP-Permit-Options-Report.pdf

[4] Available here: https://www.eahcprenewal.org/wp-content/uploads/2022/12/EAHCP-Permit-Renewal-Listen-and-Learn-Workshop-Report.pdf

1. The Permittees met with EAHCP program staff to review the current Covered Activities identified in Chapter 2 of the EAHCP and discuss suggested changes identified in the *Permit Options Report* and the *Listen and Learn Report*.
2. EAHCP program staff and the USFWS met to review all of the EAHCP's Covered Activities and hear the USFWS's ideas and recommendations for potential changes for consideration by the Permittees.
3. EAHCP program staff and ICF drafted proposed changes to the Covered Activities in a prior version of this memo that was reviewed by the Permittees.
4. A draft memo was reviewed by EAHCP stakeholders and the USFWS.

To consider all the suggested changes, each potential Covered Activity was screened according to the five criteria listed below. Candidate Covered Activities needed to meet all five criteria to be recommended as a Covered Activity for the renewed permit.

1. **Location:** The project or activity occurs in the Permit Area.
2. **Timing:** Construction of the project or implementation of activities is scheduled to begin after the EAHCP permit amendment is approved—anticipated to be August 2027—and the project is completed within the term of the renewed permit, which is assumed to be 30 years (through 2057).
3. **Impact:** The project or activity has a reasonable likelihood to result in take[5] of a Covered Species[6].
4. **Definition:** The location, size, and other relevant aspects of the project or activity can be defined sufficiently such that direct and indirect impacts on Covered Species can be evaluated and Conservation Measures developed to mitigate those impacts.
5. **Practicability:** Inclusion of the project or activity as a Covered Activity will not result in undue delays or substantial additional cost to the permit renewal process relative to the benefit of including the project or activity in the permit. In other words, it will be more cost-effective to provide incidental take permits for the project, activity, or service through the EAHCP rather than separately. Impractical Covered Activities include ones that, on their own, would add additional Covered Species, generate substantial controversy, or significantly complicate the impact analysis.

[5] *Take* is defined in section 3 of the Endangered Species Act as "harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct." USFWS further defines "harm" (50 CFR 17.3) as "...an act which actually kills or injures wildlife. Such act may include significant habitat modification or degradation where it actually kills or injures wildlife by significantly impairing essential behavioral patterns, including breeding, feeding, or sheltering."

[6] The current list of EAHCP Covered Species was used in evaluating this criterion without any consideration for potential changes to the covered species list that may be recommended as part of the permit renewal process.

## 2.2 Summary of Changes to Covered Activities

The following sections summarize the major proposed changes to EAHCP Chapter 2, *Covered Activities*, including a brief description of the type of change, the rationale for the change, and how it was evaluated using the criteria for Covered Activities described above, if applicable. Refer to *Attachment 1: Edwards Aquifer Habitat Conservation Plan Excerpted Chapter 2 with Proposed Changes* for proposed edits to the chapter to implement these changes. Not summarized in this section are proposed minor editorial changes or factual updates to Chapter 2 where additional explanation is not necessary.

### Edwards Aquifer Authority

### Move Detailed Description of Edwards Aquifer Authority Act Regulatory Framework to Chapter 1

#### Nature of Change

Editorial change to move detailed descriptions of the Edwards Aquifer Authority (EAA) Act, types of permits, and permit administration to Chapter 1, and summarize EAA permits authorizing groundwater withdrawal with Table 2-1 in Chapter 2.

#### Rationale for Change

Detailed descriptions of the EAA Act's regulatory framework are not necessary for describing the EAA's activities for which take is authorized. The description of EAA's Covered Activities should focus on the permits it administers for the withdrawal of groundwater.

#### Covered Activity Criteria

This is an editorial change, so evaluation with Covered Activity criteria is not applicable.

### Add Aquatic Vegetation Maintenance around U.S. Geological Survey Gages

#### Nature of Change

Substantive change to add aquatic vegetation maintenance at U.S. Geological Survey (USGS) Gages #08168913 (Old Channel), #08168932 (New Channel), and #08169000 (Comal River) in the Comal Springs system and at USGS Gage #08170500 (Sewell Park) in the San Marcos Springs system.

#### Rationale for Change

Flow estimates at gages #08168913, #08168932, #08169000, and #08170500 are calculated by automated readings and are verified manually by USGS technicians using transects and flow meter measurements. Adjustments are made to the stage-discharge relationship based on manual flow measurements collected from the transect. An accurate representation of springflow is critical for assessing when flows decrease and trigger Critical Period Management in the San Antonio Pool and the Critical Period Monitoring. If a manual measurement cannot be recorded, the USGS may back-correct flow records. Since 2018, it is not uncommon for USGS to shift the flow record 20 or more cfs in either direction during a record correction at the gage and the flow record has become increasingly subject to large manual corrections. Often, this creates issues with pumping reductions and biological monitoring requirements.

The primary reason for the increase in manual flow corrections and large shifts in the flow record is due to the presence of aquatic vegetation in the Comal River and the substantial expansion of Texas wild-rice in the San Marcos River, which disrupts the ability for the USGS to accurately measure flow at the gage locations.

Providing a vegetation-free transect for USGS to conduct manual flow measurements would improve flow measurements and in turn, help the EAHCP implement and manage the critical period programs. The USGS and USFWS have expressed support for vegetation maintenance to improve flow measurements.

**Covered Activity Criteria**

- **Location**: All gages are in the Permit Area: USGS Gage #08168913 is located on the Old Channel of the Comal River in the City of New Braunfels, USGS Gage #08168932 is located on the New Channel of the Comal River, USGS Gage #08169000 is located on the Comal River below the confluence of the Old and New Channels, and USGS Gage #08170500 is located on the San Marcos River in Sewell Park at Texas State University in the City of San Marcos.
- **Timing**: The activity would occur after 2027 and over the course of the renewed permit term. Vegetation would be removed from the gage area initially and would be assessed twice monthly to ensure that the gage area stays clear. Vegetation would be removed during monthly assessments, if needed.
- **Impact**: The activity has a reasonable likelihood of taking the Covered Species, including direct removal of Texas wild-rice or removal of other aquatic vegetation species that would result in habitat loss for Covered Species (e.g., fountain darter, San Marcos salamander). The impact to Covered Species from clearing this vegetation would be considered in the permit renewal process and addressed in the take estimate under the amended EAHCP, as appropriate.
- **Definition**: The transect area to be cleared at each gage is approximately 15 square meters. The activity is understood sufficiently to evaluate its effects to Covered Species.
- **Practicability:** The Permittees conduct similar vegetation maintenance activities elsewhere on the Comal River and San Marcos River. The activity would not add undue complexity, new Covered Species, or controversy to the EAHCP. Removing aquatic vegetation at this site will enhance the ability for the EAA to measure springflow and provide accurate flow data to support EAHCP implementation and management decisions (e.g., triggering of Condition M during low flows).

## City of New Braunfels

## Update Description of Management of Public Recreational Use

### Nature of Change

Editorial change to update the description of this Covered Activity to include paddleboarding as a recreational use of the river and City of New Braunfels' enforcement of public safety and enforcement measures.

### Rationale for Change

New recreational uses (e.g., paddleboarding) of the Comal Springs systems have gained popularity since the EAHCP was approved. This warrants updating the description of the types of recreational uses occurring. More detail about how the City of New Braunfels manages public recreation through enforcement is warranted to reflect the name of the Covered Activity and the interest in recreation enforcement received during the Listen and Learn Phase.

### Covered Activity Criteria

This is an editorial change, so evaluation with Covered Activity criteria is not applicable.

## Update Description of Golf Course Diversions and Operation

### Nature of Change

Editorial update to clarify the irrigation system and water reuse on the Landa Park Golf Course at Comal Springs.

### Rationale for Change

In the current EAHCP, the description of water use at the Landa Park Golf Course reflects the initiation of a project to develop and implement a reuse water system for the golf course and states that the design process has not been completed. This process has been completed and a water reuse system is in place; therefore, the new language reflects the most updated water use for the permittee.

### Covered Activity Criteria

This is an editorial change, so evaluation with Covered Activity criteria is not applicable.

## Update Description of Boat Operations on the Comal River

### Nature of Change

Editorial change to update the description of this Covered Activity to note which types of boats are authorized on the Comal River and under what circumstances motorized boats may be used on the river system.

### Rationale for Change

This change adds clarification and more detail to the description of what types of boat activities are authorized for the Comal River.

### Covered Activity Criteria

This is an editorial change, so evaluation with Covered Activity criteria is not applicable.

## Add Major Repair and Construction Activities

### Nature of Change

Substantive change to add major repairs and new construction in and adjacent to the Old and New Channels of the Comal River, Landa Lake, and the Comal Springs system, including those that may require a Clean Water Act Section 404 permit.

### Rationale for Change

Commenters during the Listen and Learn Phase suggested adding as Covered Activities construction and major repair activities within and on the banks of Landa Lake and the Comal River. The City of New Braunfels anticipates the need for these types of activities, and the existing EAHCP covers only minor or routine repair and maintenance that does not require a Clean Water Act Section 404 permit. The City of New Braunfels Parks and Recreation Master Plan[7], completed in 2018, identifies maintenance and repair activities that may be completed during the renewed permit term, including: repair, remodeling, and upkeep of recreational access points; upkeep of City of New Braunfels Parks; renovation of the tube chute; and Landa Park Aquatic Complex renovation (spring-fed pool adjacent to Old Channel). New construction projects described in the Parks and Recreation Master Plan include a trail system in a new city park in Town Creek parcels along Dry Comal Creek.

The purpose of expanding the EAHCP's Covered Activities to include construction and major repair activities that may require a Clean Water Act Section 404 permit is to streamline the permitting process for the City of New Braunfels and to ensure that the effects of these activities are considered in the conservation strategy of the EAHCP. The EAHCP would not fund the City of New Braunfels' construction and repair activities unless these are identified as conservation measures for Covered Species.

### Covered Activity Criteria

- **Location**: The activity is in the Permit Area, in the Comal Springs system (Comal Springs, Landa Lake or the Comal River) or the adjacent riparian areas within the Permit Area.
- **Timing**: The activity would occur during the permit term, after 2027 and over the course of the renewed permit term.
- **Impact**: Direct impacts on Covered Species (e.g., fountain darter, Comal Springs dryopid beetle, and Comal Springs Riffle Beetle) and their habitat for in-stream projects or indirect impacts for

[7] Available here: https://www.nbtexas.org/DocumentCenter/View/15753/New-Braunfels-Strategic-Master-Plan-Document-MPS

projects in adjacent riparian areas that could alter water quantity or quality in the Comal Springs system.

- **Definition**: The nature of the instream or adjacent construction activities is understood well enough to include them in the renewed EAHCP so that impacts can be evaluated programmatically. As part of the permit renewal process, assumptions for the number, size, frequency, and general location of projects using best available information would be made to estimate direct and indirect impacts for estimating the amount of take that would occur for Covered Species. This estimated take would be included in the total authorized take under the renewed permit. Additional Conservation Measures to avoid, minimize, and mitigate impacts to Covered Species from construction and major repair activities would also be added under the renewed permit.
- **Practicability**: The City of New Braunfels has conducted repair, maintenance, and construction projects in the Comal Springs system within the Permit Area, requiring a Section 404 permit. These projects have required that the U.S. Army Corps of Engineers (USACE) consult with the USFWS under Section 7 of the Endangered Species Act (ESA). Expanding the activities covered under the EAHCP to include these projects would help to streamline Section 404 permitting and ensure that these projects are consistent with the biological goals and objectives of the EAHCP. Adding this activity would not add undue complexity, new Covered Species, or controversy to the EAHCP.

# City of San Marcos

## Update Description of Management of Public Recreational Use

### Nature of Change

Editorial change to update the description of this Covered Activity to include paddleboarding as a recreational use of the river.

### Rationale for Change

New recreational uses (e.g., paddleboarding) of the San Marcos River and springs systems have gained popularity since the EAHCP was approved, which warrants updating the description of the types of recreational uses occurring. More detail about how the City of San Marcos manages public recreation is warranted to reflect the name of the Covered Activity and the interest in recreation enforcement received during the Listen and Learn Phase.

### Covered Activity Criteria

This is an editorial change, so evaluation with Covered Activity criteria is not applicable.

## Update Description of Boat Operations on the San Marcos River

### Nature of Change

Editorial change to update the description of this Covered Activity to note which types of boats are authorized on the San Marcos River and under what circumstances motorized boats may be used on the river system.

### Rationale for Change

This change adds clarification and adds more detail to the description of what types of boat activities are authorized for the San Marcos River.

### Covered Activity Criteria

This is an editorial change, so evaluation with Covered Activity criteria is not applicable.

## Add Major Repair and Construction Activities

### Nature of Change

Substantive change to add major repairs and new construction in and adjacent to the San Marcos Springs system, including those that may require a Clean Water Act Section 404 permit.

### Rationale for Change

Commenters during the Listen and Learn Phase suggested adding as Covered Activities construction and major repair activities that occur instream or in riparian areas. The City of San Marcos anticipates the need for these types of activities, and the existing EAHCP covers only minor or routine repair and maintenance that does not require a Clean Water Act Section 404 permit. Infrastructure maintenance or repair activities may include the upkeep of existing river access points and bridge maintenance that may include improving concrete footers/piers, abutments, wingwalls, and riprap. Potential projects may include, but would not be limited to, Aquarena Springs Drive bridge maintenance, Hopkins bridge maintenance, and Cypress Island pedestrian bridge rehabilitation. New construction activities may include installation of pedestrian walkways and installation of new recreation access points, including installation of concrete or steps and earthwork on adjoining banks.

The purpose of expanding the EAHCP's Covered Activities to include construction and major repair activities that may require a Clean Water Act Section 404 permit is to streamline the permitting process for the City of San Marcos and to ensure that the effects of these activities are considered in the conservation strategy of the EAHCP. The EAHCP would not fund the City of San Marcos' construction and repair activities unless these are identified as conservation measures for Covered Species.

### Covered Activity Criteria

- **Location**: The activity is in the Permit Area, in the San Marcos Springs system (San Marcos Springs, Spring Lake, and San Marcos River) or adjacent riparian areas within the Permit Area.
- **Timing**: The activity would occur during the permit term, after 2027 and over the course of the renewed permit term.
- **Impact**: Direct impacts on Covered Species (e.g., fountain darter, San Marcos salamander, Texas wild-rice) and their habitat for in-stream projects or indirect impacts for projects in adjacent riparian areas that could alter water quantity or quality in the San Marcos Springs system.
- **Definition**: The nature of the instream or adjacent construction activities is understood well enough to include them in the renewed EAHCP so that impacts can be evaluated programmatically. As part of the permit renewal process, assumptions for the number, size, frequency, and general location of projects using best available information would be made to

estimate direct and indirect impacts for estimating the amount of take that would occur for Covered Species. This estimated take would be included in the total authorized take under the renewed permit. Additional Conservation Measures to avoid, minimize, and mitigate impacts to Covered Species from construction and major repair activities would also be added under the renewed permit.

- **Practicability**: The City of San Marcos has conducted repair, maintenance, and construction projects in the San Marcos Springs system within the Permit Area, requiring a Section 404 permit. These projects have required that USACE consult with the USFWS under Section 7 of the ESA. Expanding the activities covered under the EAHCP to include these projects would help to streamline Section 404 permitting and ensure that these projects are consistent with the biological goals and objectives of the EAHCP. The activity would not add undue complexity, new Covered Species, or controversy to the EAHCP.

## Texas State University

## Update Description of Management of Recreational and Educational Activities

### Nature of Change

Editorial changes to update the description of this Covered Activity to include paddleboarding as a recreational use of the San Marcos River, remove golf as a recreational use adjacent to the river, and differentiate the recreational and educational activities occurring in Spring Lake, which are only conducted when authorized by TXST, from those occurring in the San Marcos River.

### Rationale for Change

New recreational uses (e.g., paddleboarding) of the San Marcos River have gained popularity since the EAHCP was approved, which warrants updating the description of the types of recreational uses occurring. The Texas State University golf course has been closed since 2015 and will remain closed in the foreseeable future. The existing EAHCP is not clear that recreational and educational activities occur in Spring Lake only when authorized by TXST, so a separate covered activity heading is added to make this distinction.

### Covered Activity Criteria

These changes are editorial in nature for the purpose of clarifying existing Covered Activities, so evaluation with Covered Activity criteria is not applicable.

## Update Description of Vegetation Management

### Nature of Change

Editorial change to update the description of this Covered Activity to clarify the location of vegetation management activities and to clarify how floating vegetation mats are managed and why they are removed.

### Rationale for Change

The change adds detail on where Covered Activities occur and how floating vegetation mats are managed by the Permittee.

### Covered Activity Criteria

This is an editorial change, so evaluation with Covered Activity criteria is not applicable.

## Update Description of Diving Classes in Spring Lake

### Nature of Change

Editorial change to eliminate the detailed description of Texas State University's diving classes conducted in Spring Lake (e.g., number of students, number of dives) and instead refer to the Spring Lake Management Plan for this detail.

### Rationale for Change

The details about various types of diving classes and specifics as to the number of students and/or dives per class are not necessary for including in the EAHCP. This level of detail is more appropriate in the Spring Lake Management Plan, which will be referenced in the EAHCP. This way, if certain dive class specifics need to change, these changes would not require amending the EAHCP or incidental take permit.

### Covered Activity Criteria

This is an editorial change, so evaluation of Covered Activity criteria is not applicable.

## Update Description of Research Programs

### Nature of Change

Editorial changes to update the description of Research Programs, including the conditions on the Covered Activity.

### Rationale for Change

The change clarifies the responsible party as the Meadows Center for reviewing research proposals to determine if there is a potential for take and specifying the requisite course for individuals providing diving support to research studies.

### Covered Activity Criteria

This is an editorial change, so evaluation of Covered Activity criteria is not applicable.

## Update Description of Water Diversion from Spring Lake and San Marcos River

### Nature of Change

Editorial change to update the description of this Covered Activity to correct water diversion numbers in the current EAHCP.

### Rationale for Change

The change corrects water diversion numbers for Spring Lake and the San Marcos River for surface water rights issued by Texas Commission on Environmental Quality (TCEQ) and held by Texas State University.

### Covered Activity Criteria

This is an editorial change, so evaluation with Covered Activity criteria is not applicable.

## Update Description of Management of Golf Course and Grounds

### Nature of Change

Editorial change to include management of recreational intramural fields in the description of the land use and management of the previous Texas State University Golf Course location.

### Rationale for Change

The Texas State University Golf Course is no longer used as a golf course. The University currently uses a portion of the previous golf course location as intramural fields and recreational use. The update reflects a change in management activities at this location. Ongoing management activities include application of fertilizer and pesticides, mowing, and landscaping. The change updates the activity to reflect current land use practices.

### Covered Activity Criteria

This is an editorial change, so evaluation with Covered Activity criteria is not applicable.

## Update Description of Boat Operations

### Nature of Change

Editorial change to update the description of this Covered Activity to note which types of boats are authorized on the San Marcos River and Spring Lake and under what circumstances motorized boats may be used on the river system.

### Rationale for Change

This change adds clarification and adds more detail to the description of what types of boat activities are authorized for the San Marcos River and Spring Lake.

### Covered Activity Criteria

This is an editorial change, so evaluation with Covered Activity criteria is not applicable.

## Add Major Repair and Construction Activities

### Nature of Change

Substantive change to add major repairs and new construction in and adjacent to the San Marcos Springs system, including those that may require a Clean Water Act Section 404 permit.

**Rationale for Change**

Commenters during the Listen and Learn Phase suggested adding construction activities, major construction projects, and activities on banks to the EAHCP Covered Activities. Texas State University anticipates the need for these types of activities[8], and the existing EAHCP covers only minor or routine repair and maintenance that does not require a Clean Water Act Section 404 permit. The following activities are anticipated:

- Recreation access points would be repaired, stabilized or constructed.
- Sewell Park access points would be improved, maintained, and repaired as needed. Bank stabilization activities would be implemented, including areas near the Sessom Creek Confluence and San Marcos River headwaters.
- Concrete walls along portions of Sewell Park and Upper Sewell (below the dam) would be repaired, replaced, or removed.
- Improvements may include replacing existing walls with natural river banks.
- Development of recreational/educational trails adjacent to Spring Lake.
- Installation of a floating pedestrian bridge along a portion of the Slough Arm or southern portion of Spring Lake.
- Improvement or replacement of concrete curbing along the headwaters area of Spring Lake. These improvements or replacements could be considered conservation measures since they are proximate to major spring orifices and habitat and are in danger of failing.

  The purpose of expanding the EAHCP's Covered Activities to include construction and major repair activities that may require a Clean Water Act Section 404 permit is to streamline the permitting process for the Texas State University and to ensure that the effects of these activities are considered in the conservation strategy of the EAHCP. The EAHCP would not fund the Texas State University's construction and repair activities unless these are identified as conservation measures for Covered Species.

**Covered Activity Criteria**

- **Location**: In Spring Lake or the San Marcos River (Spring Lake Dam to City Park) or adjacent riparian areas within the Permit Area.
- **Timing**: After 2027 over the course of the renewed permit term.
- **Impact**: Direct impacts on Covered Species and their habitat for in-stream projects or indirect impacts for projects in adjacent riparian areas that could alter water quantity or quality in Spring Lake or the San Marcos River.

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[8] Texas State University will be initiating a University Master Planning process in 2023, which will identify specific facilities and campus improvements that will be completed. The focus of the Master Plan will be the eastern side of the campus, which includes areas around the San Marcos River and Spring Lake. The Master Plan would be completed in 2024; however, preliminary information on proposed projects would be available in spring of 2024. Once available, the list of projects will be evaluated to determine if they warrant coverage under the EAHCP, and the EAHCP's recommended Covered Activities for Texas State University will be updated, as needed.

- **Definition**: The EAHCP would cover these activities programmatically. Assumptions for the number, size, frequency, and general location of projects using best available information would be made to estimate direct and indirect impacts for estimating the amount of take that would occur for Covered Species and to define Conservation Measures to avoid, minimize, and mitigate impacts.
- **Practicability**: Texas State University has conducted repair, maintenance, and construction projects in the San Marcos Springs system within the Permit Area, requiring a Section 404 permit. These projects have required that USACE consult with the USFWS under Section 7 of the ESA. Expanding the activities covered under the EAHCP to include these projects would help to streamline Section 404 permitting and ensure that these projects are consistent with the biological goals and objectives of the EAHCP.

### Texas Parks and Wildlife Department

Texas Parks and Wildlife Department is not a permittee under the EAHCP and is not seeking incidental take authorization under the amended EAHCP for its creation of a State Scientific Area in the Permit Area. As such, the description of Texas Parks and Wildlife Department activities is proposed for removal from the EAHCP's Covered Activities. Any EAHCP implementation responsibilities that remain with Texas Parks and Wildlife Department would be described in the implementation chapter of the EAHCP.

## 2.3 Activities Considered but Not Recommended for Coverage

The following projects or activities were considered for coverage in the renewed EAHCP but are not proposed, as explained below.

### Spring-Fed Pool Diversions at City of New Braunfels

A reinforced toe is planned to be installed at the spring-fed pool diversion. This activity is not recommended for coverage because it is scheduled to occur in 2023—before the current permit term expires—and would require a USACE Section 404 permit. Because the project requires a Section 404 permit, it will receive take authorization through the federal consultation associated with that permit (i.e., through an ESA Section 7 consultation and biological opinion).

### Spring Lake Dam Improvement

Improvements to Spring Lake Dam are required to meet TCEQ Dam Safety Program guidelines. These improvements would be required in the next 3 to 5 years—before the current permit term expires—and would require a USACE Section 404 permit. Therefore, the project will receive take authorization through the federal consultation associated with that permit (i.e., through an ESA Section 7 consultation and biological opinion).

### Cape's Dam Repair or Removal

Cape's Dam Repair or Removal was initially discussed for including as a Covered Activity. However, the City of San Marcos does not yet have clear plans for Cape's Dam. Furthermore, the location and extent of direct and indirect impacts on Covered Species are highly uncertain. The project is also controversial. As such, this project does not meet the definition or practicability criteria to be recommended for coverage.

### San Antonio Water System Infrastructure Installation and Maintenance

San Antonio Water System (SAWS) has obtained ESA Section 10(a)(1)(B) permits for installing pipelines and pumphouses to authorize take of listed karst species and salamanders. Expanding the Covered Activities to include this type of infrastructure installation that does not have a direct impact on the San Marcos or Comal Springs systems would increase the complexity of the EAHCP by adding other Covered Species. SAWS has elected to pursue coverage for these types of activities on an as-needed basis through other ESA Section 10 or Section 7 take authorizations. SAWS infrastructure projects do not meet the practicability criterion to be recommended for coverage.

### Commercial Recreation Outfitters

Under the current EAHCP, incidental take resulting from recreational activities conducted by commercial outfitters may be covered under a voluntary Certificate of Inclusion (COI). To date, no outfitters have applied for or received a COI under the program. Based on feedback from meetings with the Permittees, the Permittees decided to remove the voluntary COI provision from the EAHCP due to lack of participation and an expected lack of future interest from recreational outfitters.

## 2.4 Changes to Covered Activities Needing Further Evaluation

Based on the comments received from Permittees, stakeholders, and the USFWS on draft versions of this memo and the excerpted Chapter 2 (Attachment 1), certain Covered Activities need to be evaluated further for how they are described in the EAHCP. These Covered Activities are listed below. Any subsequent changes to these Covered Activities will be proposed via additional technical memoranda and/or draft EAHCP chapter and reviewed by stakeholders, USFWS, and Permittees.

Covered Activities needing further evaluation for how they are described in the EAHCP include the following.

- **Evaluate the descriptions for management of recreational use for City of New Braunfels, City of San Marcos, and Texas State University.** USFWS and stakeholder comments suggest that the descriptions for recreation management should be evaluated further to ensure that the description addresses all anticipated recreational activities that are likely to result in take while not being too general to cause uncertainty as to which recreational activities are covered and which are not.
- **Review *Diversion of Water from Spring Lake and San Marcos River* for accuracy and clarity.** Additional coordination is needed between the ICF, EAHCP program staff, Texas State, and the City of San Marcos to revise and update surface water diversion information so that the water right and diversion volume limit and location information is accurate, current, and relevant.
- **Determine if the Aquifer Storage and Recovery (ASR) facility should be described as a Covered Activity in Chapter 2 or only in Chapter 5 as a mitigation measure**. Use of the ASR for springflow protection is included in the EAHCP as a minimization measure in Chapter 5. It is unclear what adverse impacts use of the ASR would have on Covered Species, so this activity

may not need to be described in Chapter 2 as an activity for which SAWS seeks take authorization.

- **Evaluate whether management of open space adjacent to Springs systems needs coverage.** USFWS commented that it is "…unclear how the golf course and grounds management and management of recreation fields will have an effect on species, and thus needs coverage." Additional evaluation is needed to determine the likelihood of take resulting from management and maintenance of the golf course in New Braunfels and the recreational fields at Texas State University.
- **Avoid duplicate descriptions of Covered Activities.** USFWS commented that "For ease of implementation, understanding this document, and compliance monitoring, it would be beneficial to combine duplicate activities (e.g., vegetation management, recreation, repair and construction activities)." Avoiding duplicate descriptions of Covered Activities, which are presently organized by Permittee, would require modifying the chapter's organization and this warrants further evaluation before such modification could be proposed.

Attachment 1

# Edwards Aquifer Habitat Conservation Plan
# Excerpted Chapter 2 with Proposed Changes

***Note to Reviewer:*** *Text below is excerpted directly from the current EAHCP (updated in 2021). Any gray-shaded text indicates proposed edits for the EAHCP permit renewal. The excerpted text does not include the sections in the current EAHCP that list the Minimization and Mitigation Measures and Measures that Contribute to Recovery for each Permittee; these measures will be addressed in a subsequent technical memorandum.*

## 2.1 Covered Activities

The Applicants seek incidental take coverage for four categories of activities that may result in incidental take of the fish and wildlife Covered Species: (1) the regulation and use of the Aquifer; (2) recreational activities in the Comal and San Marcos spring and river ecosystems; (3) other activities in, and related to, the Comal and San Marcos springs and river ecosystems; and (4) activities involved in and related to the implementation of the minimization and mitigation measures in these ecosystems (described in Chapter 5).

Regulation of Edwards Aquifer groundwater withdrawals is the responsibility of the Edwards Aquifer Authority (EAA). The EAA seeks coverage for the entities it authorizes to use the Aquifer. The San Antonio Water System (SAWS), the City of New Braunfels, the City of San Marcos, and Texas State University seek incidental take coverage, as Applicants, for their pumping from the Aquifer authorized by the EAA.

The cities of New Braunfels and San Marcos and Texas State University have the authority to manage the spring and river ecosystems within their respective jurisdictions including many aspects of the use of the ecosystems for recreation and education. They are seeking incidental take coverage for these activities.

Each of the Applicants will be responsible for the implementation of minimization and mitigation measures as well as measures that contribute to the recovery of the Covered Species, each seeks coverage for any take that may result from these measures.

The following is a description of the specific activities for which incidental take coverage is sought. Descriptions of the measures that will be implemented to minimize and mitigate the impacts of the incidental take are set out in Chapter 5.

## 2.2 Edwards Aquifer Authority

### 2.2.1 Groundwater Withdrawal Authorization and Management

***Note to Reviewer:*** *The text describing the EAA Act and associated rules that is proposed for removal from this section will be summarized in Chapter 1 of the EAHCP as background information pertaining to the regulatory framework of the plan.*

Relative to the HCP, the EAA's primary statutory obligation is to authorize and manage the withdrawal of groundwater from the Aquifer. The EAA carries out its statutory powers through rulemaking, decisions of the General Manager, decisions of other authorized staff, and orders, or other decisions of the Board of Directors.

The EAA seeks incidental take coverage for the EAA's programs that implement these statutory functions. In addition, the EAA seeks coverage for entities who are both authorized under the EAA Act and the EAA's rules to withdraw groundwater from the Aquifer within the jurisdictional boundaries of the EAA and in compliance with the Act and rules. Table 2-1 summarizes the EAA's groundwater withdrawal permits included as Covered Activities.

**Table 2-1. Edwards Aquifer Authority Groundwater Withdrawal Permits Included as Covered Activities**

| Permit Type | EAA Act Section | Description | Subject to Annual 572,000 ac-ft/yr Cap[1] |
|---|---|---|---|
| Initial Regular and Regular Permits | 1.16 | Permits initially issued based on historical use during the historical period from June 1, 1972, through May 31, 1993, and new permits, issued after August 12, 2008, resulting from the sale or amendment of an initial regular permit, or the consolidation of two or more initial regular permits.[2] | Yes |
| Term Permits | 1.19 | Issued for a defined term up to a maximum of 10 years | No |
| Emergency Permits | 1.20 | Issued for preventing the loss of life, or to prevent severe, imminent threats to public health or safety | No |
| Recharge Recovery Contracts | 1.44 | Entered into pursuant to Aquifer storage and recovery projects conducted to increase the yield of the Aquifer, protect springflows, and ensure minimum springflows of the Comal and San Marcos Springs | No |
| Exempt Wells | 1.15, 1.16, 1.33 | Exempt from the duty to obtain a groundwater withdrawal permit, but must register well with the EAA | No |

[1] Permits not subject to the annual statutory cap on Aquifer withdrawals of 572,000 ac-ft/yr are addressed in Section 8.1, *Changed Circumstances*.

[2] Although the EAA Act provides in Section 1.18 that the EAA may also issue Additional Regular Permits, this portion of the act cannot be implemented because no additional water is available for permitting under the 572,000 ac-ft/yr cap established by the Legislature in 2007.

For more information on the EAA Act and Rules, including permit transfers and amendments and the Critical Period Management Program, refer to Section 1.5.2, *Edwards Aquifer Authority*.

## 2.2.2 Vegetation Maintenance around U.S. Geological Survey Gages

Flow measurements at United States Geological Survey (USGS) gages #08168913, #08168932, #08169000 and #08170500 are calculated by automated readings and are verified manually by USGS technicians using transects and flow meter measurements. Adjustments are made to the stage-discharge relationship based on manual flow measurements collected from the transect. An accurate representation of springflow is critical for assessing when flows decrease and trigger Critical Period Management in the San Antonio Pool or Critical Period Monitoring. If a manual measurement cannot be recorded, the USGS may back-correct flow records, which can create issues with pumping reductions and biological monitoring requirements.

Three USGS Gages are located in the Comal River Springs system in the City of New Braunfels. USGS Gage #08168913 is located on the Old Channel of the Comal River, USGS Gage #08168932 is located on the New Channel of the Comal River, and USGS Gage #08169000 is located on the Comal River, below the confluence of the Old and New Channels. USGS Gage #08170500 is located on the San Marcos River at Aquarena Springs Drive and Sewell Park at Texas State University in the City of San Marcos. The EAA seeks incidental take coverage for removing aquatic vegetation from an area of approximately 15 square meters at each gage site to maintain a vegetation-free transect for USGS to conduct manual flow measurements. Initial vegetation removal would be pulled manually by hand and then the transect would be assessed approximately twice monthly and hand-pulled as needed to ensure that the gage transect area stays clear.

## 2.3 City of New Braunfels

The Comal Springs, Landa Lake, and the Comal River are located within the boundaries of the City of New Braunfels. The City has the authority to manage the ecosystems of the Comal Springs, Landa Lake, and the Comal River within its geographical boundaries. These ecosystems are also used for recreational activities that are regulated in part by the City. Further, the City of New Braunfels diverts surface water from the Comal River.

As described below, the City seeks incidental take coverage for the recreational activities within its jurisdiction, the management of the ecosystems of the Comal Springs, Landa Lake, and Comal River, the diversion of water from the Comal River, and city-sponsored construction projects that occur instream and adjacent to the Comal River, Comal Springs, and Landa Lake.

### 2.3.1 Management of Public Recreational Use of Comal Springs and River Ecosystems

Public recreational use of the Comal Springs and River ecosystems includes, but is not limited to, swimming, wading, tubing, boating, canoeing, kayaking, paddleboarding, scuba diving, snorkeling, and fishing. Related activities include operation of the wading pool at Landa Park on Spring Run 2, non-motorized vessels on Landa Lake, and all tubing, regardless of origin of the tuber or tube, on the Comal River from the confluence of the Dry Comal Creek to the confluence of the Guadalupe River. During high-use periods, the New Braunfels Police Department stations officers in the Comal River to protect public safety. The City of New Braunfels Park Rangers enforce recreation ordinances within City boundaries. Where this recreational use is facilitated in any respect by the City of New Braunfels, including but not limited to providing public access or outfitting services, the City of New Braunfels seeks incidental take coverage for impacts of these Covered Activities.

### 2.3.2 Management of Water Levels in the Comal River

The City of New Braunfels operates gates, culverts, and dam structures from Landa Lake to the Old Channel (three culverts), New Channel U.S. Geological Survey (USGS) Weir, Spring-fed Pool Inlet, Wading Pool Weir, Clemens Dam, USGS Weir Dam #2, Golf Course Weir, and Mill Pond Dam (joint New Braunfels Utility and City of New Braunfels operation) to maintain constant elevations of the Landa Park Spring-fed Pool and to regulate flow regimes in the Old and New Channels during high and low flow events.

The City of New Braunfels also has a permit from TCEQ for 40 acre-feet of impounded water at Clemens Dam (Permit 18-3827, City of New Braunfels Tube Chute). This permit is non-consumptive and establishes the constant level in the Comal River upstream of Clemens Dam to the confluence of the Old Channel and confluence of the Dry Comal Creek

The City seeks incidental take coverage for the operation of these structures including any incidental take that may occur during their operation such as by entrapment of a Covered Species.

### 2.3.3 Golf Course Diversions and Operation

The City of New Braunfels seeks incidental take coverage for the maintenance and upkeep of the Landa Park Golf Course adjacent to the Old Channel of the Comal River, including the use of plant protectants and the diversion of water from the Old Channel to maintain the golf course.

Irrigation water for the golf course is obtained via a single diversion from the Old Channel permitted by TCEQ (Permit 18-3824, Permit 18-3824A, Permit 18-3824B, and Permit 18-3826). The diversion is located approximately 200 yards upstream of Hinman Island Drive and considerably downstream of the Old Channel Long-Term Biological Goal reach. The total water that is permitted for that diversion is 300 ac-ft/yr (200 ac-ft under permit 18-3824 and 100 ac-ft/yr for permit 18-3826). Permit 18-3826 is the more junior water right. The total diversion rate allowed under both permits combined is 2 cfs. Currently, the pump for the diversion is capable of diverting only 1 cfs. The surface water diversion will be operated in accordance with TCEQ rules including any TCEQ order to reduce or stop diverting water during low flows.

Historically, the Landa Park Golf Course does not use its full permitted water rights for irrigating the Golf Course. To reduce dependency on Comal River water further, the City of New Braunfels, in collaboration with New Braunfels Utilities, used a grant provided by the Texas Water Development Board to develop and implement a reuse water system that can be used to maintain the golf course by supplementing or, when feasible, replacing the surface diversions used for irrigation purposes. The water irrigation system has been installed on the golf course and is awaiting New Braunfels Utilities to implement a system-wide water reuse program to supply the irrigation system.

### 2.3.4 Spring-Fed Pool Diversions and Operation

The City of New Braunfels seeks incidental take coverage for the impacts of its use and operation of the Landa Park Spring-fed Pool adjacent to the Old Channel of the Comal River. The City of New Braunfels is authorized to divert 8 ac-ft/yr of water from the Old Channel and impound it in the pool by TCEQ Permit 18-3826. Because the water is returned to the Old Channel, this diversion is permitted as a non-consumptive use. Maintenance operations (routine cleaning, algae removal, chemical application pursuant to label instructions, and filling/emptying) will be conducted according to the 2003 Comal Ecosystem Management Plan (Appendix N) or any updates to this plan agreed to by the USFWS and the Permittees. Surface water diversions will be operated in accordance with TCEQ rules as established by Permit 18-3826.

### 2.3.5 Boat Operations on Comal River and Landa Lake

The City of New Braunfels seeks incidental take coverage for the boats it operates on the Comal River and Landa Lake related to research, enforcement, litter collection, and maintenance activities. The City of New Braunfels uses non-motorized boats such as kayaks and canoes for all routine maintenance and research activities. Motorized boats are used by law enforcement and first responders for emergency purposes only on the Comal River and Landa Lake.

### 2.3.6 Infrastructure Maintenance, Repair, and Construction

The City of New Braunfels seeks incidental take coverage for existing infrastructure maintenance and repair, and construction or installation of new infrastructure and facilities located instream or on City of New Braunfels property immediately adjacent to the Comal Springs system or that directly affects the Comal Springs system.

Routine, minor repairs include activities such as upkeep of access points or walkways and stairways adjacent or leading to the springs or river. Major repairs or new construction activities include stabilization or reconstruction of recreational access points, construction of new access points, major repair of banks, and other activities significantly modifying infrastructure or facilities in the Comal Springs system. New construction activities may include installation of new river access points, including installation of concrete or stone steps and associated earthwork on adjacent banks.

In general, these activities may include the following components:

- Removal of riparian and aquatic vegetation.
- Relocation or biotic salvage of Covered Species in accordance with approved relocation plans.
- Dewatering at construction sites.
- Installation of best management practices (BMPs), including, but not limited to those to reduce downstream sedimentation and for human health and safety.
- Installation of concrete, riprap, boulders, and steps on banks.
- Installation of bridge piers or temporary abutments.
- Earthwork on banks or instream.
- Reestablishment of flow.

## 2.4 City of San Marcos

The City has the authority to manage the ecosystems of the San Marcos River and Springs within its jurisdiction. These ecosystems are also used for recreational activities that are regulated in part by the City. The City of San Marcos also is authorized to pump water from the Aquifer.

The City seeks incidental take coverage for the recreational activities within its jurisdiction, management of the San Marcos River and Springs ecosystem, permitted use of the Aquifer, and city-sponsored construction projects that occur instream and adjacent to the San Marcos River and Springs.

### 2.4.1 Management of Recreational Use of San Marcos Springs and River Ecosystems

Recreational uses of the San Marcos Spring and River ecosystems occurring within City of San Marcos parks adjacent to the San Marcos River include, but are not limited to, swimming, wading, tubing, boating, canoeing, kayaking, paddleboarding, snorkeling, SCUBA diving, and fishing. The City of San Marcos seeks incidental take coverage for its management of public recreation and for the individuals who recreate in accordance with all applicable laws and regulations.

### 2.4.2 Boat Operations on San Marcos River

The City of San Marcos seeks incidental take coverage for its boat operations on the San Marcos River related to emergency response, emergency response training, law enforcement, research, litter collection, and maintenance activities. The City typically uses kayaks and non-motorized inflatable boats, with occasional use of electric trolling motors. The use of gas-powered motors would be reserved only for emergency situations when excessive currents are present, such as a rescue during a flood event.

### 2.4.3 Infrastructure Maintenance, Repair, and Construction

The City of San Marcos seeks incidental take coverage for maintenance and repair of existing infrastructure and construction or installation of new infrastructure located instream or on City of San Marcos property immediately adjacent to the river or in a location where the construction or maintenance activity has the ability to directly affect the San Marcos Springs and River ecosystem.

Routine, minor repairs would include activities such as repairs to river access points and to pedestrian walkways adjacent to the river. Major infrastructure repair activities include, but are not limited to, bridge maintenance and repair, including full bridge replacement and repair of concrete footers/piers, abutments, wingwalls, and riprap; stabilization or remodeling of river access points. New construction activities may include installation of new river access points, including installation of concrete or stone steps and associated earthwork on adjacent banks.

In general, these activities may include the following components:

- Removal of riparian and aquatic vegetation.
- Relocation or biotic salvage of Covered Species in accordance with approved relocation plans.
- Dewatering at construction sites.
- Installation of BMPs, including, but not limited to, those to reduce downstream sedimentation and for human health and safety.
- Installation of concrete, riprap, boulders, and steps on banks.
- Installation of bridge piers or temporary abutments.
- Earthwork on banks or in -stream.
- Reestablishment of flow.

## 2.5 Texas State University

Portions of the San Marcos River and the San Marcos Springs (Spring Lake) are located within the jurisdiction of Texas State University. The University has the authority to manage the ecosystems of the San Marcos River and Springs within its jurisdiction. These ecosystems are used for educational and research purposes by the University, for recreational activities by the students, faculty and staff of the University and for public service activities. The University is authorized to pump water from the Aquifer and to divert water from Spring Lake and San Marcos Springs.

The University seeks incidental take coverage for the educational, recreational, and public service activities within its jurisdiction, the management of the ecosystems of the San Marcos River and Springs, the permitted use of the Aquifer, the diversion of water from Spring Lake and river, the use of the San Marcos Springs and River, and university-sponsored construction projects that occur instream and adjacent to the San Marcos River and Spring Lake.

## 2.5.1 Management of Public Recreational Use of the San Marcos River

Public recreational use of the San Marcos River includes, but is not limited to, swimming, wading, tubing, boating, canoeing, kayaking, paddleboarding, diving, snorkeling and fishing. Covered Activities include authorized recreational activities in accordance with all applicable laws and regulations.

## 2.5.2 Management of Recreational/Educational Use of Spring Lake

Recreational/educational use of Spring Lake includes, but is not limited to, boating, kayaking, paddleboarding, and snorkeling. The recreational/educational activities that occur in Spring Lake are allowed via guided-tours and/or with prior approval from The Meadows Center for Water and the Environment. Covered Activities include authorized recreational/educational activities in accordance with all applicable laws and regulations.

## 2.5.3 Vegetation Management

### 2.5.3.1 Management of Submerged and Floating Aquatic Vegetation in Spring Lake

Texas State University currently cuts and harvests submerged aquatic vegetation throughout Spring Lake with a harvester boat and manually cuts vegetation from around spring openings, the underwater archaeological site, along the wall by historic hotel (now offices for the Meadows Center), and in the diving area. Vegetation may be removed to enhance viewing from the Meadows Center's glass-bottom boats and prevent entanglement of plant material in the boat propellers.

### 2.5.3.2 Management of Aquatic Vegetation and Litter from Spring Lake Dam to City Park

Lower flows in the San Marcos River increase the likelihood of vegetation mats forming on top of Texas wild-rice which may interfere with flowering and reproduction, block sunlight and interfere with photosynthesis and slow current velocity (Power 1996). Additionally, the San Marcos River is heavily used for recreation from Spring Lake Dam to IH-35. Texas State University will remove or dislodge floating vegetation mats and litter in the River from Spring Lake Dam to City Park. The purpose of this is to benefit Texas wild-rice and other submerged aquatic vegetation used as habitat for fountain darters while enhancing the aesthetics and enjoyment of recreational activities, such as tubing, swimming, canoeing, paddleboarding, and fishing, in areas from Spring Lake Dam to City Park.

## 2.5.4 Diving Classes in Spring Lake

Texas State University provides educational activities within Spring Lake and the San Marcos River in accordance with all applicable laws and regulations. The University has designated an area as its Dive Training Area in Spring Lake; this area was the site of the underwater show of the Aquarena Springs theme park for over 40 years. The natural and cultural resources in this area have long been disturbed, hence diving activities occurring here will have minimal impact, if any, on listed species.

To minimize the impacts of its classes and programs on the habitat in Spring Lake, any individual diving outside of the Dive Training Area has to complete the Dive Authorization Course for Spring Lake.

Texas State University seeks incidental take coverage for these educational activities. Current educational activities include the following Covered Activities: Dive Authorization Course, Continuing Education SCUBA Classes, and Texas State SCUBA classes. These activities are defined in the Spring Lake Management Plan (Appendix X).

### 2.5.5 Research Programs

Research is a primary component of Texas State University's activities in Spring Lake. All research proposals will be reviewed by the staff of the Meadows Center to ensure there is no impact on Covered Species or their habitat in Spring Lake. If take cannot be avoided it will be minimized by educating the researchers as to the area where the species are located and by requiring measures to minimize any potential impacts. Any diving support to a research study in Spring Lake will be provided by individuals who have completed the Dive Authorization Course for Spring Lake.

### 2.5.6 Diversion of Water from Spring Lake and San Marcos River

Texas State University has surface water right certificates from the TCEQ, as described below. Texas State University seeks incidental take coverage for the use and operation of the authorized diversions.

#### 2.5.6.1 Spring Lake (Certificate 18-3865)

Texas State University has a 100 ac-ft/yr irrigation water right. A pump house located on the south-eastern side of the Sink Creek Slough Arm of Spring Lake diverts an average of 26 ac-ft/yr of water for the purpose of irrigating the grounds in the Spring Lake area. The permit limits the diversion rate for the diversion to 1.33 cfs.

The University also has a 534 ac-ft/yr industrial permit with a maximum permitted diversion rate of 600 gpm. The water is pumped from an intake site located just below the Spring Lake dam. The permit limits the diversion rate for the diversion to 1.33 cfs.

Texas State University has a 513 ac-ft/yr municipal water right; a 64,370 ac-ft/yr hydroelectric water right, of which 31,108 ac-ft/yr have been permanently placed in the Texas Water Trust for environmental flow protection purposes; a 100 ac-ft/yr water right for agricultural purposes retained and is in-use as of 2022 (described above); and a 700 ac-ft/yr water right to operate an artificial waterfall. The permit for the hydroelectric plant and artificial waterfall is for non-consumptive use with the water being returned to Spring Lake near the point of diversion. The diversion rate for the 513 acre-foot right is limited by the permit to 2.22 cfs. The University has not exercised these rights and has no present intention to exercise these rights. However, Texas State University may consider exchanging these rights for additional irrigation or industrial rights if future growth requires additional water resources.

In addition, the University is authorized to impound 150 ac-ft in Spring Lake.

The rate of diversion from Spring Lake for consumptive use water under TCEQ Certificate No 18-3865 is limited to a total of 4.88 cfs.

#### 2.5.6.2 San Marcos River (Certificate 18-3866)

Texas State University has 40 ac-ft/yr in irrigation rights that are not currently being used. The diversion is located on the San Marcos River at Sewell Park. The permit requires Texas State University to reduce the diversion to 20 ac-ft/yr when flow in the San Marcos River falls below 128 cfs. The permit limits the rate of diversion for this water right to 1 cfs. The University also has a 60 ac-ft/yr industrial permit used to fill and replenish seven off-channel reservoirs (old fish hatchery ponds) for biological research and related educational purposes. In 2022, Texas State University used 45.4 ac-ft/yr to replenish these ponds. The permit limits the rate of diversion for this water right to 2.22 cfs. The water is diverted at a pump house located in Sewell Park.

The total rate of diversion for consumptive use water from the San Marcos River under TCEQ Certificate No 18-3866 is limited to 3.22 cfs.

### 2.5.7 Management of Recreational Fields and Facilities

Texas State University seeks incidental take coverage for the impacts of its maintenance of recreational fields and facilities located adjacent to Spring Lake in the Sink Creek area. These areas were previously used as a nine-hole golf course; however, a portion of the former golf course was repurposed as intramural sports fields, tailgating areas, and football fields. Management practices include application of fertilizer and pesticides, mowing, and landscaping. During events, portable toilets may be used, but would be placed as far from the Spring Lake and the San Marcos River as possible to prevent spills or overflow due to flooding.

### 2.5.8 Boating in Spring Lake and Sewell Park

Texas State University seeks incidental take coverage for the impacts of its boating activities in Spring Lake and Sewell Park. Texas State University conducts guided tours in Spring Lake and rents out kayaks, canoes and paddleboards for use in Sewell Park. Activities in Spring Lake occur in the glass-bottom boat runs, and the activities downstream of Spring Lake utilize the area between Sewell Park and Rio Vista Falls. Additionally, the glass bottom boat and glass bottom kayaks operate in Spring Lake. Canoes and kayaks will also occasionally be used for research and maintenance projects in Spring Lake and in the River.

Motorized boats that are used on Spring Lake include the electric glass-bottom boats used for tours, the diesel-powered mechanical vegetation harvester, and emergency services boats as needed. Other non-motorized boats on Spring Lake include canoes, kayaks, and paddle boards used for recreational/educational purposes.

### 2.5.9 Infrastructure Maintenance, Repair, and Construction

Texas State University seeks incidental take coverage for existing infrastructure maintenance and repair, and construction or installation of new infrastructure and facilities associated with or located instream or on University property that is adjacent to or directly affects the San Marcos Springs and the San Marcos River and ecosystem. Routine, minor repairs would include activities such as repairs to access points along the river. Major infrastructure repairs or new construction activities include but are not limited to stabilization or reconstruction of access points along the San Marcos River, banks stabilization such as concrete wall installation or stabilization, replacing existing walls with natural river banks, and creating recreational trails in riparian areas adjacent to Spring Lake. New construction activities may include installation of new river access points, including installation of concrete or stone steps and associated earthwork on adjacent banks.

In general, these activities may include the following components:

- Removal of riparian and aquatic vegetation.
- Relocation or biotic salvage of Covered Species in accordance with approved relocation plans.
- Dewatering at construction sites.
- Installation of BMPs, including, but not limited to, those to reduce downstream sedimentation and for human health and safety.
- Installation of concrete, riprap, boulders, and steps on banks.
- Installation of bridge piers or temporary abutments.
- Earthwork on banks or in -stream.
- Reestablishment of flow.

## 2.6 San Antonio Water System

The San Antonio Water System (SAWS) is a water purveyor to residences, businesses and other end users in the City of San Antonio and parts of Bexar and surrounding counties. SAWS is authorized by the EAA to pump water from the Aquifer. SAWS has access or otherwise controls approximately 47 percent of the permitted water rights to pump from the Aquifer. As part of its operation, it stores water pumped from the Aquifer in an Aquifer Storage and Recovery facility (SAWS ASR) located in Southern Bexar County. The SAWS ASR is an underground storage reservoir in the Carrizo Aquifer in Southern Bexar County. As a SAWS Water Management Project it is designed to store aquifer water when demand is less than available supply. The stored water is returned to San Antonio for use during critical period when demand is high.

SAWS seeks incidental take coverage for its pumping from the Aquifer and for its use and operation of the SAWS ASR.

# Appendix G7 | **Covered Species Memorandum**

# Memorandum

| | |
|---|---|
| **To:** | Scott Storment, EAHCP Program Manager |
| **From:** | Lucas Bare, David Zippin, PhD, ICF<br>Ed Oborny, BIO-WEST |
| **Date:** | April 26, 2023 |
| **Re:** | **Evaluation of Covered Species for the Amended EAHCP** |

# Introduction

The purpose of this memorandum is to evaluate the list of proposed Covered Species for the anticipated amendment to the Edwards Aquifer Habitat Conservation Plan (EAHCP) and Incidental Take Permit (ITP) as part of what is more broadly called the EAHCP permit renewal. The term "Covered Species" as used in this memorandum includes those species for which the EAHCP Permittees would request authorization for incidental take and develop a conservation strategy with avoidance, minimization, and/or mitigation measures. We have focused this Covered Species assessment on the list of species (Attachment 1) provided by the U.S. Fish and Wildlife Service (USFWS) following in-person meetings on December 14, 2022 and January 18, 2023.

As the permit renewal process moves forward, we will use the Covered Species list to 1) continue to compile and update background data and species accounts, 2) evaluate incidental take for Covered Species with respect to Covered Activities, and 3) develop and/or update conservation strategies as necessary or warranted. This memorandum has been organized such that it can be incorporated into the amended EAHCP document and/or its appendices, as appropriate.

The EAHCP permit renewal is a multi-year and iterative planning process. The anticipated timeline for submitting the draft amended EAHCP and incidental take permit amendment application to the USFWS is the end of 2025. Throughout the planning process to identify changes to the EAHCP, components of the plan may need to be re-examined should circumstances change (e.g., identification of new scientific data or changes in regulatory status of species). As such, this memo serves as a check point to identify changes to Covered Species to carry forward in the permit renewal, but the Covered Species list will need to be evaluated throughout the planning process. Any proposed changes to the Covered Species list will be documented through additional technical memoranda or draft EAHCP chapters and reviewed by EAHCP stakeholders, USFWS, and Permittees.

# EAHCP Covered Species Background

This section provides an overview of the historical context and original process for the establishment of the existing EAHCP Covered Species. During the development of the EAHCP, the Edwards Aquifer Recovery Implementation Program (EARIP) formed a Covered Species work group charged with determining whether covering additional species, beyond the Federally listed endangered and threatened spring-associated species, was warranted. The specific criteria used for evaluation included the likelihood of listing during the permit term; effect of the Covered Activities on the species; status of knowledge about these species (in relation to meeting permit issuance criteria regarding the link between the Covered Activities and take); and potential problems with implementation. The Covered Species work group recommended 11 Covered Species, all of which were included in the EAHCP; see Table 1, reproduced from Table 1-3 from the EAHCP (EARIP 2012). Of these 11 species, eight were listed at the time. The remaining three species were not listed at the time but were under USFWS evaluation and thus had the potential to become listed during the 15-year permit term. None of those three unlisted species have been listed to date nor are they proposed for listing. A listing petition for the Comal Springs salamander was withdrawn in 2020, so this species is no longer petitioned. The only regulatory status change since the original EAHCP is the San Marcos gambusia. That species was proposed by USFWS in 2021 for delisting with the designation of presumed extinct. We expected that delisting to be finalized and take effect in 2023.

**Table 1. Species Covered by the EAHCP**

| Common Name | Scientific Name | ESA Status at the time of EAHCP Approval |
|---|---|---|
| Fountain darter | *Etheostoma fonticola* | Endangered |
| Comal Springs riffle beetle | *Heterelmis comalensis* | Endangered |
| San Marcos gambusia | *Gambusia georgei* | Endangered |
| Comal Springs dryopid beetle | *Stygoparnus comalensis* | Endangered |
| Peck’s cave amphipod | *Stygobromus pecki* | Endangered |
| Texas wild-rice | *Zizania texana* | Endangered |
| Texas blind salamander | *Eurycea* [formerly *Typhlomolge*] *rathbuni* | Endangered |
| San Marcos salamander | *Eurycea nana* | Threatened |
| Edwards Aquifer diving beetle | *Haideoporus texanus* | Petitioned |
| Comal Springs salamander | *Eurycea* sp. | Petitioned |
| Texas troglobitic water slater | *Lirceolus smithii* | Petitioned |

Source: Reproduced from Table 1-3 in the EAHCP (EARIP 2012).

The EARIP and Covered Species work group had extensive discussions on the possibility of seeking coverage for one other listed species, whooping crane (*Grus americana*), and a number of other petitioned aquifer and freshwater mussel species that had received positive 90-day findings in 2009. A detailed account of work group proceedings and findings is presented in EAHCP Section 1.4 (EARIP 2012). In summary, the EARIP Covered Species work group began with a potential list of 34 rare species and narrowed the list on the basis that they had been petitioned for listing and USFWS’s determination that listing “may be warranted,” thus indicating a greater likelihood of listing during the permit term. It was concluded that the proposed Covered Activities had the potential to most dramatically affect spring dwelling species, those that occur at the "top" of the Aquifer where spring levels fluctuate. As such, only the three surface species petitioned (Table 1) and known to inhabit these spring ecosystems were included in the EAHCP. The deep aquifer dwelling species (blind catfish) or species that did not overlap geographically with the Covered Activities were excluded from consideration.

Additionally, the work group considered downstream freshwater mussel species and whooping crane. It was concluded that seeking coverage for downstream species was not warranted because there was no evidence of take of these species from EAHCP Covered Activities. The minimization and mitigation measures developed for the EAHCP Covered Activities were specifically designed to enhance stability in the flows emerging from the spring systems at Comal and San Marcos Springs during extended periods of drought. The EARIP expected that the EAHCP would provide a net benefit to habitat conditions for the downstream species via this flow stability during extreme drought.

# Methods for Evaluating Covered Species

This section includes a description of the methods used to evaluate Covered Species for the Permit Renewal followed by an evaluation of species and recommendations for coverage and/or further evaluation.

## Methods

The methods employed to select Covered Species for the permit renewal follow the guidance provided in Chapter 7 of the joint USFWS and National Marine Fisheries Service (NMFS) "Habitat Conservation Planning and Incidental Take Permit (ITP) Processing Handbook" (HCP Handbook) (USFWS and NMFS 2016) and the specific evaluation criteria outlined in the next section.

### Evaluation Criteria

Each species presented in Attachment 1 provided by USFWS Austin Ecological Services was considered for coverage and initially screened based on "Activities That Impact Taxa or Their Habitat." These activities were evaluated in the context of EAHCP Covered Activities, and the overall list (Attachment 1) was narrowed down for further consideration. The continued evaluation adhered to the following criteria to determine if a particular species should be recommended for coverage under the amended EAHCP. In general, species meeting all four of these criteria are recommended for coverage and species not meeting one or more criteria are not recommended for coverage at this time.

- **Range.** Is the species known to occur or expected to occur within the Plan Area based on best available data and professional expertise? If not currently known or expected to occur, is it expected to move into the Plan Area during the permit term?
- **Listing status.** Is the species currently listed as threatened or endangered? If not, considering its status and threats to the species, is it likely that the species will be listed during the permit term?

- **Impact.** Will the species or its habitat be affected by Covered Activities at a level that is reasonably likely to result in take?
- **Species data.** Is there sufficient scientific data on the species life history, habitat requirements, and occurrence in the Plan Area to allow for adequate evaluation of impacts on the species and the development of Conservation Measures to mitigate those impacts?

# Evaluation and Recommendations

Table 2 presents the refined species list for consideration, including species name, whether it is currently covered in the EAHCP, whether it meets each of the Covered Species criteria, and finally, whether it is recommended for coverage or further evaluation under the amended EAHCP.

## Species Recommended for Coverage

As outlined in Table 2, nine species are recommended for coverage in the amended EAHCP at this time, which include 1 fish, 3 aquatic beetles, 1 amphipod, 1 isopod, 2 salamanders, and 1 plant:

1. Fountain darter — *Etheostoma fonticola*
2. Comal Springs riffle beetle — *Heterelmis comalensis*
3. Comal Springs dryopid beetle — *Stygoparnus comalensis*
4. Peck's cave amphipod — *Stygobromis pecki*
5. Texas blind salamander — *Eurycea rathbuni*
6. San Marcos salamander — *Eurycea nana*
7. Texas wild-rice — *Zizania texana*
8. Edwards Aquifer diving beetle — *Haideoporus texanus*
9. Texas troglobitic water slater — *Lirceolis smithii*

Seven of the eight federally listed species presently covered under the EAHCP (EARIP 2012) continue to meet all four evaluation criteria. The San Marcos gambusia is not recommended for coverage because USFWS has concluded in a proposed rule based on the best scientific data available that this species is extinct (Federal Register; 86 FR 54298). We expect this determination to stand and be finalized later this year.

Although the Edwards Aquifer diving beetle and Texas troglobitic water slater are not federally listed, they provide unique situations as discussed herein. Since the inception of drift net sampling over spring orifices, which has been conducted bi-annually since 2003 first by the Edwards Aquifer Authority and then since 2013 as part of the EAHCP's biological monitoring program, approximately 30 individual Edwards Aquifer diving beetles have been collected from Comal Springs. They are typically collected in drift nets during wet periods with subsequent high springflow output. They have also been collected in the Texas State University artesian well, but in limited numbers. To date, the Texas troglobitic water slater has only been confirmed in San Marcos at the Texas State University artesian well, Diversion Springs, and Outfall Well using drift nets (Coleman et al. 2018). Although numerous *Lirceolus* spp. individuals have been collected in the Comal Springs drift net sampling, by the time they expel from the aquifer they arrive in the nets in fragments. The only way to identify *L. smithii* from the other *Lirceolus* species is by dissecting mouth parts, which is extremely difficult when whole body specimens are not available. Based on available evidence, *L. smithii* may be found in the Edwards Aquifer below Comal Springs, although its occurrence has not yet been confirmed.

At this time, it is recommended that the Edwards Aquifer diving beetle and Texas troglobitic water slater continue to be included as Covered Species in the amended HCP. Both aquifer-dwelling species have been documented in either the immediate springs area at Comal Springs, San Marcos Springs, and likely both. Both species are currently under review and their federal listing status may change during the development of this permit renewal or during the renewed permit term. The potential for take associated with these aquifer species relative to Covered Activities is low based on the Coleman et al. (2018) conclusion that *L. smithii* is assumed to live in deep artesian portions of the Edwards Aquifer which is extensive and buffered from short-term effects of drought or declines in aquifer levels. However, both *L. smithii* and *H. texanus* could be sensitive and susceptible to harm by increased concentrations of regulated or unregulated anthropogenic contaminants. Although limited information is available for these species, existing EAHCP conservation measures targeted at protecting water quality over the aquifer are anticipated to suffice as mitigation for any minimal impact associated with Covered Activities.

Impacts to listed plants are not considered “take” under Section 9 of the ESA, so the USFWS cannot authorize incidental take of plants. However, the USFWS cannot issue a permit that would jeopardize the continued existence or adversely modify the designated critical habitat of any listed species, including plants, so covering Texas wild-rice in the amended EAHCP remains prudent.

## Data Gaps

Of the nine recommended species, important data gaps related to evaluating the Comal Springs riffle beetle and four aquifer-dwelling species remain for the amended EAHCP. To start addressing these data gaps, the EAHCP has funded a multi-year, Comal Springs riffle beetle population assessment that will be conducted in 2023 and 2024. Additionally, the EAHCP refugia applied research program has in 2023 embarked on a multi-year, Comal Springs dryopid beetle life history study at the USFWS San Marcos Aquatic Research Center. A basic understanding of the life history of this aquifer-dwelling species is a prerequisite to additional field or population assessments. Furthermore, additional understanding of subsurface habitat use of the Comal Springs riffle beetle, and additional life history studies for the aquifer-dwelling invertebrates may be warranted. Although data gaps are acknowledged for these species, we do not believe this should preclude these five invertebrates from being included in the amended EAHCP.

## Table 2. Species Evaluated, Recommended and/or Requires Further Evaluation for Coverage

| Species | | | Criteria[a] | | | | Recommended For Coverage in Permit Renewal |
|---|---|---|---|---|---|---|---|
| **Common Name** | **Scientific Name** | **Covered under EAHCP** | **Range / Habitat** | **Listing Status[b]** | **Take from Covered Activities** | **Data** | |
| **EARIP (2012) Covered Species** | | | | | | | |
| Fountain darter | *Etheostoma fonticola* | Yes | Comal and San Marcos Springs / River Ecosystems | E | Yes | Yes | Yes |
| Comal Spring riffle beetle | *Heterelmis comalensis* | Yes | Comal and San Marcos Springs | E | Yes | Yes, with known data gaps | Yes |
| Comal Springs dryopid beetle | *Stygoparnus comalensis* | Yes | Comal and San Marcos Springs | E | Yes | Yes, with known data gaps | Yes |
| Peck's cave amphipod | *Stygobromis pecki* | Yes | Comal Springs and Edwards Aquifer | E | Yes | Yes, with known data gaps | Yes |
| Texas blind salamander | *Eurycea rathbuni* | Yes | San Marcos Springs and Edwards Aquifer | E | Yes | Yes | Yes |
| Texas wild-rice | *Zizania texana* | Yes | San Marcos River | E | Yes | Yes | Yes |
| San Marcos salamander | *Eurycea nana* | Yes | San Marcos Springs / River Ecosystems | T | Yes | Yes | Yes |
| San Marcos gambusia | *Gambusia georgei* | Yes | Presumed extinct | Proposed for delisting | Presumed extinct | Last documented occurrence in Plan Area in 1983 | No |
| Comal Springs salamander (now grouped with Fern Bank salamander) | *Eurycea sp. (Eurycea pterophila)* | Yes | Comal Springs and Edwards Plateau | Pet. W (NL) | Yes | Yes | No |
| Edwards Aquifer diving beetle | *Haideoporus texanus* | Yes | Comal and San Marcos Springs and Edwards Aquifer | Pet. / UR | Yes | Yes, with known data gaps | Yes |
| Texas troglobitic water slater | *Lirceolis smithii* | Yes | San Marcos Springs and Edwards Aquifer | Pet. / UR | Yes | Yes, with known data gaps | Yes |
| **Bexar County Deep Aquifer species** | | | | | | | |
| Toothless blindcat | *Trogloglanis pattersoni* | No | Bexar County Deep Aquifer | Pet. / UR | Yes | No | Undetermined |
| Widemouth blindcat | *Satan eurystomus* | No | Bexar County Deep Aquifer | Pet. / UR | Yes | No | Undetermined |
| Mimic cavesnail | *Phreatodrobia imitata* | No | Bexar County Deep Aquifer | Pet. / UR | Yes | No | Undetermined |

| Species | | | Criteria[a] | | | | Recommended For Coverage in Permit Renewal |
|---|---|---|---|---|---|---|---|
| **Common Name** | **Scientific Name** | **Covered under EAHCP** | **Range / Habitat** | **Listing Status[b]** | **Take from Covered Activities** | **Data** | |
| **Edwards Plateau salamanders** | | | | | | | |
| Texas salamander | *Eurycea neotenes* | No | Edwards Plateau Streams / springs | Pet. / UR | No | Yes | No |
| Cascade Caverns salamander (former Comal blind salamander) | *Eurycea latitans* | No | Edwards Plateau Streams / springs | Pet. / UR | Yes | Yes, with known data gaps | No |
| Blanco blind salamander | *Eurycea robusta* | No | Presumed extinct or another species | NL | Presumed extinct or another species | One specimen | No |
| **Barton Springs segment salamanders** | | | | | | | |
| Austin blind salamander | *Eurycea waterlooensis* | No | Barton Springs Segment of the Edwards Aquifer | E | Under evaluation | Yes | Undetermined |
| Barton Springs salamander | *Eurycea sosorum* | No | Barton Springs Segment of the Edwards Aquifer | E | Under evaluation | Yes | Undetermined |
| **Terrestrial plants** | | | | | | | |
| Bracted twistflower | *Streptanthus bracteatus* | No | Uvalde, Medina and Bexar Counties | T | No | Yes | No |
| **Riverine or Coastal species** | | | | | | | |
| False spike | *Fusconaia mitchelli* | No | Guadalupe River | PE | Under evaluation | Yes | Undetermined |
| Guadalupe fatmucket | *Lampsilis bergmanni* | No | Upper Guadalupe River | PE | Under evaluation | Yes | Undetermined |
| Guadalupe orb | *Cyclonaias necki* | No | San Marcos and Guadalupe Rivers | PE | Under evaluation | Yes | Undetermined |
| Whooping crane | *Grus americanus* | No | Texas Gulf Coast | E | No | Yes | No |

[a] **Criteria**

Range: The species is known to occur or is likely to occur within the Plan Area.

Listing Status: The species is either:

- Listed under the federal ESA as threatened or endangered, or proposed for listing;
- Expected to be listed under the ESA within the permit term.

Impact: The species or its habitat would be adversely affected by Covered Activities that may result in take of the species.

Data: Sufficient data exist on the species' life history, habitat requirements, and occurrence in the study area to adequately evaluate impacts on the species and to develop conservation measures to mitigate these impacts to levels specified by regulatory standards.

[b] **Listing Status**

E = federally listed as endangered
T = federally listed as threatened
PE = proposed endangered
Pet. / UR = petitioned for federal listing / currently under review
Pet. W = petition withdrawn
NL = Not Listed

## Recommendations to Remove Covered Species

There are two Covered Species in the current EAHCP not recommended for continued coverage under this amendment (Table 2). As previously mentioned, the San Marcos gambusia is not recommended for coverage because USFWS has concluded that this species is extinct (Federal Register; 86 FR 54298) resulting in the USFWS delisting proposal on September 30, 2021.

The Comal Springs salamander is not recommended for continued coverage because of a very low likelihood of listing in the future due to a change in taxonomic status. Additionally, the petition to list the Comal Springs salamander was withdrawn by the petitioners (WildEarth Guardians) in 2020 based on new genetic data. Work from Devitt et al. (2019) determined the Comal Springs salamander to be genetically identical to the Fern Bank salamander (*Eurycea pterophila*) which has no federal status. Therefore, Fern Bank salamander appears to be genetically similar to other relatively common Texas Hill Country salamanders.

## Species Requiring Further Evaluation

For eight species listed in Table 2, a recommendation for coverage cannot be made at this time and more evaluation is needed. These species include Bexar County deep aquifer species, Barton Springs Segment of the Edwards Aquifer salamanders, and riverine species.

The status of all three Bexar County deep aquifer species are under review by USFWS, and the agency anticipates a 12-month finding for the toothless blindcat and widemouth blindcat in 2023 to determine whether listing is warranted, listing is warranted but precluded, or listing is not warranted. Should listing be deemed warranted for these aquifer species, further evaluation will be needed to determine if there is sufficient scientific data on the species life history to allow for adequate evaluation of impacts and the development of conservation measures to mitigate for those impacts.

The Barton Springs salamander and Austin blind salamander have not been documented from the San Antonio (or Southern) segment of Edwards Aquifer (BSEACD 2018). However, both salamander species are federally listed as endangered and flow path investigations have documented that during extreme drought, the potential exists for some portion of groundwater to flow past San Marcos Springs toward Barton Springs (Land et Al. 2011). In particular, the Blanco River may contribute to the Barton Springs segment of the Edwards Aquifer during drought (Hunt et al. 2019). It is important to highlight that both salamander species are covered under the Barton Springs / Edwards Aquifer Conservation District Habitat Conservation Plan (BSEACD 2018). Regardless, further investigation of these potential hydrologic interactions need to occur prior to making a formal recommendation on covering these species.

USFWS identified six freshwater mussel species potential affected by Covered Activities (Attachment 1). The Texas fatmucket (occurring in the Colorado River basin), Texas fawnsfoot (occurring in the Colorado River, Brazos River, and Trinity River basins), and the Texas pimpleback (occurring in the Colorado River basin) do not occur within the Plan Area. The Guadalupe orb, the false spike, and the Guadalupe fatmucket were proposed to be listed as endangered under the ESA on August 26, 2021 (USFWS 2021) and a final rule to list these species is expected in 2023. These three freshwater mussel species located in the Guadalupe River basin within the EAHCP Plan Area are currently state listed as threatened (TPWD 2022). The Guadalupe orb is considered endemic to the Guadalupe River drainage in two separate and isolated populations (USFWS 2021). Recent phylogenetic research indicates the false spike is restricted to the lower Guadalupe River drainage (Smith et al. 2021). The Guadalupe fatmucket is believed to only occur in the Guadalupe River drainage within the Edwards Plateau (above the Balcones fault line) (Inoue et al. 2020). Given the likelihood that USFWS will list these riverine species, further evaluation is needed to determine if they will be affected by Covered Activities at a level that is reasonably likely to result in take and if there is sufficient data for the development of Conservation Measures for these species.

# Species Evaluated but not Recommended for Coverage

An additional five species were considered (Table 2) but are not recommended for coverage in the amended HCP at this time. These species include several Edwards plateau salamanders a terrestrial plant and a coastal bird.

The USFWS is currently working on a Species Status Assessment (SSA) for the petitioned Texas salamander and Cascade Caverns salamander. Early results from tissue analysis suggest that the Texas, Cascade Caverns, and Fern Bank salamanders are all genetically similar. If these early results prove accurate, federal listing of these Texas Hill Country salamanders would be unlikely. These species have a low likelihood of being federally listed, are not documented in the immediate Comal and San Marcos Springs systems; and have limited to no potential for take from Covered Activities. However, should listing be proposed for either of these species, a further evaluation of potential impacts specific to Covered Activities may be warranted.

In March 2022, USFWS announced that the Blanco blind salamander did not warrant listing (Federal Register; 87 FR 14227). We do not recommend covering this species because the USFWS has concluded that the one record for this species in the EAHCP Plan Area was either misidentified or this species is extinct.

On April 11, 2023, the final rule for the bracted twistflower as a threatened species was published (Federal Register; 88 FR 21844). This terrestrial plant is found within the EAHCP Plan Area in Uvalde, Medina and Bexar Counties. However, based on activities that impact the bracted twistflower, (Attachment 1) there is no indication that any Covered Activities would result adverse effects to the species, so we do not recommend it for inclusion as a Covered Species at this time. If there is potential for adverse effects to occur to this species from Covered Activities, avoidance and minimization measures for the species could be included in the amended EAHCP.

The whooping crane is not recommended for coverage as it occurs outside of the Plan Area, and it cannot be determined that the Covered Activities affect this species at a level that is reasonably likely to result in take. Although the USFWS notes that reduction in freshwater inflows to habitat are an impact to this species (Attachment 1), it is not possible given best available data and information to attribute a certain amount of take of this migratory coastal avian species due to the pumping of the Edwards Aquifer that is covered under the EAHCP.

# Recommendations to Add Covered Species

Following the HCP Handbook guidance, evaluation criteria, and assessment of projected Covered Activities, there are presently no new species recommended for coverage in the amended HCP.

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# Attachment 1
# **U.S. Fish and Wildlife Service Species List**

***Note**: The U.S. Fish and Wildlife identified the species in the table below as those potentially affected by the EAHCP's Covered Activities. Best available scientific data and information about these species will be identified throughout the permit renewal process to determine if they should be included as EAHCP Covered Species.*

| Species | Status | Activities that Impact Taxa or their Habitat |
|---|---|---|
| **Birds** | | |
| Golden-Cheeked Warbler (*Setophega chrysoparia*) | Endangered | • Habitat removal, degradation, or fragmentation<br>• Construction: heavy machine work within or within 300' of habitat during the breeding season, understory thinning in habitat, introduction of new (increase predators) or "hard" (buildings) edge |
| Whooping Crane (*Grus americana*) | Endangered | • Reduction of freshwater inflows to habitat. Upstream reservoir construction, water diversions for agriculture, and human use reduce freshwater inflows. Groundwater withdrawals may also reduce freshwater inflows.<br>• Collision with utility lines, wind turbines, or fences during migration.<br>• Noise and activity disturbances during the wintering season that could temporarily displace WHCR from preferred feeding or resting sites, limiting their ability to obtain food resources.<br>• Unintended chemical (e.g., oil) releases in or around WHCR habitat, including contaminants associated with runoff from agricultural and industrial activities. |
| Piping Plover (*Charadrius melodus*) | Threatened | • In this area, only wind related projects within migratory route and wind energy projects |
| Red Knot (*Calidris canutus rufa*) | Threatened | • In this area, only wind related projects within migratory route and wind energy projects |

| Species | Status | Activities that Impact Taxa or their Habitat |
| --- | --- | --- |
| **Springs and Aquifer Species** | | |
| Southern Edwards Aquifer Listed Species:<br>• San Marcos Salamander (*Eurycea nana*)<br>• Texas Blind Salamander (*E. rathbuni*)<br>• Fountain Darter (*Etheostoma fonticola*)<br>• Peck's Cave Amphipod (*Stygobromus pecki*)<br>• Comal Springs Riffle Beetle (*Heterelmis comalensis*)<br>• Comal Springs Dryopid Beetle (*Stygoparnus comalensis*)<br>• Texas Wild-Rice (*Zizania texana*)<br>• San Marcos Gambusia (*Gambusia georgei*) | Threatened, Endangered | • Any in-stream and adjacent bank work in the Comal and San Marcos rivers<br>• Any activities near Fern Bank Spring or Hueco Springs<br>• Water drawdown<br>• Decreases in water quality, including due to development<br>• Sedimentation<br>• Floods that scour surface habitat<br>• Vegetation removal, including riparian for some species<br>• Nonnative species<br>• Habitat disturbance including recreation<br>• Alteration of stream morphology<br>• Subsurface species that are pumped out of groundwater wells in areas that they occur<br>• Catastrophic spills, including chemical spills and treated and untreated water |
| Under Review Species:<br>• Edwards Aquifer diving beetle (*Haideoporus texanus*)<br>• Texas troglobitic water slater (*Lirceolus smithii*) | Under Review | • Individuals that are pumped out of groundwater wells in areas that they occur<br>• Water drawdown<br>• Decreases in water quality, including due to development and storm water runoff<br>• Catastrophic spills, including chemical spills and treated and untreated water |
| Bexar County Deep Aquifer Species:<br>• Widemouth Blindcat (*Satan eurystomus*)<br>• Toothless Blindcat (*Trogloglanis pattersoni*)<br>• Mimic Cavesnail (*Phreatodrobia imitata*) | Under Review | • Individuals that are pumped out of groundwater wells in areas that they occur<br>• Water drawdown and pollution<br>• Oil and gas wells may be a threat |
| Barton Spring Segment Salamanders:<br>• Austin Blind Salamander (*E. waterlooensis*)<br>• Barton Springs Salamander (*E. sosorum*) | Endangered | • Any in-stream and adjacent bank work near spring habitat<br>Water drawdown<br>• Decreases in water quality, including due to development and storm water runoff<br>• Sedimentation<br>• Floods that scour surface habitat<br>• Vegetation removal, including riparian for some species<br>• Nonnative species<br>• Habitat disturbance including recreation |

| **Species** | **Status** | **Activities that Impact Taxa or their Habitat** |
|---|---|---|
| | | • Alteration of stream morphology<br>• Individuals that are pumped out of groundwater wells in areas that they occur (this may be rare)<br>• Catastrophic spills, including chemical spills and treated and untreated water |
| Cascade Caverns Salamander (*Eurycea latitans*) & Texas Salamander (*Eurycea neotenes*) | Under Review | • Any in-stream and adjacent bank work near spring habitat<br>• Water drawdown<br>• Decreases in water quality, including due to development and storm water runoff<br>• Sedimentation<br>• Floods that scour surface habitat<br>• Vegetation removal, including riparian for some species<br>• Nonnative species<br>• Habitat disturbance including recreation<br>• Alteration of stream morphology<br>• Individuals that are pumped out of groundwater wells in areas that they occur (this may be rare)<br>• Catastrophic spills, including chemical spills and treated and untreated water |
| Devil's River Minnow (*Dionda diaboli*) | Threatened | • Habitat loss<br>• Reduction of water quality and contamination due to adjacent urban setting<br>• Catastrophic spills<br>• Reduction of water to habitat, through aquifer and/or surface withdrawals<br>• Introduction of nonnative species<br>• Industrial and agricultural development for populations in Mexico |
| **Freshwater Mussels** | | |
| Central Texas Mussels:<br>• Guadalupe Fatmucket (*Lampsilis bergmanni*)<br>• Texas Fatmucket (*Lampsilis bracteata*)<br>• Texas Fawnsfoot (*Truncilla macrodon*)<br>• Guadalupe Orb (*Cyclonaias necki*)<br>• Texas Pimpleback (*Cyclonaias petrina*)<br>• False Spike (*Fusconaia mitchelli*) | Proposed and Under Review | • Increased fine sediment<br>• Changes in water quality<br>• Altered hydrology in the form of inundation<br>• Altered hydrology in the form of loss of flow and scour of substrate<br>• Predation and collection<br>• Barriers to fish movement |

| Species | Status | Activities that Impact Taxa or their Habitat |
|---|---|---|
| **Reptiles** | | |
| Plateau Spot-Tailed Earless Lizard (*Holbrookia lacerata*) | Under Review | • Disturbances that increase fire ant prevalence<br>• Urbanization and roads<br>• Invasive species (mostly red imported fire ants and exotic grasses)<br>• Conversion of grasslands to agriculture and other uses |
| **Terrestrial Invertebrates** | | |
| Bexar County Karst Invertebrates:<br>• Government Canyon Bat Cave Meshweaver (*Cicurina vespera*)<br>• Government Canyon Bat Cave Spider (*Tayshaneta microps*)<br>• Cokendolpher Cave Harvestman (*Texella cokendolpheri*)<br>• Madla Cave Meshweaver (*C. madla*)<br>• Robber Baron Cave Meshweaver (*C. baronia*)<br>• [no common name] Beetle (*Rhadine exilis*)<br>• [no common name] Beetle (*R. infernalis*)<br>• Helotes Mold Beetle (*Batrisodes venyivi*) | Endangered | • Subsurface disturbances associated with construction activities or other development in karst habitat. Potential effects can include crushing or injuring individuals; and/or altering or destroying caves or mesocaverns.<br>• Surface alterations that affect the surface hydrology (e.g., parking lots, roads, buildings, or other impervious covers) and alter the surface runoff regime within in karst habitat.<br>• Alteration of shrub/canopy around Cave entrance and footprint, if known - Vegetation removal that may impact temperature regimes and/or runoff into cave entrance.<br>• Chemical releases, other hazardous materials, or illegal dumping in karst habitat. |
| American Bumble Bee (*Bombus pennsylvanicus*) & Variable Cuckoo Bumble Bee *(Bombus variabilis*) | Under Review | • Habitat destruction especially from agriculture, livestock grazing<br>• Pesticide use<br>• Competition from non-native bees |
| Monarch Butterfly (*Danaus plexippus*) | Candidate | • Pesticide and insecticide use<br>• Conversion of grasslands to agriculture<br>• Urban development<br>• Loss of milkweed and nectar resources |
| **Mammals** | | |
| Tricolored Bat (*Perimyotis subfalvus*) | Endangered | • Wind energy<br>• Spread of white-nose syndrome (e.g., from interaction with bat habitat or bats)<br>• Loss of suitable roosting and foraging habitat, such as forest removal or conversion<br>• Disturbance of winter locations for hibernation |

| Species | Status | Activities that Impact Taxa or their Habitat |
|---|---|---|
| **Terrestrial Plants** | | |
| Black Lace Cactus (*Echinocereus reichenbachii* var. *albertii*) | Endangered | • Competition from introduced invasive grasses<br>• Clearing of native vegetation<br>• Use of herbicides for brush control<br>• Collection<br>• Activities that disturb habitat and increase prevalence of red imported fire ants<br>• Pesticides that affect pollinators<br>• Trampling by livestock and feral hogs |
| Tobusch Fishhook Cactus (*Sclerocactus brevihamatus* ssp. *tobuschii*) | Threatened | • Infestations by insect larvae have caused catastrophic population declines<br>• Juniper encroachment<br>• Feral hogs<br>• Collection |
| Bracted Twistflower (Streptanthus bracteatus) | Threatened | • Primary threat to habitats & survival: urban and residential development<br>• Herbivory from over-abundant ungulate herds,<br>• Decreased wildfire frequency (BRTF is likely a fire-dependent spp.)<br>• Increased juniper density<br>• Demographic and genetic effects of small population sizes<br>• Habitat deterioration from recreational activities<br>• Powdery mildew infections |
| Big Red Sage (*Salvia penstemonoides*) | Under Review | • Aquifer drawdown/lowering of the water table<br>• Commercial uses<br>• Flooding<br>• Herbicides<br>• Erosion<br>• Habitat disturbance |

# Appendix G8 | **Existing Conditions Memorandum**

# Memorandum

| | |
|---|---|
| **To:** | Scott Storment, EAHCP Program Manager |
| **From:** | Erin Hitchcock and Lucas Bare, ICF |
| **Date:** | September 15, 2023 |
| **Re:** | **Proposed Changes to EAHCP Existing Conditions for the Permit Renewal** |

# 1. Introduction

The Edwards Aquifer Habitat Conservation Plan (EAHCP) Permittees are currently preparing updates and revisions to the EAHCP for the incidental take permit (ITP) renewal. This memo outlines the process used to identify proposed changes to the Existing Conditions chapter of the EAHCP (Chapter 3). It also summarizes the proposed updates to Chapter 3. Although this memo strives to identify as many of the updates as possible within Chapter 3, some updates are contingent upon information that is not yet available and cannot be determined at this time. Therefore, this memo includes information on the current progress made to update the chapter and details the outstanding information needed to finish updating it as part of the complete, amended EAHCP.

Examples of Existing Condition updates that cannot be determined at this time are those pertaining to Covered Species. At a minimum, seven listed species will be covered in the amended HCP. However, additional data regarding the species will be needed to evaluate fully the other species being considered for coverage. Specifically, there are currently eight species for which a recommendation for coverage cannot be made at this time and further evaluation is needed.[1] These species include Bexar County deep aquifer species, the Barton Springs Segment of the Edwards Aquifer salamanders, and riverine mussels. The Covered Species list is expected to be evaluated throughout the planning process and finalized in 2024.

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1 Refer to the Evaluation of Covered Species for the Amended EAHCP Memo (dated April 26, 2023) for more information on species proposed for coverage.

The EAHCP permit renewal process is a multi-year planning process.[2] We anticipate submitting the draft amended EAHCP and ITP amendment application to the U.S. Fish and Wildlife Service (USFWS) in 2025. Given this timeline, some Existing Conditions information will need to be updated as close to submittal of the amended EAHCP as possible to ensure that the document includes the most current information (e.g., hydrology data). This memo identifies information for which updates are recommended to occur during preparation of the complete, amended EAHCP (anticipated during the first half of 2025) to avoid duplicative update efforts.

Consistent with the process for other EAHCP chapter updates, once all Existing Conditions changes and updates have been made, the changes identified will be reviewed and then "signed-off" on by the EAHCP Implementing Committee. After that, the changes will be incorporated into the amended EAHCP and submitted to the governing bodies of the ITP Permittees, and, if approved, then submitted to the USFWS with the ITP amendment application.

This memo describes the general process for identifying changes to the Existing Conditions. It also summarizes the proposed changes, which are categorized by topic (as shown below). The proposed text edits to the Existing Conditions chapter of the EAHCP are provided in ***Attachment 1: Edwards Aquifer Habitat Conservation Plan, Chapter 3, with Proposed Changes***.

# 2. Evaluation of Existing Conditions

The Existing Conditions chapter of the EAHCP (Chapter 3) provides the foundation for assessing how Covered Activities affect ecologic and hydrologic systems, species' habitats, and the species occurring within the EAHCP Plan Area. The sections that follow describe the evaluation process for updates to the EAHCP's Existing Conditions discussion for the permit renewal process.

## 2.1 Process for Evaluating Existing Conditions

The process for identifying potential changes to the EAHCP's Existing Conditions discussion started with a review of the current Existing Conditions chapter. We identified conditions that are either 1) different from those of the original HCP and need updating or 2) may be different, depending on the outcome of outstanding information or decisions. We then identified information that could be updated at this time as well as information that should be as current as possible in the amended HCP; therefore, requiring update during preparation of the complete amended EAHCP, anticipated during the first half of 2025. In addition, the chapter was reviewed for relevancy to the covered species effects analysis, conservation strategy, and the monitoring program. Sections or information determined to be irrelevant or extraneous are removed from the chapter.

### 2.1.1 Proposed Changes

A summary list of the changes proposed for Chapter 3, *Existing Conditions* is provided below. For each change, we indicate whether the change has been made in Attachment 1 or whether we recommend the change be made later to account for the most current data.

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[2] A detailed project schedule is available here: [- PREAHCP_Detailed Schedule_230410 (eahcprenewal.org)]

<u>Proposed Revisions to *Climate* (Section 3.1)</u>

- Update general temperature and precipitation information for region, based on recent data, information, and sources (some changes made, and others proposed for 2025).
- Update rainfall data with most current data and information (changes proposed for 2025).
- Remove climate change discussion (formerly Section 3.1.3) from Chapter 3 and address in the *Temperature and Rainfall Scenarios Report*, which will include downscaled climate scenarios (changes made).
- Update drought discussion, based on current information, and re-evaluate drought of record, based on most current information and conditions (some changes made, and others proposed for 2025).
- Update assessment of rainfall and drought data, including methodology used for determining data distribution (changes proposed for 2025).
- Update all figures and tables (changes proposed for 2025).

<u>Proposed Revisions to *Edwards Aquifer-fed Springs* (Section 3.2)</u>

- Update general spring conditions, based on recent data and information (some changes made and others proposed for 2025).
- Update summary of flows by spring (changes proposed for 2025).
- For pending Covered Species decisions, consider updating discussion of other springs to ensure that this section is relevant to Covered Species and effects analysis (2025).
- Update and/or refresh all figures (changes proposed for 2025).

<u>Proposed Revisions to *Edwards (Balcones Fault Zone) Aquifer* (Section 3.3)</u>

- Minor text clarifications (changes made).
- Edwards Aquifer Authority (EAA) to update all EAA report references and information, based on current studies, reports, and in-house information (changes expected in 2023/2024).
- Update and/or refresh all figures (changes proposed for 2025).

<u>Proposed Revisions to *Description of the Edwards Aquifer, Comal Springs, and San Marcos Springs Ecosystems* (Section 3.4)</u>

- General updates to spring ecosystem descriptions (changes made).
- Update spring ecosystem descriptions, based on current biological monitoring program information (changes proposed for 2025).
- Updates needed for any Covered Species added and relevant to specific ecosystems (changes to be determined for 2025).

- Add discussion of deep aquifer if deep aquifer species (such as blind catfish) are added as Covered Species (changes proposed for 2025).
- Add discussion of downstream conditions if riverine mussel species (such as Guadalupe Orb) are added as Covered Species (changes proposed for 2025).
- Remove Fern Bank Springs discussion as this spring is not relevant to the covered species effects analysis (i.e., the EAHCP does not estimate take at Fern Bank Springs), conservation strategy, or monitoring program (changes proposed for 2025).
- Update and/or refresh all figures (changes proposed for 2024/2025).

Proposed Revisions to *Listed Covered Species* and *Other Covered Species* Sections (Sections 3.5 and 3.6)

- Update list of covered species listed as threatened or endangered that are addressed in HCP once covered species list is finalized (changes proposed for 2025).
- General updates to species accounts, based on recent data and information (changes made).
- Update species accounts as appropriate, based on most recent biological monitoring program data and the final Covered Species list (changes proposed for 2025).
- Remove discussion of San Marcos gambusia because it will be removed from the list of covered species in the amended EAHCP (formerly Section 3.5.8 [changes made]).
- Remove discussion of Comal Springs salamander because it will be removed from the list of covered species in the amended EAHCP (formerly Section 3.6.3 [changes made]).
- Add species accounts for any species added to the covered species list anticipated to be finalized in 2024 (changes proposed for 2025).
- Update and/or refresh all figures (changes proposed for 2025).

References

- Update references, as applicable, and compile updated references list for Chapter 3 and include in the Literature Cited chapter (changes proposed for 2025).

# Attachment 1
# Edwards Aquifer Habitat Conservation Plan
# Chapter 3, with Proposed Changes

# Attachment 1
# Edwards Aquifer Habitat Conservation Plan, Chapter 3, with Proposed Changes

[*Note to reviewer: Gray highlight indicates updated text. Yellow highlight indicates a placeholder for future update.*]

## 3.1 Climate

### 3.1.1 Climate of South-Central Texas

The prevailing climate of the Habitat Conservation Plan (HCP) study area varies from subtropical steppe in the western region to subtropical subhumid in the central and eastern regions (see Figure 3-1) (Bradley and Malstaff 2004). The subtropical steppe is characterized by semi-arid to arid conditions (Stamm et al. 2015). The subtropical subhumid climate is typified by long, hot summers and short, mild winters; the subtropical humid climate exhibits higher humidity and slightly milder summers than the subtropical steppe. Prevailing winds are generally southerly, except during winter when they are frequently from the north. Latitude, elevation, and proximity to the Gulf of Mexico influence the climate of the region.

The average annual temperature in the study area is about 21 degrees Celsius (°C) (70 degrees Fahrenheit [°F]). The average annual high temperature ranges from 27°C to 31°C (80°F to 87°F) (Figure 3-2) (National Oceanic and Atmospheric Administration [NOAA] 2022). Average monthly high temperatures range from 34°C (93°F) to 37°C (99°F) (NOAA 2022). Summertime temperatures commonly exceed 38°C (100°F). Winters are generally mild, with average monthly low temperatures ranging from about 5°C (41°F) to 12°C (54°F). Temperatures fall below freezing about 22 days each year (NOAA 2022).

Average annual precipitation within the region varies from east to west, with the eastern portion receiving more precipitation than the western portion. For example, average annual precipitation is about 22 inches in western Kinney County and about 40 inches in eastern Caldwell County (Figure 3-3); however, in some years, the region may receive as much as 50 inches or as little as 10 inches of precipitation (NOAA 2022). During the period of 1934 to 2021, San Antonio averaged 32.4 inches of precipitation (NOAA 2022). Historically, precipitation is highest during May and September and lowest during the winter. Stalled cool fronts and summer tropical storms may result in above-average precipitation.

The potential for an incidence of high-magnitude flooding is greater for the Balcones Escarpment area of central Texas than for any other region of the United States (Caran and Baker 1986; Saharia et al. 2017). In part, this is due to the climatic provenance of central Texas; the area lies within a convergence zone of high- and low-pressure air masses. In addition, tropical storms and hurricanes that originate in the Gulf of Mexico produce some of the area’s heaviest rainfall (Patton and Baker 1976). Once rainfall hits the ground, infiltration rates are a function of landscape physiography and antecedent conditions (i.e., the amount of water stored in the soil profile before the rainfall began). Along the Balcones Escarpment, valleys are narrow and the slopes are sparsely covered by vegetation.

**Figure 3-1. Climate Regions of Texas [refresh figure]**

**Figure 3-2. Annual Average High Temperature, 1971- 2024 [Update figure]**

**Figure 3-3. Average Annual Precipitation in Inches, 1971- 2024 [Update figure]**

The surface is either marked by exposed bedrock or overlain by thin layers of upland soils. This area is known as "flash flood alley." Below the Escarpment, soils of the Blackland Prairies have low absorption rates or infiltration capacities (Caran and Baker 1986; Patton and Baker 1976). Interacting together, these factors severely limit infiltration and greatly increase runoff and drainage discharge.

Regional surface water features and near-surface soil moisture levels are subject to evaporation, especially during hot summer months. Average gross lake-surface evaporation in the region ranges from approximately 2 inches in January to approximately 7 to 11 inches in August (Texas Water Development Board [TWDB] 2022). Evapotranspiration percentages vary throughout the region, with an average of approximately 60 percent of regional precipitation lost through evapotranspiration (TWDB 2022).

### 3.1.2 Floods and Tropical Storms

As stated in Runkle et al. (2022), there were more than 85 tropical storms and hurricanes in Texas between 1900 and 2020; approximately half of these storms were hurricanes. Since 2000, Texas has experienced numerous severe storms and destructive hurricanes, including Hurricane Harvey (Category 4), Hurricane Rita (Category 3), and Hurricane Ike (Category 2) (Runkle et al. 2022). Occasionally, these storms move inland, resulting in severe weather over the region. As moisture-laden air masses move inland from the Gulf of Mexico, they are forced to rise at the Balcones Escarpment, then mix with low-pressure fronts from the north or west. Such systems have resulted in some of the largest storms ever recorded in the United States, with high winds, excessive rainfall, hail, and tornadoes.

Flash flooding is common within the Plan Area due to the susceptibility to extreme rainfall events that are exacerbated by the thin soils, exposed limestone bedrock, and steep slopes that characterize the area and promote runoff (Furl et al. 2018). One notable event occurred in May 2015, during a spring season marked by record setting rainfall across Texas. Within the Plan Area, the Blanco River watershed received an average of 165 mm of precipitation across 15 hours (Furl et al. 2018). A catastrophic floodwave moved through the Blanco River resulting in severe and deadly flooding.

## 3.1.3 Temperature and Precipitation Trends in Texas, Based on the Historical Record from 1895

Temperatures in Texas have risen almost 1.5°F since the beginning of the 20th century (Runkle et al. 2022). According to data compiled by the National Climatic Data Center (2010) over the period of record between 1895 and 2010, the temperature in Texas has increased at a rate of about 0.1°F per decade, or about 1°F over the past century.

Precipitation is widely variable across Texas, both spatially and temporally. Since modern record-keeping, historically significant droughts have been recorded in the late 1910s, the early 1950s, and the early 2010s; the driest calendar years were 1917, 1956, and 2011. The driest consecutive 5 years was the period from 1952 to 1956; the wettest was the period from 2015 to 2019. Droughts often coincide with strong and extended La Niña events.

A multi-year drought in the 1950s continues to be used as the worst-case scenario for water-resources planning in many regions (i.e., the official drought of record), including the EAA management area, although the more recent 2011 drought was the worst single-year drought in recorded history (Nielson-Gammon 2012). Notably, the Lower Colorado River Authority officially recently recognized a new drought of record that includes 2011 for the nearby Colorado River Basin, which is located just north of the Edwards Aquifer Authority's management area (LCRA, 2019). The new drought of record for the Lower Colorado River Basin is October 2007 to April 2015.

## 3.1.4 Droughts

Droughts are generally thought of as extended events, lasting months, years, or even decades, starting with periods of reduced rainfall. However, "flash droughts," brought on in a matter of days because of precipitation deficits accompanied by extreme high temperatures or high winds and a lack of humidity, are a growing phenomenon (Otkin et al. 2018). Texas experienced a flash drought in 2012. Seasonal summer droughts, accompanied by seasonal low flows, are commonplace in Texas. Many small creeks run intermittently during the summer months when precipitation is often less than needed to compensate for a high level of evapotranspiration and minimal surface runoff. Drought may also result in springflow decreases, which can act to reduce the availability of aquatic habitat. Extended periods of reduced or no precipitation are also common in Texas. Those periods of time, combined with high summer temperatures, can lead to severe drought conditions in which even larger creeks, streams, and springs run dry and inflows into mainstem rivers are greatly reduced.

Serious droughts have been recorded in some parts of Texas in every decade since 1900. Droughts result from lower-than-normal precipitation levels; however, years with above-average precipitation totals may still experience low water availability, especially after dry periods when soil moisture may not rebound. Therefore, the *annual average amount of rainfall* does not reflect occurrences of droughts or the impacts that droughts have on Edwards Aquifer (Aquifer) and the living organisms that depend on it. Averaging the rainfall data tends to mask the duration and intensity of droughts.

Droughts vary significantly in duration and intensity. Riggio et al. (1987) conducted a comprehensive analysis of droughts, using monthly rainfall data for sites across Texas from 1931 to 1980. They found that at least five droughts of extended duration and extreme intensity have occurred since 1931 in the Plan Area (Riggio et al. 1987). Between 1931 and 1985, the frequency of occurrence for the three-month drought in the Edwards Plateau region varied from 62 to 70 occurrences, depending on location. During the same period, the frequency of occurrence for the six-month drought varied from 32 to 40 occurrences (Riggio et al. 1987). Fewer than 24 occurrences of the 12-month drought were recorded between 1931 and 1985 (Riggio et al. 1987). Although droughts are cyclic in nature, they are not consistent in frequency.

The 6-year drought that occurred from 1951 through 1956 is considered the drought of record for the Aquifer because it was the most severe drought recorded, according to documented Aquifer records maintained since 1934. This drought resulted in the only known cessation of the artesian flow at Comal Springs, occurring in 1956 and lasting for 144 days (Longley 1995).

To understand the drought of record and how it relates to the long-term climate of the Aquifer, a study using dendrochronology was conducted using existing databases to evaluate historic drought patterns in the Aquifer region (Mauldin 2003). Dendrochronology is the use of tree-ring analysis to evaluate historic climatic conditions. It is an established, critical element of climate research (Blasing and Fritts 1976; Robinson 1976; Stahle et al. 1985; Stahle and Cleaveland 1988; Cook et al. 1999). An extensive database of tree-ring data for the southwest was used in the analysis (Cook 2000). Data collected from existing databases was correlated with the Palmer Drought Severity Index (PDSI) for a 280-year period (1700–1979). The PDSI is a standard measure of soil moisture conditions and used to classify drought frequency, intensity and duration. It has a range of -4.0 to 4.0, with an average year falling between -0.5 and 0.5. Droughts are defined as -1.0 through -4.0. Over the 280-year period studied, 25.7 percent of the years were drought years (Mauldin 2003).

The study showed that droughts are not uncommon to the Aquifer region; however, they are usually short in duration and generally not too intense. During the 280-year period (1700 through 1979), the Aquifer region experienced 40 droughts of various lengths. The duration of the average drought was 1.8 years; droughts that lasted only 1 year were more common. Long-term droughts, defined as those exceeding 3 years in duration, occurred only four times; three of those were in the 1700s. The fourth long-term drought was the drought of record (1951–1956), which lasted 6 years. The drought of record was the most intense long-term drought (-2.32 average PDSI, peaking at about -3.1); however, six other droughts were more intense for shorter durations (PDSI > -3.1) (Mauldin 2003). Therrell (2000), also using tree-ring analysis, concluded that the drought of record was the most prolonged period of sustained drought in the past 347 years. The drought of record represents only 2.1 percent of the 280-year period analyzed and only 2.5 percent of the 40 droughts.

Although the nature of future drought stress remains unclear, for those areas where climate models suggest drying, such as the southwest, including the western half of Texas (Seager et al. 2007), extreme droughts as severe or more severe than those encountered in the instrumental record are more likely (Burke et al. 2006).

## 3.1.5 Likelihood of a Repeat of the Drought of Record Based on Historical Data

In response to concerns about the likelihood of a reoccurrence of a significant drought that could adversely affect spring systems during the term of the permit, the potential for a repeat of the drought of record was analyzed from three perspectives: the long-term regional rainfall pattern, based on tree-ring data; the regional pattern of rainfall from the instrumental rainfall records; and a probabilistic analysis, based on the characteristics of the historic instrumental data.

### 3.1.5.1 Long-term Regional Rainfall Pattern (1500 to 2010)

Based on a recent evaluation using tree-ring data as a proxy for annual rainfall, Cleaveland and Votteler (in preparation) have provided a depiction of the climate in the Edwards Aquifer region of Texas during the past 500 years. They identified the pattern of significant drought events in Divisions 6 and 7, which correspond to the Edwards Aquifer contributing zone and recharge zone, respectively, for this period. Significantly, the period ending in 1956 was the second-driest 5-year period, the fourth-driest 10-year period, and the second-driest 20-year period in both divisions, indicating that it was a significant event of low frequency during this period.

### 3.1.5.2 The Regional Rainfall Record (1895 to 2010)

**Figure 3-5 displays the regional rainfall record from 1895 to 2024.**

### 3.1.5.3 Probabilistic Assessment of Recurrence of the Drought of Record

Although not necessarily intuitive, annual rainfall totals are essentially random, with little evidence for between-year associations (Hershfield 1963; Guttman 1989). The distribution of annual rainfall totals is often nearly normal (or Gaussian) (Hershfield 1963) but also can be represented by other statistical distributions. Guttman (1989) recommends evaluation of the data of interest prior to making assumptions as to the appropriate statistical descriptor.

Rainfall data for the period from 1895 to 2010 (Table 3-1 and Figure 3-6) were evaluated as to their approximation to a normal distribution. The mean rainfall during the period was 25.37 inches per year (s.d. = 6.575), with a minimum of 11.22 inches in 1956.

The distribution of this data was assessed using Microsoft Excel 2010 and the SYSTAT 11 statistical software package. Annual rainfall data were compared with a number of statistical distributions but fit best with and were not significantly different from a normal distribution (see Figure 3-6).

Because the 1956 drought of record was the result of a multi-year sequence of drier-than-average years, the 1895–2010 rainfall data set was also examined by calculating 3-, 5-, 7-, and 10-year running averages (Figures 3-7 through 3-10). Each of these sequences was also normally distributed. With this analysis, it was not possible to identify which sequence (3-, 5-, 7-, or 10-year sequence) would be the best descriptor of what occurred in the drought of record; therefore, all of the sequences were evaluated.

Although the rainfall in 1956 was the lowest annual total for the entire period (11.22 inches), it does not stand out significantly from other years (see Figure 3-6). However, the 3-, 5-, 7-, and 10-year sequences ending in 1956 are distinguishable in the period, particularly the 5- and 7-year sequences.

From the normal distributions for each of these sequences (from the individual yearly totals and the 3-, 5-, 7-, and 10-year totals), the cumulative probabilities for the drought of record were calculated, based on the normal distributions (Table 3-2).

From the data in Table 3-2, it can be inferred that, if the overall climatic regime from the past 11 years were to continue into the near-term future, the probability of a recurrence of a year as dry as 1956 is approximately 1.6 percent in any given year. The probability of a 3- or 5-year period as dry as the drought of record is approximately 0.2 percent, and the probability of a 7- or 10-year period as dry as the drought of record is 0.1 percent or less (Table 3-3).

**Table 3-1. Annual Rainfall Records From Texas Climate Division 6 [update table and source**

**Figure 3-5. Division 6 Rainfall [update figure]**

**Figure 3-6. Division 6 Rainfall Frequency Distribution [update figure]**

**Figure 3-7. Three-year moving average rainfall 1895–2024 [update figure]**

**Figure 3-8. Five-year moving average rainfall 1895–2024 [update figure]**

**Figure 3-9. Seven-year moving average rainfall 1895–2024 [update figure]**

**Figure 3-10. Ten-year moving average rainfall 1895–2024 [update figure]**

**Table 3-2. Probability of Drought of Record, Based on 1895–2010 Annual Rainfall Totals [update table]**

| Number of Years in Drought Sequence | Mean for Drought of Record (inches) | Calculated Cumulative Probability* P(rainfall < drought of record) |
|---|---|---|
| 1 | 11.20 | 0.0161 |
| 3 | 14.60 | 0.00211 |
| 5 | 17.44 | 0.00219 |
| 7 | 17.27 | 0.00034 |
| 10 | 19.38 | 0.00119 |

*Calculated from 1895–2010 rainfall data.

**Table 3-3. Calculated and Modeled Probability of Recurrence of Drought of Record [update table]**

| Number of Years in Drought Sequence | Mean for Drought of Record (inches) | Calculated Cumulative Probability* P(rainfall < drought of record) | Monte Carlo Modeled Cumulative Probability for Future Periods** | | |
|---|---|---|---|---|---|
| | | | 8 Year (2010–2018) | 15 Years (2010–2025) | 25 Years (2010–2035) |
| 1 | 11.20 | 0.0161 | 0.094 | 0.16 | 0.241 |
| 3 | 14.60 | 0.00211 | 0.011 | 0.026 | 0.038 |
| 5 | 17.44 | 0.00219 | 0.009 | 0.009 | 0.041 |
| 7 | 17.27 | 0.00034 | 0 | 0 | 0.005 |
| 10 | 19.38 | 0.00119 | 0.001 | 0.007 | 0.017 |

*Calculated from 1895–2010 rainfall data.
**Based on 1,000 iterations.

### 3.1.5.4 Effects of the Drought of Record on Comal Springs

The severity of the drought of 1956 and its impact on water levels at Landa Lake are unique in the hydrologic record for central Texas. The most critical period of low flow at Comal Springs was during the summer months of 1956 when the springs ceased the artesian flow. Landa Lake went from being "full" in early June to being "dry" (that is, not flowing) in August of that year. A description of what occurs at Comal Springs when water levels drop has been previously described by LBG-Guyton Associates (2004) and is summarized below.

Spring runs #1 and #2 stop flowing at Landa Park with a well water elevation of 622 feet above mean sea level (ft MSL) when total Comal Springs flow is about 130 cubic feet per second (cfs). Spring run #3 stops flowing at Landa Park with a well water level of 620 ft MSL; this is also the current lake level, as controlled by the dam. Total Comal Springs flow at this point is about 50 cfs. Spring runs #1 and #2 went dry during the summer of 1953 as well as from the summer of 1954 until January 1957. Spring run #3 stopped flowing during the summer of 1955 as well as from May until December 1956. Although the flows from spring runs #1, #2, and #3 stop with a Landa Park well level of 620 ft MSL, there was still flow out of Landa Lake due to spring discharge from other spring runs into the lake itself. When the water elevation at the Landa Park well declined to about 619 ft MSL, total spring discharge went to zero. During 1956, spring discharge was zero for 144 consecutive days, from June 13 to November 3. At that point, flow stopped at the New Channel dam, but water was still able to flow though the culvert to the Old

Channel. Below a Landa Park well elevation of approximately 618 ft MSL, the elevation of the lake bottom immediately upstream of the culvert prevented flow from reaching the Old Channel culvert. Spring discharge could presumably still occur at water levels as low as the lowest lake-bottom elevation of 613 ft MSL. However, for such discharge to occur, an outlet at that elevation would need to be constructed that would discharge to a location at a lower elevation (such as Old Channel).

Large parts of the lake bottom emerged at a lake elevation of 618 ft MSL. The north end of the lake, north of Spring Island, also emerged at about 618 ft MSL. Although there were some deeper pools at the north end, flow from north to south was probably interrupted. Figures 3-11a and 3-11b are photographs of the southern end of Landa Lake that were taken in the summer of 1956. The water level in the individual pools within the lake appeared to be about 617to 618 ft MSL. The lowest level of Landa Park well (613.34 ft MSL) was reached on August 21, 1956. The deepest pool, just south of Spring Island, had a bottom elevation of 613 ft MSL. Newspaper clippings indicate that there may have been 6 inches of water left in the deep pools.

### 3.1.5.5 Effects of the Drought of Record on San Marcos Springs

San Marcos Springs is at the end of a flow system for the Aquifer that includes most of the outcrop, streams, and the Blanco River in Hays County. The springs receive recharge from this area, and they often exhibit a rapid flow response to storm events in this region. San Marcos Springs also appears to receive a regional base flow of about 50 to 100 cfs that bypasses discharge at Comal Springs (LBG-Guyton Associates 2004). Although San Marcos Springs did not go dry during the drought of record in the summer of 1956, spring discharge declined to 47 cfs. Increases in seasonal water levels and flows in the artesian section of the Aquifer (San Antonio pool), however, do not always result in increases in discharge at San Marcos Springs.

Most of the spring discharge at San Marcos is through spring complexes in the bottom of Spring Lake. There are few, if any, subaerial springs, such as those that occur at Comal Springs. Although some of the springs have distinct orifices where discharge can be measured, most of the spring discharge appears to be through rock rubble or sand boils in large, flat sand-plain areas. The southern springs appear to discharge groundwater from the regional flow system, while the northern springs receive their discharge from the more localized recharge zone in Hays County. Discharge rates in the southern springs would be expected to be far more stable under varying flow conditions than the northern springs, which should be more variable in proportion to total spring discharge values.

### 3.1.5.6 Effect of Drought on Hueco Springs

Following Barr (1993), only recent drought and springflow data are presented here. The larger of the two springs, Hueco I, typically exhibits constant flow but has been documented to stop flowing during severe droughts (Ogden et al. 1986), such as in 1984. However, Hueco I did not stop flowing during the drought occurring in 1989–1991. Hueco II is an intermittent spring that typically stops flowing during the driest months of the year (Barr 1993). The Permittees do not own or have jurisdiction over these springs or the surrounding ecosystems.

**Figure 3-11a. Historic Photo of Landa Lake [keep figure]**

**Figure 3-11b. Historic Photo of Landa Lake [keep figure]**

# 3.2 Edwards Aquifer-fed Springs

Texas originally had 281 known, major non-saline springs; of those, only four were defined as first-magnitude springs, having a flow of more than 100 cfs. These four consist of Comal Springs, San Marcos Springs, Goodenough Springs, and San Felipe Springs. Goodenough and San Felipe Springs are in Val Verde County, west of the Edwards Balcones Fault Zone Aquifer. Goodenough has since been inundated by the impoundment of Amistad International Reservoir (Brune 1975). Comal and San Marcos Springs remain the largest springs in Texas, and flow from these springs is supplied principally by the Edwards Aquifer. Other spring outlets of the Aquifer within the jurisdiction of the Edwards Aquifer Authority (EAA) include Leona Springs, San Pedro Springs, San Antonio Springs, and Hueco Springs (see Figure 3-12). Total annual discharge from the six most significant springs listed in Table 3-4 during the period of record (1934 to 2009) has varied from 69,800 acre-feet (ac-ft) in 1956 to 802,800 ac-ft in 1992, with an average annual discharge of 385,700 ac-ft (EAA 2010b).

## 3.2.1 Comal Springs Physical Description

Comal Springs, located in the city of New Braunfels in Comal County, is the largest natural spring system in Texas. At 623 ft MSL, Comal Springs is one of the lowest-elevation springs fed by the Aquifer. The springs discharge from four major orifices of varying sizes with associated spring runs as well as from numerous smaller discharge points. In 1847, Comal Springs was impounded to form Landa Lake for irrigation purposes (see Figure 3-12) (Abbott and Woodruff 1986; Linam et al. 1993). Water discharging from Comal Springs has been recharged from numerous areas upgradient in the Aquifer recharge and contributing zones. Longer regional-scale flowpaths primarily originate primarily in Bexar and Medina Counties, while short, localized groundwater contributions to springflow occur in Comal County. Dye tracer tests at Comal Springs suggest that separate flowpaths contribute to individual spring orifices. For instance, spring runs #1, #2, and #3 have been shown to have a larger contribution from localized shallow flowpaths, while spring orifice #7 reflects water emerging from regional deeper flowpaths (EAA 2010).

Although Comal Springs is generally perennial, with a historical average flow for the period 1934 to 2021 of 287 cfs (EAA 2021), individual springs and/or spring runs have ceased flowing during recorded history. Cessation of spring discharge occurred during the drought of record in 1956 for 144 days, from June 13 to November 4 (U.S. Fish and Wildlife Service [USFWS] 1996). In contrast, the record high average annual flow for Comal Springs is 534 cfs in 1973. Throughout implementation of the Edwards Aquifer Habitat Conservation Plan (EAHCP) (2013–2022) and its associated conservation measures, average annual flow for Comal Springs has been 258 cfs.

**Figure 3-12. General Location Map of Springs [refresh figure]**

**Table 3-4. [Update table]**

### 3.2.2 San Marcos Springs Physical Description

San Marcos Springs, near the base of the Balcones Escarpment in the city of San Marcos in Hays County, is the second-largest spring system in the state and the source of baseflow to the San Marcos River (Figure 3-12). At 574 ft MSL, San Marcos Springs exhibits the lowest elevation of the major springs in the San Antonio segment of the Aquifer. Impoundment of San Marcos Springs for irrigation resulted in the creation of Spring Lake in 1849 (Bousman and Nickels 2003). The springs discharge from six major and several minor orifices at the bottom of Spring Lake, including from below and along the side of the Meadows Center for Water and the Environment office building. During wet years, San Marcos Springs receives a greater contribution from local sources; during dry years, San Marcos Springs receives a greater contribution from regional flowpaths (Johnson and Schindel 2008). Local stream recharge from the Blanco and Guadalupe Rivers and the Sink, Purgatory, York, Dry Comal, and Alligator Creeks contributes to San Marcos Springs where it crosses the recharge zone (Brune 1981). San Marcos Springs is also supplied by "regional underflow past the Comal Springs area" (Guyton et al. 1979). Because San Marcos Springs is lower in elevation than Comal Springs and farther down the pathway of the flow of water within the confined artesian Aquifer zone, discharge at Comal Springs appears to dampen spring output at San Marcos Springs. Historical average annual flow for the period 1957 to 2021 was 176 cfs (EAA 2021). Although Comal Springs went dry for approximately 144 days in 1956 (USFWS 1996), San Marcos Springs remained flowing and has historically had the most constant spring discharge. During that same year, the springs did reach a recorded low discharge of 47 cfs. In contrast, the record high average daily flow for San Marcos Springs was 451 cfs in 1992. Throughout implementation of the EAHCP (2013–2022) and its associated conservation measures, average annual flow for San Marcos Springs has been 180 cfs.

## 3.3 Edwards (Balcones Fault Zone) Aquifer

This section provides a general description of the hydrological boundaries of the Aquifer, hydrological zones, and hydraulic properties.

The Aquifer, referred to as the Edwards Balcones Fault Zone Aquifer by the TWDB (2006a), is one of nine major aquifers in Texas, covering approximately 4,350 square miles across parts of 11 Texas counties. The Aquifer has focused recharge zones, enhanced secondary porosity, and excellent geochemical water quality conditions. These factors make the Aquifer one of the most productive groundwater reservoirs in the country (Sharp and Banner 1997). The Aquifer is the primary source of water for a large portion of central Texas with almost 2 million people (EAA 2010b; U.S. Census Bureau 2010). It supports cities, towns, rural communities, farms, and ranches. The water is used for a range of purposes (e.g., to support municipal, industrial, and manufacturing uses; produce steam for generating electricity; facilitate irrigation, mining, and livestock operations; and sustain recreational uses). The Aquifer also supports several major springs that provide habitat for a number of endangered and threatened species.

The Aquifer extends from a groundwater divide in Kinney County, through the city of San Antonio, northeast to Bell County. Within this area, the Aquifer comprises three segments:

the southern (San Antonio) segment, the Barton Springs (Austin) segment, and the northern segment. Historical hydro-geological data support the presence of a groundwater divide running west-northwest from the city of Kyle in Hays County, which, under normal conditions, hydrologically separated the San Antonio and Austin (Barton Springs) segments. At this location, under most conditions, groundwaters from the San Antonio and Austin segments do not mix. Generally, groundwater north of the divide flows north, while groundwater south of the divide flows south. This groundwater divide may be diminished substantially during drought conditions. A recent study (HDR 2010) suggests that as water levels in the Aquifer decline during major droughts and with current levels of pumping, this groundwater divide diminishes, allowing the potential for some groundwater to bypass San Marcos Springs and flow north into the Barton Springs segment of the Aquifer and toward Barton Springs. The third segment of the Aquifer, which is known as the "northern segment," is hydrologically separated from the Barton Springs segment by the Colorado River. The focus of this groundwater discussion will be on the San Antonio segment of the Aquifer.

The San Antonio segment of the Edwards Aquifer is approximately 180 miles long, stretching from the city of Brackettville in Kinney County to an area north of Kyle in Hays County, Texas (see Figure 3-16). It varies in width from 5 to 40 miles. This segment of the Aquifer extends through all or part of 11 counties: Zavala, Frio, Atascosa, Guadalupe, Kinney, Uvalde, Medina, Bexar, Comal, Caldwell, and Hays. As described in Section 3.2.1, the Aquifer lies under several streams in three major river basins, the Nueces, the San Antonio, and the Guadalupe.

**Figure 3-13. Climate Regions of Texas [keep and refresh figure]**

The San Antonio segment of the Aquifer holds water that drains from approximately 8,000 square miles in some 12 counties in the contributing and recharge zone. The water-bearing body of the Aquifer itself underlies approximately 3,600 square miles in eight counties. The total volume of circulating freshwater in the Aquifer is estimated at 173 million ac-ft (Bureau of Economic Geology 1995), making it one of the most productive aquifers in the United States, although the amount of recoverable groundwater is not known. The Aquifer, which historically has been the sole source of water for the city of San Antonio (USGS 1995; EAA 2001), provides base flow to the three river basins mentioned above (USGS 1999). Annual discharge from springflow and pumping has frequently exceeded average annual recharge. Median annual recharge for the period of record (1934-2021) was 547,000 ac-ft, while median annual discharge from springflow and pumping was 706,900 ac-ft (EAA 2021).

The Aquifer is considered a karst aquifer. Flow in the Aquifer is very complex (USGS 1995) and typical of other karst aquifers. It occurs over a wide range of hydraulic conductivity (e.g., flow through the rock matrix [least conductive], flow in planar fractures and bedding planes, turbulent flow through integrated conduit systems [most conductive]). In general, most storage occurs in the matrix, while most flow occurs in the fractures/faults and conduits. Matrix and conduit components may or may not mix effectively. Thus, groundwater in some components of the Aquifer may have very long residence times and be relatively resistant to surface contamination, while other components of the Aquifer may have extremely rapid travel times and be very vulnerable to contamination. The vulnerable parts of the Aquifer are also the most productive, feeding major springs and wells.

In addition to the variability of flow velocities, flow directions are also variable in karst aquifers. Flow directions are influenced by both regional and local hydraulic gradients, but they are also controlled by the location and orientation of conduit systems. Karst aquifers may be influenced by development and changes in geologic formations that occurred under previous water flow regimes; thus, flowpaths may not follow local topography or surface watersheds. It is common for flow in karst aquifers to cross watershed boundaries, which are typically considered groundwater divides in other types of aquifers. Furthermore, the pattern and direction of flow in a karst aquifer is often water-level dependent because high water levels can utilize older flowpaths and travel in non-linear directions, using conduits formed under older groundwater regimes, which may differ from modern ones.

Generally, the water flows south-southeastward from the recharge zone along low permeabilities and steep hydraulic gradients within the unconfined portion of the Aquifer. As the water flows into the confined portion of the Aquifer, the flow direction changes toward the east and northeast within the low-gradient, highly permeable artesian zone. The water is then discharged from several springs, predominantly Comal and San Marcos Springs (Section 3.2.1). Although the Aquifer contains vast reserves of water, a large volume of water cannot be extracted without affecting springflow and the overall water budget. This is because the springs are higher in elevation than much of the confined artesian zone. This relationship is similar to a bucket of water with holes at the top that are analogous to the spring locations. Although water is available in the lower portions of the bucket, it cannot be extracted without affecting the flow of water through the holes (springs) at the higher levels. The water budget of the Aquifer (recharge, discharge, and springflow) is discussed in Section 3.3.3.

The San Antonio segment of the Aquifer consists of a recharge zone and artesian zone (see Figure 1-1). Each of these components is described below. The Aquifer is also affected by a contributing zone. Development over the contributing and recharge zones of the Aquifer is regulated under rules established by the Texas Commission on Environmental Quality (TCEQ) Edwards Aquifer Protection Program (2010). Section 3.3.2, below, provides an overview of these regulations.

## Contributing Zone

The contributing zone is composed of drainage areas and catchments of surface streams upstream of the recharge zone that subsequently flow over the recharge zone. Much of the contributing zone lies over the older Glen Rose Formation, upthrust by the Balcones faulting. In the upthrown fault blocks, the Edwards Group rocks have been eroded away and are not present. Here, the Upper Glen Rose is exposed and classified as being the “contributing zone” to the Aquifer. The contributing zone of the San Antonio segment of the Aquifer is a surface component, not technically part of the Aquifer, which consists mainly of the drainage areas and catchments of surface streams, creeks, and rivers that subsequently flow over the Aquifer’s recharge zone in the Nueces, San Antonio, and Guadalupe River Basins. The contributing zone encompasses some 5,400 square miles in all or part of Edwards, Real, Kerr, Bandera, Kendall, Gillespie, Blanco, Bexar, Comal, Hays, Kinney, Uvalde and Medina Counties (see Figure 1-1). This area is important because of its substantial contribution to Aquifer recharge. Future development in the contributing zone will affect the quality and quantity of water draining to the recharge zone of the Aquifer.

## Recharge Zone

The recharge zone (also known as the unconfined zone) of the Aquifer is an approximately 1,250-square-mile area where heavily faulted and fractured Edwards limestone outcrops at the land surface allow large quantities of water to flow into the Aquifer. The recharge zone stretches as a band from an area north and west of San Marcos and New Braunfels and then southwesterly to an area north of San Antonio before continuing westerly through the northern portions of Bexar, Medina, Uvalde and Kinney Counties. Recharge occurs when streams and rivers cross the permeable formation and a portion of their flow seeps underground or precipitation or runoff falls directly on the outcrop. Water flows are driven by gravity to discharge at water-table springs, enter deep-flow systems and discharge at artesian springs, or recharge the confined zone of the Aquifer. Surface water reservoirs on the recharge zone, such as Medina Lake, also contribute large amounts of water to the Aquifer. Except for the Guadalupe River, all rivers and streams that cross the outcrop of the Aquifer lose major portions of their flows to the Aquifer through joints, faults, and sink holes as well as other karst features (USGS 1995). Where the Guadalupe River crosses the recharge zone, it may either gain or lose water from the Aquifer, depending on Aquifer levels. This is due to water levels in the river being near the groundwater table, whereas other creeks and streams are generally at significantly higher elevations. Three river basins cross the Aquifer area: the Nueces, the San Antonio, and the Guadalupe River. Extending from the west, the Nueces River Basin covers more than half of the Aquifer area.

Several major tributaries in the Nueces River Basin traverse the Aquifer recharge zone, including the Nueces, West Nueces, Frio, Dry Frio, and Sabinal Rivers as well as Hondo Creek. The portion of the San Antonio River Basin in the recharge zone extends from the Medina River to Cibolo Creek and includes the headwaters of Leon and Salado Creeks. Only a small portion of the Guadalupe River Basin intersects the eastern Aquifer area. However, two of the basin tributaries, the Comal and San Marcos Rivers, are fed primarily by the Aquifer at the Comal and San Marcos Springs.

Under normal conditions, most of the Aquifer recharge occurs in the basins west of Bexar County (USGS 1995) where the Edwards limestone outcrop is very wide at the surface. In the recharge zone, there are no other geologic formations overlying the Edwards limestone. It is therefore exposed at the surface.

Periods of recharge are intermittent because most streams in south-central Texas are ephemeral; however, the recharge capacity of surface water into the Aquifer is extremely efficient due to the karstic nature of the system. Water passing over the contributing zone and into faults, fractures, and swallets of the recharge zone is rapidly transferred directly to the Aquifer with little or no filtration. The geologic mechanisms that form karst are complex, and many factors affect how karst is expressed in current settings. These factors control the way the groundwater system evolves and ultimately how groundwater is recharged, transmitted, and naturally discharged through the Aquifer system.

## Artesian Zone

The artesian zone (also known as the confined zone of the Aquifer) is between two relatively impermeable formations, the Glen Rose Formation below and the Del Rio clay above (Ferrill et al. 2004). The weight of water entering the Aquifer from the recharge zone creates tremendous pressure on water that is already present in the formation. Flowing artesian wells and springs exist where this pressure is strong enough to force water to the surface along faults or through wells. This zone is where the highest capacity wells and largest springs exist (Collins and Hovorka 1997). Examples of natural springs under artesian conditions are San Marcos and Comal Springs in the northeast. Groundwater movement through the Aquifer is generally controlled by a number of barrier faults that disrupt the continuity of the permeable Edwards limestone. This movement tends to be from the higher elevations in the west to discharge areas in the east. The displacement of strata ranges from very large, which causes permeable and impermeable layers to be juxtaposed, to very small. Water moves more freely through the Aquifer when displacement is minimal. In addition, groundwater divides exist in the west near Brackettville and in the east near Kyle; therefore, the central portion of the Aquifer is hydro-geologically separated from Edwards limestones on either side (see Figure 3-16).

## Transition Zone

The transition zone consists primarily of younger bedrock overlying the artesian zone of the Edwards Group that has been down thrust to the east in the Balcones Fault Zone. These younger and generally less permeable rocks of the transition zone overlie and form the upper confining units to the artesian zone of the Aquifer. Although the surface bedrock in the transition zone is generally less permeable and karstified than the rocks of the Edwards Group, it was also extensively fractured and faulted by the Balcones Fault Zone and hosts some high-permeability pathways into the artesian zone. An exception is the Austin Chalk Formation, which is well karstified in some areas and hosts significant springs that discharge Aquifer water, such as San Antonio and San Pedro Springs (Veni 2009).

## Contributing Zone within Transition Zone

The contributing zone within the transition zone is defined in Title 30 of the Texas Administrative Code, Chapter 213, as the area generally south and east of the recharge zone—specifically, those areas where stratigraphic units not included in the Edwards Aquifer crop out at topographically higher elevations and drain to stream courses where stratigraphic units of the Edwards Aquifer crop out and are mapped as the recharge zone.

## Hydraulic Properties

Aquifer transmissivity (i.e., the ability of water to pass through the Aquifer, as measured by hydraulic conductivity and thickness) is high. According to Maclay and Small (1986), transmissivity of the Aquifer in the San Antonio area varies from 1 to 2 million square feet per day, allowing some wells in the city of San Antonio to discharge as much as 10,000 gallons per minute (gpm) or more (USGS 1995). One particular well was documented by the EAA to produce between 25,000 and 36,000 gpm. Highest transmissivity was determined to exceed 4,300,000 square feet per day in Comal County near Comal Springs; the smallest was 130 square feet per day in the saline water zone (Maclay and Land 1988). The linear distance at which water may move through the Aquifer appears to vary greatly, depending on location. Ogden et al. (1986) documented travel from up to 1,000 feet per day to only a few feet per day. Recent tracer tests conducted by the EAA revealed discrete groundwater flowpaths near Panther Springs Creek, with apparent (point-to-point) groundwater velocities ranging from 43 to 17,490 feet per day from the recharge zone to the transition/artesian zone of the Aquifer (EAA 2010a). Other evidence of high porosity of the Aquifer is the ability of Aquifer water levels to quickly respond to rainfall and recharge events as well as the rapid decline in water levels over a large area due to increased pumpage.

The Knippa Gap near Sabinal in eastern Uvalde County (see Figure 1-1) is a major controller of groundwater flow within the western portion of the Aquifer. The Knippa Gap is a geological restriction within the Aquifer that allows a substantial flow of groundwater from west to east but restricts the flow long enough to maintain higher groundwater levels in the Uvalde pool compared with the San Antonio pool (Green et al. 2008). Wells to the west of the Knippa Gap display much less variability in water levels than wells to the east. Water entering the recharge zone in northwestern Uvalde County appears to flow through the gap to reach the main freshwater zones of the Aquifer in Medina and Bexar Counties.

Flow models for the Aquifer show groundwater flowing east-northeast from Uvalde and Medina Counties, eventually discharging at Comal, Hueco, and San Marcos Springs; numerous small springs; or extracted by groundwater pumping from wells (Kuniansky et al. 2001). However, recent tracer studies in northern Bexar County performed by the EAA found that water flows from north to south with very rapid flow velocities (Johnson et al. 2009). In addition, these studies found that flowpaths may be more complex than originally thought, with rapid groundwater transport dominated by karstic conduit flow.

## Freshwater/Saline Water Interface

The freshwater/saline water interface (also known as the “Bad Water Line,” or BWL) delineates the Edwards Aquifer’s eastern and southern boundaries. It is not an actual, well-defined boundary but rather a transition zone on the southern and eastern limits of the Aquifer, extending from west of Kinney County through Bexar County and northward beyond the northern extent of the San Antonio region of the Aquifer. Wells to the south and southeast of this line typically display total dissolved solids (TDS) concentrations greater than 1,000 milligrams per liter (mg/l). Wells on the other side of this line typically have TDS concentrations equal to or less than 1,000 mg/l. The reason the “bad-water line” exists is not clear. In some places, it coincides with geologic features such as faults; in other places, there is no obvious geologic control. The presence of “bad” or more saline water appears to be more associated with relative permeabilities of the Aquifer rather than a density boundary between two different water types, which commonly exists in coastal sand aquifers. Wells in the transition zone have sections of brackish water that overlie freshwater, which, in turn, overlie brackish water, indicating that the type of rock and porosity influences the salinity of the water. It has been hypothesized that increased pumping of freshwater from the Aquifer may lead to an expansion of the bad-water zone, which could be detrimental to existing irrigation and municipal wells. In 1985, the EAA, in cooperation with USGS, TWDB, and the San Antonio Water System (SAWS), began testing in the fresh/saline interface area for possible saline-water encroachment into the freshwater zone. In 1997, the EAA reported that there were no significant changes in water quality in the test wells between 1985 and 1997 and that normal changes in Aquifer water levels have little effect on the quality of freshwater near the interface.

### 3.3.1 Inter-formational Flow into the Edwards Aquifer

The Edwards Aquifer receives most of its recharge directly where the limestone of the Person and Kainer Formations outcrop. However, a significant component of groundwater flow enters the Aquifer directly as inter-formational flow from the Trinity Aquifer. The recent Groundwater Availability Model for the Hill Country Portion of the Trinity Aquifer indicates that as much as 2,400 ac-ft per year for each linear mile of the Edwards-Trinity boundary in Bexar and Comal Counties (Jones 2011) exits the southern boundary of the recent Groundwater Availability Model, indicating possible flow from the Trinity Aquifer into the Edwards Aquifer. This value is lower to the west in Medina and Uvalde Counties (660 ac-ft/year/mile) and lowest farther east in Hays and Travis Counties (350 ac-ft/year/mile). Green (2011) has also demonstrated that losing streams in the contributing zone (Upper Glen Rose outcrop) are much more connected with the Edwards Aquifer than previously thought. In the Barton Springs segment of the Edwards Aquifer, it has been shown that Upper Glen Rose is in close hydraulic connection with the Edwards Aquifer, as documented by monitoring sophisticated multi-port wells (Smith and Hunt 2011). Dye tracer studies in northern Bexar County indicate that a very prolific connection exists between the two aquifers and documented rapid groundwater flow across faults that juxtapose the Edwards and Trinity Aquifers.

### 3.3.2 Groundwater Quality of the Edwards Aquifer

## Rules Governing Groundwater Quality

Regulations governing the quality of groundwater in Texas have interrelated state and federal regulatory functions. In 1974, the federal Safe Drinking Water Act was passed to protect sources of public drinking water. This act, amended in 1996, mandated enforceable drinking water standards, as established by the U.S. Environmental Protection Agency (EPA). The TCEQ has assumed responsibility for enforcement of drinking water standards in Texas and has established standards that meet or exceed those of the EPA. The Edwards Aquifer was designated as a sole-source aquifer, and TCEQ promulgated rules regulating development activity over zones of the Aquifer in eight counties, pursuant to 30 Texas Administrative Code, Chapter 213. The counties are Kinney, Uvalde, Medina, Bexar, Comal, Hays, Travis, and Williamson. Subchapter A applies to all regulated activities (defined as construction-related or post-construction activity) within the recharge zone, certain activities within the surrounding transition zone that stretches along the eastern and southern boundary of the recharge zone, and other activities that may contaminate the Aquifer and hydrologically connected surface streams. Under these rules, developers must submit an application, including an Aquifer protection plan, to the TCEQ prior to certain types of activity in the recharge, transition, or contributing zones of the Aquifer. For proposed development, including any regulated construction-related activity over the recharge zone, a water pollution abatement plan (WPAP) is required. The WPAP must include a geological assessment report, identifying pathways for the movement of contaminants to the Aquifer, and a report on best management practices and measures to prevent pollution in the Aquifer. After the plan is approved, notice must also be filed in the county deed records that the property is subject to an approved Aquifer protection plan. Certain facilities are also prohibited from being built in the recharge or transition zones, such as Type 1 municipal solid waste landfills and waste disposal wells. Subchapter B applies to regulated activities in the Aquifer's contributing zone. All activities that disturb the ground or alter a site's topographic, geologic, or existing recharge characteristics are subject to regulation, which would require either sediment and erosion controls or a contributing zone plan (CZP) to protect water quality during and after construction. Exemptions include construction of single-family residences on lots larger than 5 acres where no more than one single-family residence is located on each lot; agricultural activities; oil and gas exploration, development, and production under the jurisdiction of the Texas Railroad Commission; clearing of vegetation without soil disturbance; and maintenance of existing structures not involving additional site disturbance (30 Texas Administrative Code Section 213.22[6]).

The EAA has implemented a water quality protection program through rulemaking. Well construction rules have been adopted that regulate the construction, operation, maintenance, abandonment, and closure of wells (see EAA Rules, Chapter 713 [Water Quality], Subchapters B [General Provisions], C [Well Construction, Operation, and Maintenance], and D [Well Closures]). The EAA also regulates the reporting of spills (Subchapter E), storage of certain regulated substances (Subchapter F) on the recharge zone and the contributing zone of the Aquifer, and the installation of regulated tanks on the recharge zone of the Aquifer (Subchapter G). The City of San Marcos has also enacted regulations to protect water quality over the Aquifer recharge zone.

## Primary Drinking Water Standards

Primary drinking water standards are enforceable for public water supply systems and often referred to as maximum contaminant levels (MCLs). The MCL for a contaminant is the maximum permissible level of the contaminant in water that is delivered to any user of a public water system. MCLs protect drinking water quality by limiting levels of specific contaminants that can adversely affect public health and are known or anticipated to occur in public water systems. The primary standards are based on concentrations published in Title 30 of the Texas Administrative Code, Chapters 290 and 350. This concentration is the value estimated to be protective of human health and the environment.

## Secondary Drinking Water Standards

Secondary drinking water standards, which are non-enforceable, are set for contaminants that may affect the aesthetic qualities of drinking water, such as odor or appearance.

## Historic and Current Groundwater Quality Monitoring

Historically, the groundwater of the Aquifer has been considered to be of high quality—typically fresh but hard, with an average dissolved solid concentration of less than 500 mg/l (Texas Water Commission [TWC] 1992). Cooperative efforts between the EAA, USGS, and TWDB have resulted in a systematic program of water data collection. Each year the EAA monitors the quality of water in the Aquifer by sampling approximately 80 wells, eight surface water sites, and major spring groups across the region. Collection sites are typically selected to provide representative samples of the recharge zone, the shallow and deep artesian zone, the springs, and the surface streams that flow across the recharge zone as well as areas with historical detections of anthropogenic compounds.

Tests at the wells included measurements of temperature, pH, conductivity, alkalinity, major ions, minor elements (including heavy metals), TDS, nutrients, pesticides, herbicides, volatile organic compounds (VOCs), and other analytes.

## 3.3.3 The Edwards Aquifer Water Budget

Water levels of the Aquifer and associated flows of Comal and San Marcos Springs are affected by the rate of water entering the Aquifer (recharge) and the rate of water exiting the Aquifer (discharge). Recharge occurs as water enters the Aquifer from streams, natural catchments, recharge structures, precipitation events, and subsurface flows from adjacent aquifers. Seasonal rainfall over the region ultimately controls the rate of recharge. Discharge occurs from the withdrawal of water from wells as well as the flow of natural springs and seeps. An unknown smaller quantity is discharged to the saline water zone (USGS 1995). Discharge is greatly affected by water demand and the rate of pumping. If recharge is high, the Aquifer can sustain higher levels of pumping while maintaining higher levels of springflows. However, if low seasonal recharge is followed by reduced rainfall and high rates of pumping, then Aquifer levels will decline, with resulting decreased spring discharges. Historic recharge and discharge of the Aquifer and effects on springflow are discussed below.

## Groundwater Recharge

Estimates of the average annual recharge of the Aquifer vary according to changes in weather cycles and resulting precipitation over the recharge and contributing zones. The USGS (1995) cites an average annual recharge of 635,000 ac-ft. However, Klemt et al. (1979) indicate an average annual recharge of approximately 651,000 ac-ft. Data from the EAA's 2021 Hydrologic Data Report (EAA 2021) indicate an average annual groundwater recharge of 695,000 ac-ft for the period of record (1934–2020) and an even higher annual average of 965,400 ac-ft during the last 10-year period (2000–2009). Estimated contributions of the major river basins to annual recharge during the period of record (1934–2009) are listed in Table 3-5.

Estimated recharge to the Aquifer varied greatly from 1934 to 2009, as indicated in Figure 3-17. Variability was correlated with annual precipitation and corresponding runoff into the major river and creek basins. Lowest annual estimated recharge (44,000 ac-ft) occurred during 1956, at the peak of the drought of record. Highest estimated recharge (2,486,000 ac-ft) occurred in 1992. Rates of infiltration of water carried by the streams across the recharge zone have been estimated by the USACE (1965) to range from 500 to more than 1,000 cfs. Recent modeling studies using the Hydrologic Simulation Program Fortran (HSPF) indicate that land-based recharge outside of stream channels across the nine basins varies from a low of 2 percent to a high of 76 percent (EAA 2010b), whereas 24 to 98 percent of recharge across the nine basins occurs in stream channels as channel loss (LBG Guyton Associates 2005). In addition, some recharge to the Aquifer originates from inter-formational flow from adjacent aquifers, such as the Trinity Aquifer. Recent studies by Green and Bertetti (2010) indicate that a substantial volume of water enters the Aquifer directly through a cross-formational flow of recharged water to the Trinity Aquifer (Glen Rose limestone). Dye tracing conducted by the EAA in northern Bexar County suggests rapid and direct groundwater flowpaths from the Trinity to the Edwards Aquifers (Johnson et al. 2009). Estimates of the contribution from adjacent hydraulically connected aquifers have been estimated by the EAA (2010a) to vary from 5,000 to 60,000 ac-ft/year.

**Table 3-5. Contributions of Major River Basins to Average Annual Recharge of the Edwards Aquifer, 1934–2009 [update table]**

**Figure 3-17. Estimated Annual Recharge and 10-year Floating-average Recharge for the San Antonio Segment of the Edwards Aquifer, [update info and period]**

## Groundwater Discharge

Water is diverted from the Aquifer through wells; it also exits from natural springs and seeps occurring near geological faults along the Edwards Formation and Balcones Escarpment. Wells are the principal source of water for agricultural, municipal, and industrial uses in the region. The depths of wells range from less than 500 feet in the unconfined Aquifer to more than 3,000 feet in the confined Aquifer in the western region (USGS 1995). Wells in the area can be very large, with casing diameters ranging from 10 to 30 inches. These wells are capable of pumping in excess of 35,000 gpm. Average annual discharge from wells over the period of record (1934–2021) was 318,000 ac-ft (44.7 percent of all discharge), in comparison to 384,400 ac-ft (55.3 percent) from springflow (EAA 2021). During droughts, the proportion of well discharge to spring discharge changes considerably. During 1956, at the height of the drought of record, wells contributed 82 percent of the discharge in comparison to 18 percent for springs. During the drought of 2008, wells contributed 51 percent of the total discharge, while spring discharge was 49 percent. Values for average and median discharge are provided in the EAA 2010b.

Well discharge has generally increased over the period of record, from a point beginning in 1968 and running through 1989, with annual discharge consistently exceeding average annual recharge (USGS 1995). Pumping peaked in 1989 at an estimated level of 542,000 ac-ft. Since 1980, as a result of increased pumping, there has been greater fluctuation in springflow, along with increased time required for recovery, even during a period that recorded the two highest levels of Aquifer recharge (1992 and 2004). Examination of Figure 3-18 indicates increases in pumping beginning in 1982,1987, and 1996, resulting in higher fluctuation of springflow.

# 3.4 Description of the Edwards Aquifer, Comal Springs, and San Marcos Springs Ecosystems

The Aquifer and associated springs (Comal Springs, San Marcos Springs, and Hueco Springs) are unique aquatic ecosystems with some of the greatest diversity in groundwater and spring-associated species in the world (Bowles and Arsuffi 1993; Culver and Sket 2000; Holsinger and Longley 1980; Longley 1981; Reddell 1994).

**Figure 3-18. Groundwater Pumping Compared to Springflow to the Edwards Aquifer [update figure].**

## 3.4.1 Edwards Aquifer Ecosystem

The Aquifer lies within the Balcones Fault Zone, on the eastern boundary of the Edwards Plateau. It extends from a groundwater divide in Kinney County, through San Antonio, then continues northeast to Bell County. The recharge zone occurs in the Balcones Fault Zone at the Aquifer outcrop where the cretaceous limestones are exposed at the surface. Dissolution of the Edwards limestone throughout the recharge zone creates defining features such as caves and sinkholes. Groundwater levels typically vary with weather and season and have the potential to rapidly fluctuate following heavy rainfall. Water quality within the Aquifer is generally good because quick recharge through karst features limits water-rock interactions, thereby reducing dissolved solids (TWDB 2016). Within the contributing and recharge zones, water quality is heavily influenced by rainfall, stream infiltration, and increased groundwater velocities. Within the Artesian Zone, however, water quality is more stable because of the slower groundwater velocities and increased volume of water (EAA 2021). Focused recharge, enhanced cavernous porosity, and geochemical water quality conditions makes this one of the most productive groundwater reservoirs in the country (Sharp and Banner 1997). It may be one of the most biologically diverse karst aquifers in the world because of the high degree of interconnectedness between the conduits. Culver et al. (2003) showed that patterns of biodiversity were positively correlated with the number of caves and the distance from the late Cretaceous Sea. In addition, Hutchins et al. 2015 suggested that biological diversity within the Aquifer might be supported through chemolithoautotrophy, the process by which an organism obtains energy through the oxidation of inorganic compounds, a stable energy source that increases resource exploitation and reduces competition.

The Aquifer supports a highly modified biological assemblage that is adapted to deep water environments, including catfish, salamanders, and aquatic crustaceans with vestigial or no eyes. Several studies investigating the occurrence of aquifer-dwelling biota have reported up to 55 aquatic species, taxonomically representing seven phyla, 11 classes, and 17 orders of organisms (Hutchins et al. 2021). Several species are listed by the USFWS as endangered or threatened or have been proposed for listing (see Section 3.5).

The hydrology of the Aquifer is directly related to surface water ecosystems because water in the springs flows from the Aquifer at the base of the Balcones Escarpment (McKinney and Sharp 1995). Therefore, the systems are intertwined by water quantity, quality, and thermal conditions while separate with respect to the biological organisms that directly rely on sunlight and surface energy.

## 3.4.2 Comal Springs Ecosystem

The Comal Springs ecosystem (Figures 3-19a and 3-19b) originates from the Aquifer through multiple spring orifices, primarily in Landa Park in New Braunfels. The system comprises four major springs and several smaller spring runs that feed into Landa Lake. Together, the spring runs and Landa Lake form the headwaters of the Comal River, which covers 3.1 miles before its confluence with the Guadalupe River, making it the shortest river in Texas. From Landa Lake, water flows into two channels, the original “Old Channel” and a “New Channel” created in 1847 when the river was dammed and a millrace was hand excavated to provide water for William Merriweather’s saw and grist mill.

**Figure 3-19a/b. Comal Springs Ecosystem [keep figures]**

During low flow conditions, most of the flow is directed to the Old Channel, however, it flows mostly to the New Channel during high flow conditions. The two channels rejoin 1.6 miles downstream from Landa Lake (McKinney and Sharp 1995). The long term (1933–2022) median discharge from the Comal Springs ecosystem, including the Old Channel and New Channel, is 304 cfs (USGS 08169000). The median flow in the Old Channel from 2012 to 2022 was 57 cfs (USGS 08168913). Over the years, extensive urban development along the banks, channel modification, and recreational activities related to parks and tube chutes have altered the Comal Springs system (McKinney and Sharp 1995). Despite a few small dams, channelization, and some diverted springflow for a water park, Schlitterbahn, the Old Channel retains many of its natural characteristics. The New Channel, however, has a more uniform width and, in some areas, a limestone bottom. The New Channel stream modifications are associated with several constructed dams to control overflow and tube chutes to enhance recreational use.

Although bank and channel modifications have occurred because of development and recreation, water temperatures remain near constant in the system overall. Temperatures do display variability among a longitudinal gradient, with more variation as distance from spring source increases. Low variation occurs in spring runs and at Landa Lake, while variation increases in the Old Channel and New Channel from upstream to downstream (BIO-WEST 2022). For example, in 2022, median temperature variation within a reach increased from 1.1°C in Landa Lake, to 1.5 °C in Old Channel, and 2.9°C in New Channel Downstream. Overall, annual median temperature throughout the Comal Springs ecosystem ranged from 23.8°C (74.8°F) upstream of Landa Lake to 23.9 °C (75.0 °F) at the New Channel and 24.4°C (75.2°F) at the Old Channel (BIO-WEST 2022). In addition, the ecosystem exhibits high water quality, with low nutrient and bacteria levels (EAA 2021; USFWS 1996).

The biotic community in Comal Springs includes a diverse assemblage of submerged aquatic vegetation, benthic macroinvertebrates, fishes, and amphibians. Approximately 10 species of submerged aquatic vegetation and several species of bryophyte are dominant in the Comal Springs ecosystem (Williams 2011). Historical accounts of aquatic vegetation indicate that much of the native vegetation in Landa Lake and the Old Channel was displaced with non-native species; therefore, a native aquatic vegetation restoration plan was developed for Landa Lake and the Old Channel in 2013. Prior to EAHCP restoration efforts, Landa Lake was dominated by *Vallsineria*. The Old Channel historically supported large stands of *Ludwigia* and filamentous algae, but those native species were replaced by *Hygrophila*. Post-restoration mapping in 2018 indicated that *Hygrophila* was drastically reduced to only the spillway in Landa Lake and the lower half of the Old Channel; however, because the likelihood of reinfestation is high, continued maintenance is necessary to keep *Hygrophila* from re-establishing (BIO-WEST 2019). Currently, *Vallsineria* dominates the vegetation community in Landa Lake, while bryophytes dominate restored areas of the Old Channel. Flood events, flood pulses along Dry Comal Creek, and high recreational use can yield reduced vegetative cover in the New Channel. Between disturbance events, dominant vegetation within the New Channel often consists of *Cabomba* and *Hygrophila*. Among the fish community, the dominance of spring-associated species (e.g., Guadalupe roundnose minnow [*Dionda nigrotaeniata*], Texas shiner [*Notropis amabilis*], and fountain darter [*Etheostoma fonticola*]) indicates a healthy spring ecosystem (BIO-WEST 2022). Generally stable trends in benthic macroinvertebrate communities suggest a healthy community. Despite urban development, the Comal Springs ecosystem still exhibits high biotic integrity (Munscher et al. 2019; Scanes 2016). Several organisms occurring in the Comal Springs ecosystem are listed by the USFWS as threatened or endangered. The listed species will be discussed in further detail in Section 3.5.

### 3.4.3 San Marcos Springs Ecosystem

The San Marcos Springs ecosystem (Figures 3-20a through 3-20c) originates from several springs throughout Spring Lake in Hays County, forming the headwaters of the San Marcos River. The San Marcos River extends 68.2 miles to its confluence with the Guadalupe River. San Marcos Springs has the most environmental stability and flow reliability of any spring system in the southwestern United States (USFWS 1996). This spring system has never stopped flowing in recorded history, although discharges dropped to approximately 46 cfs during the drought of record in the 1950s. The long-term (1956–2022) median discharge from the San Marcos Spring system was 174 cfs (BIO-WEST 2022). Temperatures in the Upper San Marcos River remain nearly constant year-round (21°C to 23°C [70°F to 73°F]) (BIO-WEST 2022), showing slight variability along a longitudinal gradient as distance from spring sources increases.

As with the Comal River, the San Marcos River is a haven for recreational activities. Upstream flood control dams within the watershed of the San Marcos River have enhanced recharge to the Aquifer by allowing water behind the dams, which would have gone downstream as irretrievable rapid flow, to infiltrate and contribute to the recharge system. Hydrologically, these dams have also reduced the magnitude of scouring flood events downstream, allowing an accumulation of sediments and encroachment of non-native vegetation. A major source of the accumulated sediments is provided by Sessom Creek, which receives runoff from the Texas State University campus (Earl and Wood 2002). These sediments are accumulating at a high rate, and even significant floods are unable to erode and transport them. Because flood control measures on the San Marcos River have prevented large scouring floods from occurring, the deposited sediments remain near the confluence of Sessom Creek and the San Marcos River, about 40 yards downstream from Spring Lake Dam. The sediments act as fill in the natural channel, making the channel downstream shallower than it would otherwise be and creating a spit that extends about halfway across the San Marcos River at the confluence with Sessom Creek. In 2021, the City of San Marcos began an improvement project on Sessom Creek to address the problem of increased sediments in the San Marcos River by creating grade controls and providing bed and bank stabilization. This effort will reduce sedimentation and preserve habitat in the area downstream of Spring Lake Dam.

The biological uniqueness and high degree of endemism found in Spring Lake and in the Upper San Marcos River can be attributed to thermal stability, consistent water chemistry, and a reliable flow (USFWS 1996). Downstream of Spring Lake Dam, the Upper San Marcos River flows over mostly gravel habitats with many shallow riffles and deeper runs. Lemke (1989) documented 31 species of aquatic macrophytes on the Upper San Marcos River, with 23 species being native. Among native vegetation, dominant taxa consist of Texas wild-rice, *Potamogeton*, *Hydrocotyle*, *Cabomba*, and *Sagittaria*. Increasing competition with non-native species, *Hydrilla* and *Hygrophila*, and resulting displacement for native species have been concerns. Control of non-native vegetation, mitigation of floating vegetation mats, and enhancement of Texas wild-rice have occurred as a result of implementation of the EAHCP since 2013 (EAA 2012).

**Figure 3-20a/b/c. San Marcos Springs Ecosystem [keep figure]**

Hydrilla has been greatly reduced to an undetectable level from Spring Lake to downstream of Hopkins Street, and removal efforts for *Hygrophila* are following closely behind. The Upper San Marcos River boasts a diverse fish assemblage, with spring-associated fishes (e.g., Guadalupe roundnose minnow, largespring gambusia [*Gambusia geiseri*], and Texas shiner) dominating community abundance in the upper and middle portions (BIO-WEST 2022). One spring-associated endemic species, the San Marcos Gambusia *Gambusia georgei*, was designated as endangered in 1980 and last collected in 1983. In September 2021, the USFWS proposed to remove this species from the Federal Lists of Endangered and Threatened Wildlife and Plants due to extinction (USFWS 2021). Despite more than 170 years of urbanization and resulting changes to stream morphology, instream habitats, water quantity and quality, and introduced species, the Upper San Marcos River retains a persistent fish community (Kollaus et al. 2014). Stable trends in aquatic life use over time, ranging from “intermediate” in Spring Lake to “exceptional” at Spring Lake Dam and Interstate 35, suggest that a robust benthic macroinvertebrate community exists (BIO-WEST 2022). Several organisms occurring in the San Marcos Springs ecosystem are listed by the USFWS as either threatened or endangered and therefore will be discussed in further detail in Section 3.5.

## Hueco Springs Ecosystem

Hueco Springs is in Comal County, on private property, approximately 4 miles north of New Braunfels, near the junction of Elm Creek and the Guadalupe River. It is the seventh-largest spring in Texas; it includes two main groups of springs, one on each side of River Road. These springs flow from the Hueco Springs fault, which is a major structural feature within the Aquifer with an offset of approximately 400 feet (Guyton and Associates 1979). The springs consist of two orifices at a high elevation (approximately 658 ft MSL); therefore, they have variable flow and often go dry or have long periods of low flow during drought (Abbott and Woodruff 1986). The maximum discharge for Hueco Springs was 260 ac-ft per day (131 cfs) in 1968 (Brune 1975) but has averaged about 70 ac-ft per day. Hueco Springs recharge has both local and regional components, originating from the nearby Dry Comal Creek and Guadalupe River Basins and from longer flowpaths from San Antonio (see Figure 3-13) (Otero 2007). Hueco Springs was documented as having elevated nitrate levels (> 5 parts per million [ppm]) during the drought of the 1950s, but most values since that time have been below 2 ppm. One measurement was just above 2 ppm in 2000 (Johnson et al. 2009).

This spring complex consists of two main groups of springs, issuing from the floodplain of the Guadalupe River. Hueco I (Hueco A) is a large, typically perennial spring on the west side of River Road in an undeveloped area. Hueco II (Hueco B) is an intermittent spring on the east side of River Road located in a campground. Hueco Springs has a local recharge component that could be enhanced by strategically placed recharge dams (Barr 1993). Fauna recorded from this site include the elmid beetle, *Microcylloepus* sp., and the water penny beetle, *Psephenus texanus*, along with surface-dwelling amphipods, oligochaetes, caddisfly larvae, crayfish, clams snails, aquatic isopods, three species of copepod (*Acanthocyclops vernalis, Mesocyclops edax,* and *Skstodiaptomus* sp.), hypogean amphipods (*Stygobromus russelli*) (Zara 2003), an aquifer salamander (possibly *Eurycea rathbuni*), and the federally listed Peck's cave amphipod, *Stygobromus pecki* (Barr 1993).

# 3.5 Listed Covered Species

Seven species that depend entirely on the Aquifer and associated springs are currently listed as endangered or threatened by the USFWS. Incidental take may be allowed for all of these species if covered by an Endangered Species Act (ESA) Section 10(a)(1)(B) permit. The ESA does not prohibit take of listed plants, except on federal lands (16 United States Code [U.S.C.] Section 1532[8] and Section 1532[14]).

Listed species addressed in the HCP include (with date of listing):

## Endangered

- Fountain darter (*Etheostoma fonticola*) (35 FR 16,047 [October 13, 1970])
- Comal Springs riffle beetle (*Heterelmis comalensis*) (62 FR 66,295 [December 18, 1997])
- Comal Springs dryopid beetle (*Stygoparnus comalensis*) (62 FR 66,295 [December 18, 1997])
- Peck's cave amphipod (*Stygobromus pecki*) (62 FR 66,295 [December 18, 1997])
- Texas wild-rice (*Zizania texana*) (43 FR 17,910 [April 26, 1978])
- Texas blind salamander (*Eurycea* [formerly *Typhlomolge*] *rathbuni*) (32 FR 4,001 [March 11, 1967])

## Threatened

- San Marcos salamander (*Eurycea nana*) (45 FR 47,355 [July 14, 1980])

A brief life history of each species covered in the HCP is provided below, including details that are relevant to the HCP.

### 3.5.1 Fountain Darter (*Etheostoma fonticola*)

The fountain darter, a member of the family *Percidae*, is endemic to the San Marcos and Comal Rivers. This species was first collected in 1884 in the San Marcos River just below its confluence with the Blanco River and in 1891 in the Comal River (Schenck and Whiteside 1976). Historically, fountain darter distributions throughout the San Marcos River extended from Spring Lake downstream to just below its confluence with the Blanco River as well as throughout the Comal River from the headwaters downstream to its confluence with the Guadalupe River (Schenck and Whiteside 1976). Currently, fountain darter distributions remain similar and occur in the San Marcos River from Spring Lake downstream to just above its confluence with the Blanco River as well as the entirety of the Comal River, including Landa Lake (BIO-WEST 2022; McKinney and Sharp 1995; Schenck and Whiteside 1976).

Fountain darters are among the smallest darters, belonging to the subgenus *Microperca* within the genus *Etheostoma*. Fountain Darters can be identified by their olive-green coloration, abbreviated lateral line, midlateral row of elongated dark blotches, dark spots at the base of the caudal fin, and suborbital bars (Page and Burr 1979; Schenck and Whiteside 1976). Stenothermal conditions and high water clarity in both spring systems enhance the persistence of fountain darters throughout their range (Kollaus et al. 2014; Schenck and Whiteside 1977; Simon et al. 1995). Fountain darters typically have slack-water affinities and often associate with habitats that include undisturbed sand and gravel substrates, rock outcrops, and submergent vegetation (i.e., algae, bryophytes, vascular plants) for feeding, reproduction, or cover (Alexander and Phillips 2012; McKinney and Sharp 1995; Schenck and Whiteside 1977; USFWS 1996). Young darters are often found in heavily vegetated slack-water habitats, while adults can be found in all habitats (Schenck and Whiteside 1976). Although fountain darters are frequently associated with vegetation, the relationship is not exclusive. The use mechanisms (e.g., feeding, reproduction, cover) remain unknown (Edwards and Bonner 2022). Densities are higher in ornate vegetation such as bryophytes or *Cabomba* (BIO-WEST 2022), suggesting that darters associate with structurally complex habitats. The type and amount of food consumed changes with growth and varies, depending on the invertebrate community composition within the reach (Schenck and Whiteside 1977). Generally, food sources for fountain darters consist of small aquatic invertebrates such as copepods, aquatic insect larvae, and amphipods (McKinney and Sharp 1995; Schenck and Whiteside 1977). Fountain darters are stationary feeders that use visual cues, primarily during the day, as they wait for prey to approach (Schenck and Whiteside 1976; USFWS 1996). Fountain darters are relatively sedentary, moving an average of 10 meters throughout the course of a year under a stable flow regime (Dammeyer et al. 2013). Another study, conducted under low-flow scenarios, similarly suggested that fountain darters remain relatively stationary, moving an average of 20.9 meters, with maximum movement of 131 meters (BIO-WEST 2014).

Some studies suggest that fountain darters exhibit continuous spawning year-round (Hubbs 1985; Strawn 1955); however, a more recent study demonstrated that fountain darters display a protracted annual reproductive cycle, with the optimum reproductive season in the spring

(Nichols 2015). Fecundity is believed to be lower in fountain darters than other species of darters and could be related to the influence of repeated spawnings throughout the year (Nichols 2015; Schenck and Whiteside 1977). This species exhibits sexual dimorphism, with the males having four morphological forms that differ in size, color, and shape (Schenck and Whiteside 1977). Vegetation is considered necessary for egg deposition (Strawn 1956), although fountain darters utilize a variety of substrates, including PVC tubing and glass in the hatchery setting (Brandt et al. 1993). Males produce a small amount of transparent milt (sperm) to fertilize the adhesive eggs (Hubbs 1958). Little or no parental care is provided to the eggs or young (Schenck and Whiteside 1977). Several laboratory studies have shown reductions in egg production between 25°C (77°F) and 26°C (79°F) and in larval production between 24°C (75°F) and 25°C (77°F) (Bonner et al. 1998; Brandt et al. 1993; McDonald et al. 2007). Wild fountain darters often experience a 2°C temperature fluctuation, but this fluctuation might not affect fountain darter recruitment in the wild because darters of less than 15 millimeters (mm) were still observed as temperatures approached 26°C (79°F) (BIO-WEST 2022).

Between 1954 and 1973, the original population of fountain darters was extirpated from the Comal River (Linam et al. 1993; Schenck and Whiteside 1976). It is believed that a combination of a rotenone treatment by the Texas Fish, Game, and Oyster Commission in 1951 to remove non-native Rio Grande cichlids (*Herichthys cyanoguttatus*), a lack of springflow for a 6-month period in 1956, and a flood from Blieders Creek in 1971 all potentially contributed to extirpation (Linam et al. 1993; Schenck and Whiteside 1976). A collection by Hubbs and Strawn (1957) that occurred between the rotenone treatment and the zero springflow conditions of 1956 indicated fountain darter presence in the system but did not indicate abundance. Fountain darters were listed as federally endangered in 1970 (USFWS 1970; 35 FR 16047) and deemed “the little fish that roared” (Votteler 1998) as legislative and judicial battles led to the creation of the Edwards Aquifer Authority to regulate groundwater pumping and protect springflow in San Marcos and Comal Springs. Critical habitat for the fountain darter was designated at Spring Lake and its outflow as well as the San Marcos River downstream to 0.5 mile below the Interstate 35 bridge (45 FR 47355, 47364 [July 14, 1980]). In 1975, a total of 457 fountain darters from the San Marcos River were re-introduced into the Comal River, from which the present Comal population is descended (Linam et al. 1993; Schenck and Whiteside 1976).

Several studies have attempted to provide fountain darter population abundance estimates, but the estimates either have no confidence intervals (103,000) (Schenck and Whiteside 1976) or wide-ranging confidence intervals (15,900–107,700) (Linam et al. 1993), thereby calling the estimates into question. Population abundance is difficult to estimate because of the fountain darter’s small body size, the range of sampling methods used in the past, and the difficulty in accounting for all of the habitat dynamics in calculations. Although recent population estimates have not been generated, long-term monitoring of fountain darters indicate that high densities exist in the San Marcos and Comal Rivers. In the Upper San Marcos River, long-term (2001–2022) median fountain darter densities range from 1.5 darters per square meter ($m^2$) in Spring Lake to 2.0 darters/$m^2$ in City Park and at Interstate 35. In the Comal River, fountain darter densities range from 1.5 darters/$m^2$ in the Upper Spring Run to 11.0 darters/$m^2$ at Landa Lake (BIO-WEST 2022). Furthermore, among vegetation taxa, fountain darter densities are highest in bryophyte (16.8 darters/$m^2$) and *Cabomba* (12.3 darters/$m^2$).

Threats to fountain darters include diminished springflow, poor water quality, and habitat destruction (USFWS 1996). Initially, it was believed that the trematode *Centrocestus formosanus,* hosted by the red-rimmed Melania (*Melanoides tuberculata*), posed a serious threat to the fountain darter after *C. formosanus* was first identified from a fountain darter in the 1990s and later high numbers of encysted metacercariae were observed on the darters (Cantu et al. 2013). This trematode attacks the gills of the fountain darter, causing reddening, swelling, and bleeding that could lead to increased stress and reduced ability to avoid predators. Laboratory studies suggested that, in early stages of infestation and under moderate parasite loads, *C. formosanus* did not affect reproduction (BIO-WEST 2002). In addition, infestation by the trematode *Haplorchus pumilio* has been observed encysted in the connective tissue around the heads and fins (Huston et al. 2014), which may exacerbate the effects of *C. formosanus*. Monitoring studies aimed at understanding distribution and density of *C. formosanus* and *H. pumilio* were conducted from 2013 to 2022. Results suggested that, although flow generally explains density trends for both trematodes through an inverse relationship with densities increasing under low-flow conditions, there has been an overall decrease in cercariae concentrations over time (BIO-WEST 2022). Coupled with stable fountain darter densities over time in both systems, this indicates that *C. formosanus* and *H. pumilio* might pose less of a threat to fountain darter populations than initially believed. However, continued monitoring of parasite concentrations and additional research, particularly during periods of low flow, into snail population trends, as well as infection rates in snail, fish, and bird hosts, would provide deeper understanding of these parasite population dynamics.

### 3.5.2 Comal Springs Riffle Beetle (*Heterelmis comalensis*)

The Comal Springs riffle beetle (Coleoptera: Elmidae) was first collected from Comal Springs in 1976, as described by Huston et al. (1988); it also occurs in San Marcos Springs (Gibson et al. 2008; Gonzales 2008). Although some riffle beetles are capable of flight, the Comal Springs riffle beetle is a flightless aquatic beetle, measuring about 2 mm long (Huston et al. 1988; USFWS 1997). Both larvae and adults are entirely aquatic, with the adults feeding mainly on algae and detritus scraped from submerged weeds and rocks (Brown 1987). Stable isotope analysis indicated Comal Springs riffle beetles derived more than 80 percent of their essential amino acids from bacteria, in contrast to surface species that derived essential amino acids from a mix of algae, bacteria, and fungi (Nair et al. 2021).

Comal Springs riffle beetles are found in the flowing, uncontaminated waters of spring runs but also occupy areas along the Landa Lake shoreline where springflow is present or areas of upwelling springflow, including the deepest portions of Landa Lake (BIO-WEST 2002; Bowles et al. 2003). They have also been documented at spring orifices along the headwaters of Spring Lake (Gibson et al. 2008). They tend to be most abundant within 20 centimeters of spring outlets and prefer a low flow, darkness, and elevated carbon dioxide levels (Cooke et al. 2015). They have a narrow range of thermal tolerance, with a preferred temperature of approximately 23°C (73°F) (Cooke et al. 2015). Relative to other elmid species, they are the most sensitive to thermal stress and have a median lethal temperature of 26.9°C (80.4°F) (Nair et al. 2023). Water flow appears to be important to respiration, thermal tolerance, and survival of this species; therefore, a reduction in water flow or drying of spring runs could be a limiting factor to their survival (USFWS 1997). Individuals tend to orient downward in the substrate and toward flow (BIO-WEST 2002), a behavioral response that may permit individuals to move to suitable habitat when springflow is reduced at the surface. However, because this species was not identified until 1976, well after the documented drought of record and cessation of springflow at Comal Springs during the 1950s, the question of survivability of the species during no-flow periods remains unanswered. In addition to behavioral responses, the presence of individuals in deeper areas of Landa Lake, which are somewhat removed from the spring runs, may have facilitated survival despite loss of habitat and provided a source for recolonization.

The presence of males is necessary for egg production by females. Egg production is a function of their longevity (Kosnicki 2020, 2022), with eggs hatching after an average of 25 days, larvae reaching a final (seventh) instar after 4 months, and adults surviving approximately 1 year (BIO-WEST 2017). The design of captive housing chambers has changed over time as knowledge of their captive survival and propagation requirements has become better known. A manual was recently developed that documents the history of their captive husbandry and current best practices (USFWS 2022). In summary, Comal Springs riffle beetles are housed in different variations of dark flow-through chambers containing leaves and/or conditioned wood as a food source and limestone rocks for habitat complexity; monitoring efforts have been reduced because they are light sensitive, and disturbance increases mortality (USFWS 2022).

In 2007, the USFWS designated 19.8 acres of the Comal Springs complex and 10.5 acres of the San Marcos Springs complex as critical habitat for this species (USFWS 2007); in 2013, this critical habitat designation was revised to 54 acres of surface critical habitat (USFWS 2013). Water withdrawals and pollution from hazardous materials, pesticide use, construction, and stormwater are all listed as threats to this species and its ecosystem (USFWS 2007).

### 3.5.3 Comal Springs Dryopid Beetle (*Stygoparnus comalensis*)

The Comal Springs dryopid beetle (Coleoptera: Dryopidae) is the only known subterranean aquatic (stygobiotic) species in its family; it was first collected in 1987 and described by Barr and Spangler (1992). Specimens have been collected throughout the Comal Springs system, but most adults have been found in spring run #2 and the upwellings around Spring Island. The species has also been collected at Fern Bank Springs in Hays County (Barr and Spangler 1992; Gibson et al. 2008). This species reaches a length of about 3 mm and has a translucent, slightly pigmented appearance. It has evolved vestigial eyes and greatly reduced (non-functional) micropterous wings (Shepard 2019), which are likely to reduce energy expenditure on organs that were not useful in relatively hydrologically stable subterranean and spring habitats (McCulloch et al. 2009). External morphological measurements have not shown meaningful size differences between sexes, but lateral lighting can be used to illuminate internal structures through their translucent exoskeleton, which allows for non-invasive separation of sexes (Barr and Spangler 1992; Kosnicki 2019).

Comal Springs dryopid beetles are hypothesized to be associated with *Platanus* roots, and larvae and pupae maybe dependent on woody material at terrestrial margins for reaching the adult stage (BIO-WEST 2019). Behavioral trials indicated that this species prefers to reside in food resources (*Platanus* leaves), even if it requires moving against flow (BIO-WEST 2019). Females that are caught in the wild lay an egg in captivity every 7 to 8 days, but only approximately 5 percent of the eggs reach pupation after an average of 323 days. Adults produced in captivity have not reproduced (BIO-WEST 2022).

Comal Springs dryopid beetles are able to maintain a mass of small hydrophobic hairs on their underside where they retain a thin air bubble through which gas exchange occurs during respiration (Bexar Metropolitan Water District [BMWD] 1998; Chapman 1982). As water flow decreases, subsequently decreasing dissolved oxygen levels, this method of respiration loses its effectiveness. Thus, the USFWS found that dryopid beetles require flowing, uncontaminated waters for survival (USFWS 1997). Similar to most species in the ecosystem, this species faces threats such as pollution and reduced springflow (Bowles and Arsuffi 1993; USFWS 2007).

In 2007, the USFWS designated 31.8 acres of critical habitat for this species at the Comal Springs complex and 1.4 acres of critical habitat at the Fern Bank Springs complex (USFWS 2007); in 2013, the critical habitat designation was updated to encompass 39.4 acres of surface critical habitat and 139 acres of subsurface critical habitat (USFWS 2013).

### 3.5.4 Peck's Cave Amphipod (*Stygobromus pecki*)

Peck's cave amphipod (Amphipoda: Crangonyctidae) is a subterranean aquatic crustacean, first collected in 1964 by Steward Peck and described by Holsinger (1967). Peck's cave amphipod is known only from the Comal Springs system, including Comal Springs and Panther Canyon Well, and from Hueco Springs (Gibson et al. 2008). Extensive collection efforts have been unable to locate the species in other localities (Barr 1993; Gibson et al. 2008; USFWS 1997). Genetically, there appear to be separate populations of Peck's cave amphipod. Currently, there is sufficient gene flow to prevent isolation (Ethridge et al. 2013; Lucas et al. 2016). The genus *Stygobromus* is highly diverse, with more than 130 described species (all subterranean); at least nine species are in Texas (Ethridge et al. 2013; Gibson et al. 2021). Three species co-occur with *S. pecki*: *S. bifurcatus*, *S. flagellatus*, and *S. russelli*.

Individuals that are caught in the wild and then housed and fed leaves and fish flakes in captivity lived up to 2.7 years, although it appears that *S. pecki* prefers live food more than *S. flagellatus* (Kosnicki and Julius 2019). Heavy morality and cannibalism have been observed in captivity, with the amount of habitat available being more important for reducing mortality than water volume. Fries et al. (2004) indicated that females have multiple broods of about 10 individuals each; newly hatched neonates are approximately 2 mm in length. Kosnicki and Julius (2019) found females produced broods of up to 28 eggs, with no relationship between female size and egg production; high levels of captive egg mortality could be due to female stress. On average, eggs were incubated for approximately 50 days, with 24 percent surviving to free-swimming neonates and having lengths of approximately 2.9 mm. None survived more than 32 days or to first molt (Kosnicki and Julius 2019).

Two critical habitat units have been designated for Peck's cave amphipod: Comal Springs and associated portions of Landa Lake as well as the Hueco Springs complex, which encompasses Hueco Springs and associated satellite springs. In 2013, the critical habitat designation was updated to encompass 38.4 acres of surface and 138 acres of subsurface critical habitat (USFWS 2013). Primary constituent elements of the critical habitat for all three federally listed aquatic invertebrate species include unpolluted, high-quality water; Aquifer water temperatures between 68°F and 75°F; adequate dissolved oxygen levels and food supply; and substrates between 0.3 and 5.0 inches in diameter. Water withdrawals and pollution from hazardous materials, pesticide use, construction, and stormwater are all listed as threats to this species and its ecosystem (USFWS 2007).

### 3.5.5 San Marcos Salamander (*Eurycea nana*)

The San Marcos salamander is a member of the lungless salamanders, belonging to the family Plethodontidae. San Marcos salamanders were first collected from the San Marcos Springs and described in 1938 (Bishop 1943). It was once thought that the San Marcos salamander in the San Marcos River and the Texas salamander (*Eurycea neotenes*) in the Comal River were the same; however, investigations by Chippendale et al. (1992, 1994, and 1998) have suggested that these two populations may be genetically different. The San Marcos salamander was listed as threatened by the USFWS in 1980 (USFWS 1996; 45 FR 47355). Critical habitat has been designated for the San Marcos salamander—specifically, Spring Lake and its outflow as well as the San Marcos River downstream to 50 meters below Spring Lake Dam (USFWS 1996).

San Marcos salamanders are small, reaching a maximum length of 58.4 mm; slender; and light brown in color. Prominent features include large eyes with a dark ring around the lens, well-developed and highly pigmented external gills, moderately short and slender limbs with four toes on the forefeet and five on the hind feet, and a well-developed tail fin. San Marcos salamanders are distinct compared to other neotenic *Eurycea* from Texas in that they are smaller and more slender. They have different coloration, a greater number of costal grooves (i.e., vertical wrinkles in the skin between front and hind legs), larger eyes relative to their head, and fewer teeth (Tupa and Davis 1976; USFWS 1996). As a neotenic species, the San Marcos salamander retains juvenile characteristics such as gills and tail fins throughout its adult life stage. Water issuing from the springs has a low oxygen content (30 to 40 percent saturated), causing the external gills of the San Marcos salamander to have a bright red coloration due to increased blood flow through the gills (Tupa and Davis 1976).

San Marcos salamanders are found in Spring Lake and downstream of the dam at Spring Lake (Tupa and Davis 1976; Nelson 1993). Flowing waters are one of the main components necessary for survival of the San Marcos salamander. They prefer waters that are slightly alkaline (pH 7.2) and thermally constant, approximately 21°C to 22°C (69.8°F to 71.6°F), with oxygen saturation of 40 to 50 percent and little variation in bicarbonate alkalinity (220 to 232 mg/l) (Tupa and Davis 1976). They associate with rocky areas around spring openings, requiring clean, clear waters. In Spring Lake, San Marcos salamanders most often associate with mesohabitats, consisting of gravel, cobble, and boulders with a higher coverage of *Amblystegium* sp. and filamentous algae (Diaz et al. 2015). Individuals can also be found in *Lyngbya* sp., a filamentous blue-green algae that covers shallow, sandy substrates and provides a good hiding place by means of camouflage for the salamanders (BMWD 1998; USFWS 1996). Populations have been found in front of the Meadows Center for Water and the Environment office building on concrete banks and in boulders that are covered with an aquatic moss (*Leptodictyium riparium*) (USFWS 1996). Downstream of Spring Lake in the riverine portion of their range, salamanders frequently associate with bare rock surfaces that lack macrophyte cover (Diaz et al. 2015). Numerous rooted aquatic macrophytes occur on the boundary of the salamander habitat at suitable depths, including *Sagittaria*, *Ludwigia*, and *Vallisneria*. Individuals can be found within these mats of vegetation at the shallow headwater areas because the vegetation houses food sources and offers protective cover for avoidance of predators (i.e., larger fish, crayfish, turtles, and aquatic birds) (Tupa and Davis 1976; USFWS 1996a). The main food source of the San Marcos salamander is amphipods. Stomach content analyses have shown that San Marcos salamanders also feed on tendipedid (midge fly) larvae and pupae, other small insect pupae and naiads, and small aquatic snails. San Marcos salamanders are stationary feeders, waiting for prey to come near, indicating a behavioral response to sensory cues from living prey (Tupa and Davis 1976).

Sexual maturity in male San Marcos salamanders occurs when they reach a snout-vent length of 19 mm or total length of 35 mm (Tupa and Davis 1976). MacKay (1952) found sperm in all mature males from October to May and postulated that they have a breeding season in June and another in the fall. Similarly, Tupa and Davis (1976) and Bogart (1967) performed studies on the San Marcos salamander that suggest they breed most of the year, with a peak in late spring (May and June). Females reach sexual maturity with a snout-vent length greater than 20 mm or total length greater than 35 mm. Females carrying large yellow ova were considered ready for oviposition and found in almost every month of the year. Both male and female San Marcos salamanders utilize chemical cues, in addition to visual cues, to seek out potential mates, a rare behavior in salamanders (Thaker et al. 2006). Courtship and egg deposition have not been observed, and no eggs have been collected from the San Marcos salamander's natural habitat. Typically, *Eurycea* breed in the running water of streams and springs or in caves; their adherent eggs are singly deposited on the bottom and sides of vegetation or rocks (USFWS 1996).

Attempts to estimate population size have also been made. The San Marcos salamander population found in the shallow area of Spring Lake, along the northern bank in front of the Aquarena Springs Hotel, was estimated by Tupa and Davis (1976) to be 20,880. In 1991, the population was estimated at 23,200 in the same area, at 25,238 for rocky substrates around spring openings, and at 5,213 for rocky substrates 492 feet (150 meters) downstream of the Spring Lake Dam, for a total population estimate of 53,651 (Nelson 1993). Long-term density trends indicate that densities in Spring Lake are higher than densities downstream of Spring Lake Dam (BIO-WEST 2022). Threats to the persistence of San Marcos salamander populations include reduced springflow and increased sedimentation.

### 3.5.6 Texas Blind Salamander (*Eurycea rathbuni*)

The Texas blind salamander, a member of Plethodontidae, was first collected in 1895 from the National Fish Hatchery and Technology Center (NFHTC) in San Marcos, Texas, when specimens were expelled from an artesian well drilled to supply the hatchery with water (Longley 1978). Earlier taxonomists supported the recognition of genus *Typhlomolge* (Wake 1966; Potter and Sweet 1981); however, Mitchell and Reddell (1965) stated that the Texas blind salamander represents *Eurycea,* an extreme cave-associated morphology. Based on biochemical, morphometric, and molecular techniques, Chippindale et al. (1994) concluded that the Texas blind salamander is phylogenetically within the Texas *Eurycea* group. This conclusion has been more recently supported by allozyme and mitochondrial genetic (DNA) sequence studies by Chippendale et al. (2000). The USFWS reassigned this species as *Eurycea*. Texas blind salamander was listed as federally endangered in 1967 (32 FR 4001).

The distribution of Texas blind salamander may be the Aquifer beneath and near San Marcos in an area as small as 25.9 square miles (USFWS 1996). All collections of Texas blind salamanders documented in the literature have occurred in Hays County and include the San Marcos NFHTC, Ezell's Cave, San Marcos Springs, Rattlesnake Cave, Primer's Fissure, Texas State University's artesian well, and Frank Johnson's well (Longley 1978; Russell 1976). Previously, it had been found in Wonder Cave; however, searches in 1977 did not discover any individuals (Longley 1978). Recent collections and genetic work support a more widespread distribution of this species, including four additional sites: Hueco Springs, Comal Springs, Panther Canyon Well, and Mission Bowling Well in Comal County (Bendik et al. 2013).

The Texas blind salamander is a smooth, unpigmented troglobitic (cave-adapted) aquatic species. In the wild, maximum length is reported at 145 mm, and maximum age is estimated to be greater than 10 years. However, one female at the San Marcos Aquatic Resources Center (SMARC) was estimated to be 20 years old, measuring 146.5 mm (Vieira et al. 2021). The salamander has a large and broad head, reduced eyes (two small dark spots beneath the skin), and long and slender limbs with four toes on the forelegs and five on the hind legs. Like San Marcos salamanders, Texas blind salamanders are neotenic. External gill branches and cutaneous gas exchange facilitate respiration (Emerson 1905). External characteristics to determine sex are unknown. Because of the presence of juveniles year-round, the Texas blind salamander appears to be sexually active throughout the year, most likely due to the thermally constant waters of the Aquifer. Studies of this species while in captivity have found that the Texas blind salamander differs from other salamanders in that females use chemical cues to seek males or avoid other females as well as initiate courtship (Gabor et al. 2010; Vieira et al. 2021). In addition, studies in captivity noted three spawning events in 1 year, with a clutch size of eight to 21 eggs per spawning (Longley 1978). Unpigmented eggs were attached to gravel either singly or in groups of two or three eggs. It was suggested that a constant water temperature within the Aquifer is essential for normal egg development (Longley 1978), although no thermal minima or maxima have been determined for their various life stages (Berkhouse and Fries 1995; Longley 1978). Eggs hatch within 12 to 16 days after laying, and larvae begin feeding within 1 month after hatching. Young salamanders feed on copepods; larger salamanders eat amphipods, blind shrimp (*Palaemonetes antrorum*) in captivity, daphnia, small snails, and other invertebrates. Cannibalism has also been documented with the Texas blind salamander (USFWS 1996).

### 3.5.7 Texas Wild-Rice (*Zizania texana*)

Texas wild-rice is an aquatic, monoecious perennial grass (Poaceae) that is endemic to the San Marcos River. This species was originally collected in 1892 and identified as southern wild-rice (Z. *aquatica*). However, the plant was later collected and recognized as a distinct species by W. A. Silveus in 1932 (Silveus 1933) and described as Texas wild-rice by A. S. Hitchcock in 1933 (Hitchcock 1933). Texas wild-rice is thought to have evolved in geographic isolation from other species of *Zizania*, although some suggest *Z. texana* represents a relict population that became isolated during the early Holocene (Horne and Kahn 1997). The nearest present-day population is a coastal plain population of Z. *aquatica* in southern Louisiana, approximately 400 miles (640 kilometers [km]) away. It is morphologically different from Z. *texana* (Terrell et al. 1978).

Texas wild-rice attaches to the substrate using short, tightly intertwined spongy roots (Beaty 1975). The linear leaves can be up to 3.3 feet long and 0.5 inch wide (Poole et al. 2007; Terrell et al. 1978). Texas wild-rice forms large clumps that become rooted in sand and gravel sediments, which are overlain by Crawford black silt and clay (Vaughan 1986). This species requires thermally constant temperatures, clear water, undisturbed stream bottom habitat, protection from floods, and protection to allow inflorescence (flower production) during reproduction (McKinney and Sharp 1995). It has two growth forms: submerged, which reproduces asexually, and emergent, which is capable of flowering. Both forms exhibit distinct morphological characteristics (Silveus 1933). The submerged growth form is found primarily at a depth of less than 3.3 feet in swift-moving, shallow runs with coarse sandy substrates in the Upper San Marcos River (Poole and Bowles 1999). Through the help of restoration efforts, flowering plants are now a common occurrence in the wild, as demonstrated by greater genetic diversity than would be predicted in an asexually reproducing species (Richards et al. 2007; Wilson et al. 2017). Flowering typically occurs in the spring and fall but may be seen throughout the year due to constant water temperatures. Texas wild-rice does reproduce vegetatively, from stolons, and appears to re-establish readily when uprooted and relocated during flood events. (BIO-WEST 2003a, 2003b). Texas wild-rice stands are often associated with other aquatic plant species. *Hydrilla verticillata*, *Hygrophila polysperma*, and *Potamogetan illinoensis* are commonly found growing with Texas wild-rice (BIO-WEST 2020). In the lower sections of rivers, Texas wild-rice is found in isolated clumps.

When Texas wild-rice was first described in 1933, it was found in abundance in the upper 4.0 km of the San Marcos River, Spring Lake, and contiguous irrigation ditches, requiring considerable effort by irrigation companies to control its growth (Terrell et al. 1978; Silveus 1933). By 1976, Texas wild-rice was not observed in Spring Lake. The estimated total coverage was 1,131 $m^2$ of habitat in the extreme upper and lower segments of the 1.5-mile reach of the Upper San Marcos River (Emery 1977). Drastic declines in abundance led to the listing of Texas wild-rice as an endangered species in 1978. The species' critical habitat was designated as Spring Lake and its outflow as well as the San Marcos River downstream to its confluence with the Blanco River (USFWS 1980). After the listing, continued decline occurred in the areal coverage of Texas wild-rice until it declined to just 453 $m^2$ (Vaughn 1986). Coverage began to slowly increase in 1989. It greatly increased beginning in 2013, following restoration efforts by the City of San Marcos and Texas State University (Poole et al. 2022). By 2021, Texas wild-rice reached the highest areal coverage ever documented: 17,235 $m^2$ (BIO-WEST 2021). This high coverage was most likely a result of little to no recreation in the river during 2020–2021, which was related to the COVID-19 lockdown. After its peak in April 2021, Texas-wild-rice began a decreasing trend, most likely due to the compounding effects of continued low flows and increased recreation. Historically, the species was present in an area just below a wastewater treatment plant. In 2015, a large flood event drastically reduced coverage throughout this reach, which limited the longitudinal distribution to just downstream of Cape's Dam. Despite several years of post-flood recovery, Texas wild-rice still remains rare downstream of the Interstate 35 bridge. Planting efforts have contributed to increased coverage throughout this reach in recent years. In 2017, the USFWS began maintaining refugia for Texas wild-rice. Its 430 plants are divided between the San Marcos Aquatic Research Center and Uvalde National Fish Hatchery (USFWS 2021).

The main threats to Texas wild-rice include diminished springflow and disturbances to the environment (USFWS 1996). During times of low flow, the upper portions of the culms (stems) and leaves become emergent (Terrell et al. 1978; USFWS 1996) or entirely stranded, leading to desiccation. Diminished springflow results in an increase in sedimentation, water depth, and turbidity and a decrease in current velocities, contributing to a loss of habitat for Texas wild-rice growth—specifically, throughout the lower portions of its historic range (Poole and Bowles 1999). Although water depth and current velocity are a direct result of the influence of springflow into the San Marcos River, the impacts of increased sedimentation and turbidity on Texas wild-rice are largely a result of urbanization within the contributing watershed. Cumulative turbidity caused by recreation is a major concern for Texas wild-rice. This means that impacts from turbidity due to high levels of recreation in upstream reaches (e.g., Sewell Park) will be worse in downstream reaches (e.g., Interstate 35 reach). In addition, impacts from recreationists (e.g., tubing), floating debris (e.g., aquatic vegetation cut at Spring Lake or on the property of landowners), shade that reduces photosynthesis, or interference with pollination and seed maturation can damage the plants (Beaty 1975; Poole 1992). Herbivory by nutria (Myocastor coypus), the introduced giant rams-horn snail (*Marisa cornuarietis*), and waterfowl as well as competition from aquatic plants are believed to be significant factors in reducing the size and vigor of Texas wild-rice stands (McKinney and Sharp 1995). The invasion of water trumpet (*Cryptocoryne beckettii*) in 1993 was thought to be a new threat to Texas wild-rice because it competes for nearly identical habitats. It became established in the section of the San Marcos River from the A. E. Wood State Fish Hatchery to the confluence of the San Marcos and Blanco Rivers. Extensive efforts by USFWS and volunteers have resulted in water trumpet being almost entirely removed from the river (Alexander et al. 2008).

# 3.6 Other Covered Species

There are other species within the Plan Area that are proposed for listing as threatened or endangered. The following two species are recommended for continued coverage by this HCP: Edwards Aquifer diving beetle (*Haideoporus texanus*) and Texas troglobitic water slater (*Lirceolus smithii*). These aquatic invertebrates have similar ranges, habitats, and threats as the listed species described above in Section 3.5.

The following sections summarize the locations, habitat requirements, and morphological descriptions of the two species, for which a USFWS 90-day finding indicates that listing as threatened or endangered may be warranted (74 FR 66,866 [December 16, 2009]).

## 3.6.1 Edwards Aquifer Diving Beetle (*Haideoporus texanus*)

The Edwards Aquifer diving beetle (Coleoptera: Dytiscidae: Hydroporini), also known as the Texas cave-diving beetle, is a small (up to 3.5 mm for adult; up to 5.5 mm for larvae), elongated, oval-shaped, and somewhat flattened species. It was collected as early as 1973 and later described by Young and Longley (1976); larvae were described by Longley and

Spangler (1977). This species is restricted to the subterranean waters of the Aquifer in Hays and Comal Counties where it has been collected from the Texas State University artesian well and from Comal Springs, respectively (Bowles and Stanford 1997; Gibson et al. 2008). Throughout implementation of the EAHCP (2013–2023), approximately 30 individual Edwards Aquifer diving beetles have been collected through drift net sampling over spring orifices in Comal Springs. Collection typically occurs during wet periods with high springflow output. In San Marcos Springs, collections have been confirmed at the Texas State University artesian well, but the numbers are limited. These beetles have reduced, nonfunctional eyes and greater development of the sensory setae (hairs) on their wings, legs, and mouth area (Young and Longley 1976). This species was the first blind, unpigmented, and aquifer-adapted water beetle known from North America, but three other endemic stygobiontic dytiscids are now known from Texas aquifers (Jean et al. 2012; Miller et al. 2009; Spangler and Barr 1995). The biological characteristics of all four species are poorly known. The phylogenetic placement of *H. texanus* is close to *Neoporus* and *Heterosternuta* in the subtribe Hydroporina, with two of the other stygobiontic species more distantly related within the subtribe Siettitiina (Hydroporini) and the third in the tribe Bidessini (Miller et al. 2013).

The USFWS (2009) has declared that substantial information was presented in the petition to list the species as threatened or endangered, indicating that listing of this species may be warranted due to the present or threatened destruction, modification, or curtailment of its habitat or range resulting from water drawdown and loss of water quality due to development.

## 3.6.2 Texas Troglobitic Water Slater (*Lirceolus smithii*)

The Texas troglobitic water slater, as described by Ulrich (1902), is one of four described species of *Lirceolus* in the Edwards Aquifer (Lewis and Bowman 1996; Lewis 2001). Schwartz et al. (2018) provided a key for identification of the species of *Lirceolus* in Texas, based on external morphological characteristics. Phylogeographic work on *Lirceolus* showed patterns of relatedness that follow surface river drainage basins (Krejca 2005); multiple species in the genus occur together at individual sites in the Edwards Aquifer (Schwartz et al. 2018). Members of this genus are not commonly collected. *L. smithii* is known only to discharge from artesian deep-aquifer sites; discharged individuals are typically in poor condition (Schwartz et al. 2018). In captivity, most individuals died within 24 hours, and none have survived more than 1 week (Schwartz et al. 2018).

This species was previously known from two localities in the San Marcos Springs system of Hays County: Diversion Springs and an artesian well. However, more recently, it was found at the Spring Lake outflow well by Schwartz et al. (2018). Only the single San Marcos population is known. The full extent of its range is undetermined because of the lack of other artesian wells in the area from which it could be discharged. Its deep habitat suggests it may be insulated from short-term perturbations in the aquifer; however, it is possible that pollutants in the aquifer may harm the species (Schwartz et al. 2018). Although no *Lirceolus* have formal protection, several of the species are endemic to small areas. A regional HCP in Hays County recognizes *Lirceolus smithii* as a species that could become listed as threatened or endangered in the future (Loomis Partners, Inc. et al. 2010).

The USFWS (2009) has declared that substantial information was presented in the petition to list the species as threatened or endangered, indicating that listing of this species may be warranted due to the present or threatened destruction, modification, or curtailment of its habitat or range resulting from aquifer drawdowns and decreasing water quality.

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# Appendix G9 | **Biological Goals Subcommittee Report**

# Biological Goals Subcommittee Report

2023

# Report

| | |
|---|---|
| **To:** | EAHCP Implementing, Stakeholder and Science Committees<br>Permit Renewal Contractor – ICF |
| **From:** | EAHCP Biological Goals Subcommittee |
| **Date:** | March 16, 2023 |
| **Re:** | EAHCP Biological Goals Subcommittee Report - 2023 |

## 1. Introduction

The Edwards Aquifer Habitat Conservation Plan (EAHCP) is currently in the process of renewing the Incidental Take Permit with the U.S. Fish and Wildlife Service. As part of that process, the existing components of the Habitat Conservation Plan (HCP) conservation strategy will be reassessed, new elements recommended, and modifications discussed. As a required component of habitat conservation plans, biological goals are a guide for quantified biological objectives and management actions taken through conservation measures to achieve the conservation strategy.

The joint 2016 U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service "Habitat Conservation Planning and Incidental Take Permit Processing Handbook" (HCP Handbook) defines biological goals as broad, succinct statements that work toward the vision of an HCP. Each goal can be habitat- and/or species-based. Biological goals are addressed by quantified biological objectives that are written to achieve the corresponding goal. This hierarchical process is described in Chapter 9 of the HCP Handbook which served as a reference in the development of the EAHCP biological goals.

The Plan Area (also the Permit Area) is the area in which pumping from the Aquifer is regulated by the EAA and affects the springs and spring ecosystems used by the proposed Covered Species. The Permit Area also includes recreational and other areas in which non-pumping related impacts to Covered Species will occur including the Comal Springs and River ecosystems and San Marcos Springs and River ecosystems that are under the jurisdiction of the City of New Braunfels, the City of San Marcos, and Texas State University.

## 2. Biological Goals Subcommittee Overview

The purpose of the Subcommittee was to review, discuss, and develop recommendations for biological goal(s) that should be considered for inclusion in the next EAHCP. The Subcommittee charge was approved by the EAHCP Stakeholder Committee on December 15, 2022 (**Appendix A**).

Throughout February and March 2023, four meetings were conducted in-person and virtually via Microsoft Teams. Meeting materials including meeting handouts, meeting agendas, presentations, and approved meeting minutes are in **Appendix B, C, D, and E,** respectively.

Members of the Biological Goals Subcommittee are:

- Mark Enders (Subcommittee Chair) – Stakeholder Committee (City of San Marcos)
- Rachel Sanborn – Stakeholder Committee (San Marcos River Foundation)
- Kimberly Meitzen – Stakeholder Committee (Texas State University)
- Kevin Mayes – Stakeholder Committee (Texas Parks and Wildlife Department)
- Charlie Kreitler – Science Committee (LBG-Guyton - Retired)
- Jacquelyn Duke – Science Committee (Baylor University)

## 3. Biological Goals Subcommittee Meetings

The Subcommittee convened four times to discuss the following:

- Current EAHCP biological goals.
- HCP Handbook guidance pertaining to biological goal development and structure (Chapter 9).
- Development of biological goals.
- Approval of the Biological Goals Subcommittee Report.

On February 16, 2023, the Subcommittee agreed, by consensus, to develop biological goals by reviewing the current biological goals to create new biological goals for the next EAHCP.

At this time, the San Marcos gambusia, endemic to the San Marcos River, is not considered in development of the biological goals due to its pending delisting from the Endangered Species Act (ESA). Moreover, in 2021, USFWS proposed a rule that San Marcos gambusia may be extinct (Federal Register; 86 FR 54298). The Comal Springs salamander was also not considered due to the recent removal of the petition for the species to be listed and covered by the ESA. The following are the Covered Species that were considered during the development of the biological goals:

- Texas blind salamander (*Eurycea rathbuni*)
- San Marcos salamander (*Eurycea nana*)
- Texas wild-rice (*Zizania texana*)
- Fountain darter (*Etheostoma fonticola*)
- Comal Springs riffle beetle (*Heterelmis comalensis*)
- Peck's cave amphipod (*Stygobromus pecki*)
- Comal Springs dryopid beetle (*Stygoparnus comalensis*)
- Texas troglobitic water slater (*Lirceolus smithii*)
- Edwards Aquifer diving beetle (*Haideoporus texanus*)

## 4. Biological Goals Recommendations

The following are the biological goals that the Biological Goals Subcommittee recommends the EAHCP Committees (Stakeholder, Implementing, and Science), Subcommittees (Biological Objectives and Conservation Measures), and Permit Renewal Contractor (ICF) consider for inclusion in the next EAHCP. Bolded key terms within the biological goals are described in the glossary.

A central tenet of these goals is that they are habitat-and species-based. Biological Objectives can and should consider both.

**Goal 1: Conserve** the quality and quantity of springflow and maintain **suitable** ecosystems within the **Plan Area** to provide for the **resiliency** of the **Covered Species**.

> **Reasoning**: This goal is intended to serve as a broad, overarching goal that addresses water quality and quantity, springflow, and suitable ecosystems (aquatic, riparian, and watershed) not specific to any Covered Species; but rather, all the EAHCP Covered Species collectively in the Plan Area.
>
> **Biological Objectives**: may include, but are not limited to, springflow, water quality and quantity, research, and overall ecosystem health.

**Goal 2:** Promote community engagement and awareness of the EAHCP, support land and water conservation, and mitigate **anthropogenic stressors** and **natural disturbances** within the **Plan Area** that will benefit the **Covered Species.**

> **Reasoning:** This goal is intended to address societal interactions with the EAHCP, direct and indirect anthropogenic stressors (non-native species, recreational activities, pollution, climate change and regional population growth) and natural disturbances (e.g., droughts, floods, disease, and parasites) in the Plan Area.
>
> **Biological Objectives:** may include, but are not limited to, community outreach on species and habitat sensitivity, mitigation/recovery from disturbances and stressors including maintaining refugia populations to address unpredicted events and impacts, and land and water conservation in the Plan Area.

**Goal 3: Conserve habitats,** diverse native **submerged aquatic vegetation** assemblages, and **resilient** fountain darter populations in the Comal and San Marcos spring and river systems.

> **Reasoning:** This goal is specific to supporting habitat and resilient fountain darter populations in both the San Marcos and Comal spring systems. Additionally, this goal promotes native submerged aquatic vegetation diversity to prevent a monoculture of any single vegetation species.
>
> **Biological Objectives:** may include, but are not limited to, recreation management, native submerged aquatic vegetation restoration, springflow, and water quantity and quality, and all known biotic and abiotic species needs.

**Goal 4: Conserve** and manage **resilient** Texas wild-rice populations in the San Marcos spring and river system.

> **Reasoning:** This goal is specific to maintaining resilient Texas-wild rice populations. Management includes, but is not limited to, enhancement and restoration of Texas wild-rice.
>
> **Biological Objectives:** may include, but are not limited to, genetically diverse Texas wild-rice (wild, captive, and repatriated), recreation management,

springflow, water quality and quantity, and all known biotic and abiotic species needs.

**Goal 5: Conserve habitats** to support **resilient** populations of Texas blind salamander, Comal Springs dryopid beetle, Peck's cave amphipod, Edwards Aquifer diving beetle, and Texas troglobitic water slater in the **Plan Area.**

**Reasoning:** This goal is intended to ensure suitable habitat for the aquifer-dwelling Texas blind salamander, Comal Springs dryopid beetle, Peck's cave amphipod, Edwards Aquifer diving beetle, and Texas troglobitic water slater populations.

**Biological Objectives:** may include, but are not limited to, aquifer levels, springflow, water quality and quantity , and all known biotic and abiotic species needs.

**Goal 6: Conserve habitats** to support **resilient** Comal Springs riffle beetle populations in the **Plan Area.**

**Reasoning:** This goal is specific to maintaining resilient Comal Springs riffle beetle populations.

**Biological Objectives:** may include, but are not limited to, aquifer levels, springflow, recreation management, water quality and quantity , and all known biotic and abiotic Comal Springs riffle beetle species needs.

**Goal 7: Conserve** San Marcos spring and river **habitats** and **resilient** San Marcos salamander populations in the **Plan Area**.

**Reasoning:** This goal is intended to ensure suitable habitat and support resilient San Marcos salamander populations.

**Biological Objectives:** may include, but are not limited to, springflow, water quality and quantity, riverine habitats, recreation management, and all known biotic and abiotic San Marcos salamander species needs.

## 5. Glossary of Key Terms

- **Anthropogenic stressors:** Pressures or dynamics that impact ecosystem components or processes caused by human-associated activities, including, but not limited to, non-native species, biological pathogens (disease and parasites), recreation, pollution, climate change and population growth.

- **Conserve:** The preservation, protection, restoration, and enhancement of the Covered Species and their habitats.

- **Covered Species:** Species for which incidental take is authorized in an incidental take permit and is adequately covered in a habitat conservation plan. (HCP Handbook)

- **Habitat:** The location where a particular taxon of plant or animal lives and its surroundings, both biotic and abiotic. The term includes the presence of a group of particular natural conditions surrounding an organism including air, water, soil, mineral elements, moisture, temperature, and topography. (Modified from the HCP Handbook)

- **Natural disturbances:** This term includes, but is not limited to, flood and drought events, and biological pathogens (disease and parasites).

  **Plan Area:** The specific geographic area where Covered Activities described in the HCP, including mitigation, may occur. (HCP Handbook)

- **Resilient/Resiliency:** Includes, but is not limited to, maintaining genetic diversity, redundancy via refugia as available, and other population characteristics that support withstanding and recovery from disturbance (natural and anthropogenic). Moreover, resiliency includes the adaptive capacity of self-sustaining viable populations. Viable, meaning, the ability of a species to persist over the long term, and conversely, to avoid extinction over some time period. (Modified from the HCP Handbook)

- **Submerged aquatic vegetation (SAV):** Assemblages that have been recognized as native habitat that support viable fountain darter populations.

- **Suitable:** Right or appropriate for a particular species, purpose, or situation.

## 6. References

U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS). 2016. Habitat Conservation Planning and Incidental Take Permit Processing Handbook. 361 pp + apps. https://www.fws.gov/endangered/what-we-do/hcp_handbook-chapters.html. (HCP Handbook)

# APPENDIX A

## Biological Goals Subcommittee Charge

## Biological Goals Subcommittee Charge

The Edwards Aquifer Habitat Conservation Plan (EAHCP) is currently in the process of renewing the Incidental Take Permit with the U.S. Fish and Wildlife Service. As part of that process, the existing components of the Habitat Conservation Plan (HCP) conservation strategy will be reassessed, new elements recommended, and modifications discussed. As a required component of habitat conservation plans, biological goals are a guide for quantified biological objectives and management actions taken through conservation measures to achieve the conservation strategy.

The purpose of this Subcommittee is to review, discuss and develop recommendations for the biological goal(s) that should be considered for inclusion in the next EAHCP.

**Specifically, the Subcommittee will:**

- Review the current EAHCP biological goals and the HCP Handbook as it pertains to biological goals development and structure.
- Develop initial recommendations for deletions, additions, or other changes to current biological goals.
- Finalize biological goal recommendations to be considered in the next EAHCP.
- Approve a report setting out the biological goal recommendations to be provided to the EAHCP Permit Renewal contractor.

**Members:**

- **Chair:** Mark Enders (Stakeholder Committee)
- Rachel Sanborn (Stakeholder Committee)
- Kimberly Meitzen (Stakeholder Committee)
- Kevin Mayes (Stakeholder Committee)
- Jacquelyn Duke (Science Committee)
- Charlie Kreitler (Science Committee)

**Subcommittee Organization:**

Pursuant to Subsection 8.1 of the Stakeholder Committee's operational rules, the Biological Goals Subcommittee is authorized to meet entirely through virtual means, or any combination of virtual and in-person meetings, and to finalize previously discussed drafts through email communications. Because of the short duration, Subcommittee members are not required to appoint alternates. The Subcommittee shall strive to achieve consensus on its recommendations, but, if, in the opinion of the Chair, consensus cannot be achieved by the deadline, the recommendations and report may be approved by a majority vote of the full Subcommittee as long as any member dissenting from approval is provided a reasonable opportunity to provide a succinct summary of the objections to the recommendations, which shall be included in the report.

A Subcommittee report setting out the recommendations for biological goals should be completed by March 31, 2023 and provided to the EAHCP Permit Renewal contractor by that date, with copies to the Stakeholder Committee, the Implementing Committee, the Science Committee, and the Biological Objectives Work Group.

# APPENDIX B

Meeting Handouts

# HABITAT CONSERVATION PLANNING

# AND

# INCIDENTAL TAKE PERMIT PROCESSING

# HANDBOOK

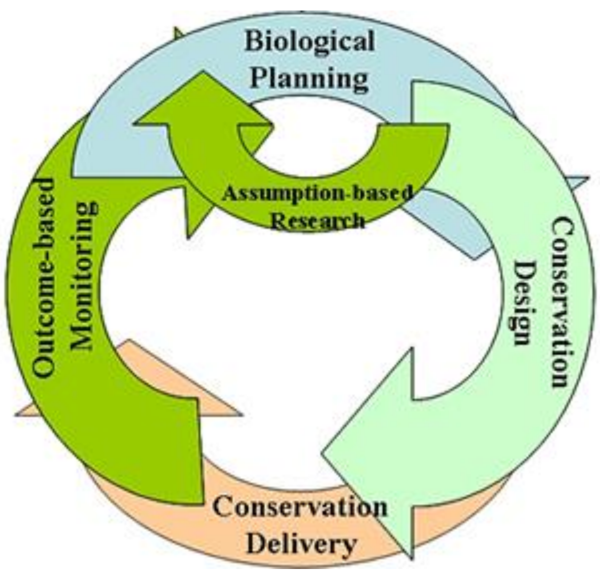
December 21, 2016

U.S. Department of the Interior
Fish and Wildlife Service

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

1. having an integrated framework to develop biological goals and objectives,
2. developing a monitoring framework to measure results,
3. developing an evaluation process to assess results, and
4. outlining a systematic learning process to use what will be learned to improve future decisions.

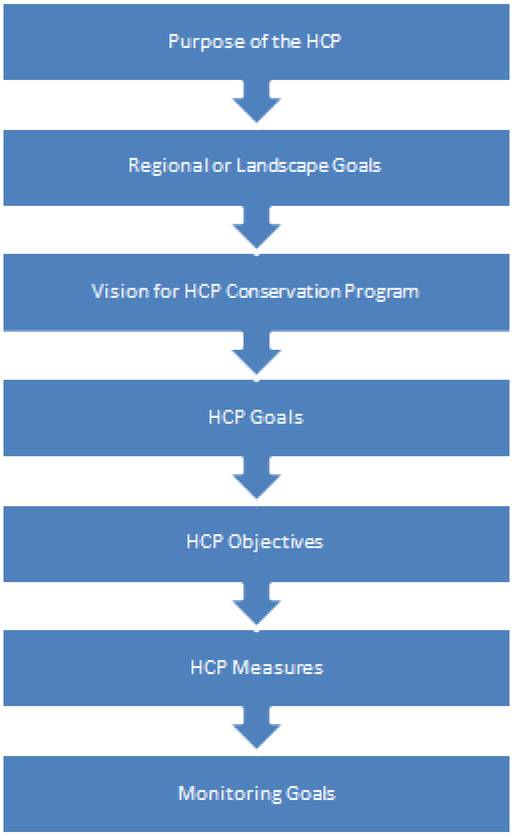
**Figure 9.0a: Strategic Habitat Conservation**




### 9.1 HCP Biological Goals

HCPs are but one conservation tool implementing conservation across different geographies at different sizes and scales. Development of the conservation strategy, including its goals, should be framed within this broader wildlife conservation context. HCP goals are built on the foundation of broader conservation efforts occurring at larger scales. Building upon the existing hierarchy of goals and purposes will improve conservation of species by allowing even modest implementation efforts to contribute to something bigger. See figure 9.1e.

**Figure 9.1e: Hierarchy of Goals and Purposes**




1. Purpose of the HCP: The purposes specified in or derived from law, regulations, agreement, etc. that broadly outlines the need for the HCP to meet regulatory purposes in harmonizing sustainable development with conservation of fish and wildlife.
2. Regional or Landscape Goals: summarize how the HCP conservation program will contribute to regional and landscape conservation goals.
3. HCP Conservation Vision Statement: A concise statement of what the HCP conservation program should be, or what we hope to do, based on the needs of species, and other mandates.
4. HCP Goal. Descriptive, open-ended, and often broad statement of desired future conditions that conveys a purpose, but does not define measurable units.
5. HCP Objective. A concise statement of what we want to achieve, how much we want to achieve, when and where we want to achieve it, and who is responsible for the work. Objectives derive from goals and provide the basis for determining strategies, monitoring effectiveness, and evaluating the success of actions.
6. HCP Conservation Actions: specific actions, tools, techniques used to meet plan objectives.
7. HCP Monitoring Goals: succinct statements of what the monitoring program will achieve.

By framing HCP goals within the context of larger conservation efforts it should become clear how the HCP may:

- affect recovery of species,
- further progress on large scale planning efforts like Landscape Conservation Cooperatives (LCCs) and State Wildlife Action Plans,
- help build more resilience and adaptive capacity for species to withstand future climatic change,
- help protect large scale migration or movement corridors.

**Helpful Hint: Consistent with agency policies and the use of the best available science, we integrate adaptation strategies for climate change effects into our planning, programs, and operations. As goals and objectives are developed we must ask if they are still attainable given the projected down-scaled effects of climate change in the HCP plan area. For example, the *Climate-Smart Conservation* guide calls for developing an initial set of goals through the lens of assessing climate impacts and vulnerability, and reviewing/revising conservation goals as needed. (See also section 9.3.2, below.)**

Biological goals broadly describe the desired future conditions of an HCP in succinct statements. Each goal steps down to one or more objectives that define how to achieve these conditions in measurable terms. A well-written goal directs work toward achieving the vision and purpose of an HCP.

It takes careful thought to develop productive and meaningful goals, and it is a critical step. In a few concise statements, goals comprise the HCP's effort in pursuit of its vision and lay the foundation from which all conservation activities arise. Management activities result from goals, and not the other way around. Goals must be developed *before* developing objectives and conservation measures to orient management direction, both during plan development and throughout implementation.

Ideally, the applicant should develop HCP goals and objectives in close coordination with the Services as they are the foundation upon which the HCP is built. An excellent resource on developing goals and objectives is the FWS's document: "Writing Refuge Management Goals and Objectives: A Handbook" (see the HCP Handbook Toolbox).

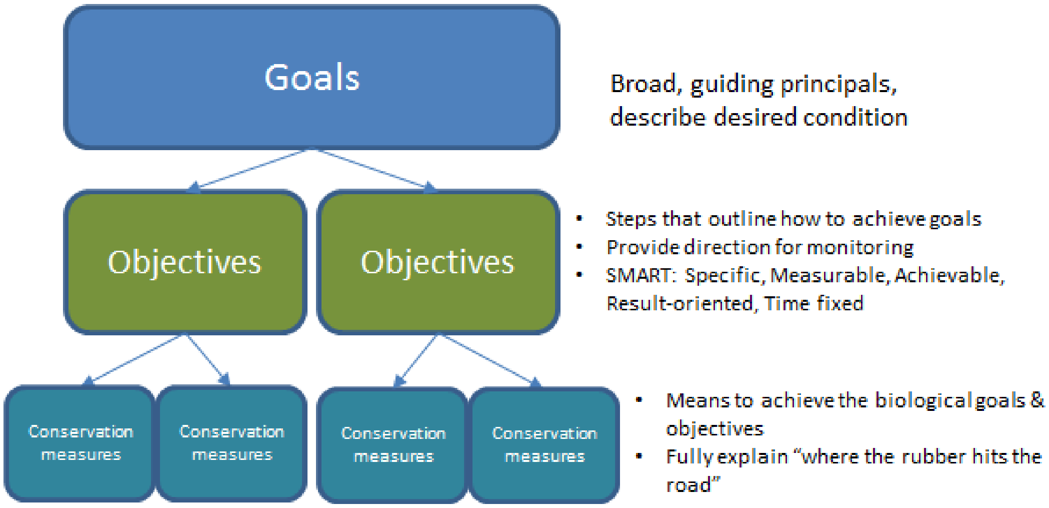
Goals and objectives guide management actions taken for an HCP to meet its conservation vision. Well-developed goals and objectives are key in focusing actions to efficiently and effectively manage the landscape to achieve the desired condition and to ultimately conserve species.

The first consideration when developing biological goals and objectives for an HCP is the scale of the plan. A biological goal for a small HCP (e.g., a single family residence) may be obvious (a well-known recovery plan objective) and simple – contributing to conservation. For example, a goal may be to contribute to the conservation of the covered species by either leaving and protecting (with a conservation easement in perpetuity) 8 acres of a 10-acre property in its natural state for the species or by purchasing the appropriate number of credits from a conservation bank before clearing and construction begins (objectives). Goals and objectives for a bigger HCP will likely require more consideration.

When developing biological goals and objectives, use existing conservation information to guide them, like: species recovery plans or outlines, 5 year status reviews, spotlight species actions plans, State Wildlife Action Plans, species status assessments, candidate conservation plans, and any other existing documents with conservation strategies for the covered species that are the best scientific information available. These plans often evaluate species' status and make recommendations about what it will take to get the population to a desired condition. To develop the most effective goals and objectives, relevant expertise (e.g., species experts, listing/recovery team members, climate change specialists, and State wildlife agencies) should be sought and included in their development.

The development of vision statements, goals, and objectives is iterative, and they may need to change during the HCP development process as the plan changes or as new information becomes available. However, it is critical that you initiate the process at the beginning and preserve the hierarchical nature of the relationship. It is important not to choose measures without objectives, develop objectives without goals, or establish goals without first articulating a vision for the HCP's conservation program. Building from the hierarchy of purpose and goals will allow you to identify existing and future efforts that may need to be refocused or eliminated. Figure 9.1a shows the relationship between goals, objectives, and measures.

**Figure 9.1a: Biological Goals and Objectives**




*9.1.1 Developing Useful Goals and Objectives*

The applicant and the Services should collaborate to develop goals. These goals serve as the foundation of the conservation strategy and should be used to guide how the rest of the plan is developed and implemented.

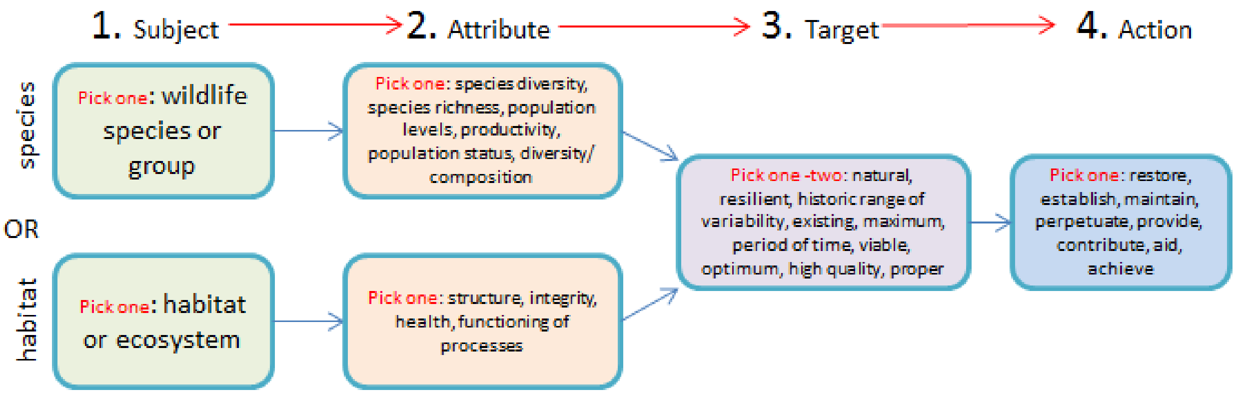
Goals must:

- broadly state desired future condition,
- be descriptive, and
- be clear and understandable to all, not just to those at the table developing them.

Figure 9.1b serves as a guide for developing and assessing biological goals. Each biological goal should contain these four elements:

1. the key **subject** of concern (e.g., a particular species or guild, a biotic community, or a habitat type);
2. the **attribute** of interest for that subject (e.g., population size, physical area covered, species composition);
3. the **target** or condition for the attribute (e.g., a number, period of time, historic condition). In selecting this, keep climate change effects in mind, since depending on the situation and timeframe for the HCP, it may or may not make sense for the target to involve the historic range of variability or existing conditions; and
4. the **action** or effort (e.g., restore, provide) that will be made to achieve the target.

**Figure 9.1b: Four Elements of a Biological Goal**




HCP goals should address the broad biological needs of the species. They can be focused on a number of species needs or reducing threats, such as:

- maintaining a specific species life history characteristic,
- providing conditions necessary for an important life history characteristic, or
- restoring something to historic or more desirable conditions, or establishing desirable conditions that facilitate transformation in response to effects of climate change or other stressors that cannot be addressed using traditional restoration approaches

All of these examples should be based on the specific needs of species in the plan area, but contribute to broader species needs.

These goals need to be forward thinking and “truthed” with a reasonableness of likely future climatic conditions. Depending on the local situation and time period covered, future-oriented goals can vary along a continuum from managing for persistence to managing for transformation, and shift over time from persistence to transformation. With climate change effects in mind, are the goals still achievable? If not, consider adjusting them to make them achievable with future climatic conditions in mind.

**Example Goals:**

Example goal 1: Bogus Bat: self-sustaining population of bogus bats in the preserve system that can withstand threats, is genetically representative of neighboring populations, and contributes to the overall recovery of the species.

Example goal 2: Swamp habitat: hydrologic integrity of the Mucky Swamp within the natural state of variability and function maintained within future climatic constraints.

#### 9.1.1.1 Habitat-Based Goals vs. Species-Based Goals

HCPs that use habitat as a surrogate for species impacts can express conservation goals in terms of habitat area trends (objectives), but there must be an established correlation between species numbers, reproduction, and/or distribution and its habitat. In addition, there must be some way to reliably determine how effective the mitigation is for covered species.

For example: a species based goal might set specific population or life history targets for a covered species, such as percent of nestlings fledged or over-winter survival. In a habitat-based approach, the goal would be based on protecting, restoring, and establishing a specific type or amount of habitat for a covered species. In the case of the habitat based goal, the connection between habitat and covered species is really important to understand. Usually, protecting unoccupied habitat for a covered species does little for the species, however protecting a corridor that connects two important habitats can be important for the species' conservation.

Example habitat-based goal:

> Goal: Maintain and enhance functional grassland communities that benefit covered species and promote native biodiversity.
>
> Goal: Improve the quality of streams and the hydrologic and geomorphic processes that support them to maintain a functional aquatic and riparian community to benefit covered species and promote native biodiversity.
>
> Goal: Maintain a functional riparian forest and scrub community at a variety of successional stages and improve these communities to benefit covered species and promote native biodiversity.

Considerations for inclusion with or as goals:

- building in fire resiliency for an area and covered species affected by increased fire
- connectivity to important habitat or populations
- climatic refugia for climate sensitive species/habitats
- building in resilience to extreme changing conditions (e.g. vegetative buffers against storm surge, restoration to stabilize habitat prone to flooding, etc.)

Example species-based goal:

> Goal: Swainson's hawk: maintain or increase population size and distribution of Swainson's hawk in the inventory area
>
> Goal: foothill yellow-legged frog: protect, maintain, or increase populations of foothill yellow-legged frog

#### *9.1.2 Responsibility for Developing Biological Goals and Objectives*

Development of goals and objectives should be done jointly with the Services and the applicant. Field Office staff should be involved and engaged in the process to develop goals and objectives as the goals and objectives will be used to guide development of the entire plan.

### *9.1.3 When to Develop Goals and Objectives*

Once the applicant and the Services have completed the 'Getting Started Questionnaire' or similar guiding document, they should start developing the hierarchy of goals and purposes. Maintaining the order of the hierarchy is important in building a strong foundation for the HCP.

### *9.1.4 Number of Biological Goals*

There must be sufficient specificity in the articulated goals to guide the conservation strategy development and implementation. In some cases, goals will be needed for each covered species. In other cases, groups of covered species can fall under the umbrella of a single goal. Each plan will be different.

## 9.2 Biological Objectives

Objectives are the incremental steps taken to achieve a goal. Objectives are derived from goals, and they provide a foundation for determining conservation measures, monitoring direction, and evaluating effectiveness of the conservation strategy. The number of objectives per goal will vary, but there should be enough to adequately describe how to achieve the goal. An implementation schedule may be beneficial if a goal has several objectives.

### *9.2.1 SMART*

SMART is an important acronym for reminding us of the essential elements of a good objective. Objectives need to be:

- **S**pecific
- **M**easurable
- **A**chievable
- **R**esult-oriented
- **T**ime-fixed

**Specific**: Objectives must clearly articulate what is to be achieved. Avoid ambiguity by phrasing objectives clearly. A clearly phrased objective is easy to understand and the meaning is difficult to misinterpret. Be as specific as possible. WHO will do the action? WHAT will they do? WHEN and WHERE will they do it? Avoid phrases that are subject to interpretation, like "maintain high-quality habitat." "High-quality habitat" can be interpreted in many ways.

**Measurable**: Objectives should contain a measurable element that we can readily monitor to determine success or failure. First ask, "What would we monitor to assess progress toward achieving this objective?" Then ask, "How do we quantify it?" For example, to determine progress toward "high-quality habitat," identify what defines "high quality." That may mean having certain plant community composition, vegetative structure and density. Then to further define "high quality habitat," quantify each component. In this example, you might list the desired proportion of each plant species, the height of a plant type, and number of individuals in a specified unit of area. The nature of the measurable element may vary, as might the difficulty in measuring it. Still, you must have something to indicate progress. While evaluating a water

# Summary of the Current EAHCP Biological Goals

1. **Fountain Darter – Comal System**
    a. Quantified as areal coverage of aquatic vegetation (habitat) within four representative reaches of the Comal system and fountain darter density (population measurement) per aquatic vegetation type. (EAHCP Table 4-1)
    b. The population measurement goal is to maintain the median densities of fountain darters observed per aquatic vegetation type per system at a level greater than or equal to that observed over the past 10 years in the EAA Variable Flow Study monitoring.

2. **Fountain Darter – San Marcos System**
    a. Quantified as areal coverage of habitat within three representative river reaches of the San Marcos system and fountain darter density (population measurement) per aquatic vegetation type (EAHCP Table 4-21).
    b. The population measurement goal is to maintain greater than or equal to the median densities per aquatic vegetation type per system over the past 10 years in the EAA Variable Flow Study monitoring.

3. **Comal Springs riffle beetle**
    a. Maintain silt-free habitat conditions via continued springflow, riparian zone protection, and recreation control throughout each of the three sample reaches.
    b. Population measurement goals is to maintain grater than or equal to the median densities observed over the past six years of EAA Variable Flow Study monitoring.

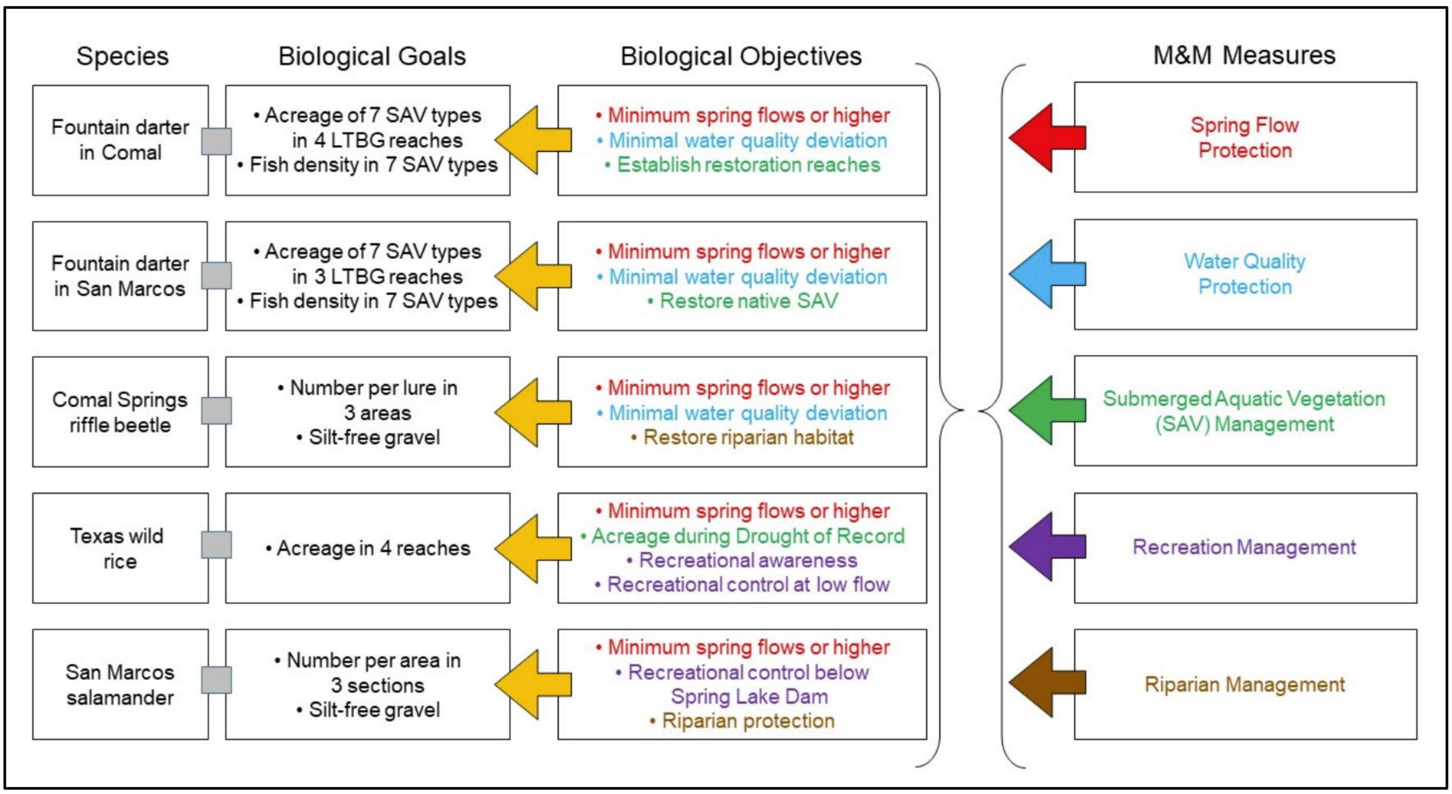
4. **Comal Springs dryopid beetle and Peck's Cave Amphipod**
    a. Note: Grouped together as subterranean species inhabiting the Comal system.
    b. Water quality goal:
        i. To not exceed a 10 percent deviation (daily average) from historically recorded water quality conditions (long-term average) within the Edwards Aquifer as measured issuing from the spring openings at Comal Springs.

5. **Texas wild-rice**
    a. Areal coverage (quantified) over a spatial extent of the San Marcos River (EAHCP Table 4-10).

6. **San Marcos salamander**
    a. Note: Goals are similar to the fountain darter and Comal Springs riffle beetle approach.
    b. Habitat perspective: Goal is to maintain silt-free habitat conditions via continued springflow, riparian zone protection, and recreation control throughout each of the three representative reaches.
    c. Population measurement goal is to maintain greater than or equal to the median densities observed over the past 10 years of monitoring (EAHCP Table 4-25).

7. **Texas blind salamander**
   a. Note: Goals are similar to the Comal Springs dryopid beetle and Peck's Cave amphipod (subterranean species).
   b. Water quality goal:
      i. Not to exceed a 10 percent deviation (daily average) from historically recorded water quality conditions (long-term average) within the Aquifer as measured issuing from the spring openings in Spring Lake.

Figure taken from the National Academies of Sciences Report 3.



# APPENDIX C

Meeting Agendas

# Biological Goals Subcommittee

Meeting 1 Agenda
February 2, 2023
2:00pm – 4:00pm

1. **Confirm attendance**

2. **Meeting logistics**

   a. Virtual meeting logistics
   b. Meeting POCs
   c. Subcommittee logistics

3. **Overview of the Biological Goals Subcommittee Charge and meeting process.**

4. **Presentation on the USFWS Habitat Conservation Planning and Incidental Take Permit Processing Handbook – Chapter 9.1: Biological Goals.**

5. **Review and discussion of the current EAHCP Biological Goals.**

6. **Discussion to identify the type of Biological Goal(s) to proceed with.**

7. **Questions from the public**

8. **Future meetings**

9. **Adjourn**

# Biological Goals Subcommittee

Meeting 2 Agenda
February 16, 2023
2:00pm – 4:00pm

1. **Confirm attendance**

2. **Meeting logistics**

   a. Virtual meeting logistics
   b. Meeting POCs

3. **Overview of Meeting #1 discussion.**

4. **Consider staff recommendation to develop new biological goals for the next EAHCP.**

5. **Discussion on the development of Biological Goals.**

6. **Questions from the public**

7. **Future meetings**

8. **Adjourn**

# Biological Goals Subcommittee

Meeting 3 Agenda
March 2, 2023
2:00pm – 4:00pm

1. **Confirm attendance.**

2. **Meeting logistics.**

   a. Virtual meeting logistics
   b. Meeting POCs

3. **Approval of meeting minutes from February 2 and February 16, 2023.**

4. **Overview of Meeting #2.**

5. **Continued discussion on suggested Biological Goals.**

6. **Next steps of the Biological Goals Subcommittee.**

7. **Questions from the public.**

8. **Future meetings.**

9. **Adjourn.**

# Biological Goals Subcommittee

Meeting 4 Agenda
March 16, 2023
2:00pm – 4:00pm

1. **Confirm attendance.**

2. **Meeting logistics.**

   a. Virtual meeting logistics
   b. Meeting POCs

3. **Approval of meeting minutes from March 2, 2023.**

4. **Review of final Biological Goal recommendations and Subcommittee Report.**

5. **Consideration to approve the Biological Goals Subcommittee Report.**

6. **Questions from the public.**

7. **Future meetings.**

8. **Adjourn.**

# APPENDIX D

Presentations

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# Biological Goals Subcommittee – Meeting #1

February 2, 2023

Microsoft Teams

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## Meeting Logistics

- Meeting Materials available on the EAHCP website under – Biological Goals Subcommittee
- Contact Olivia Ybarra for more info: oybarra@edwardsaquifer.org
- IT Support: Jesus Hinojosa: jhinojosa@edwardsaquifer.org

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# Meeting Logistics

- Decisions made by consensus.
- If consensus cannot be achieved by the deadline, the recommendations may be approved by a majority vote of the full Subcommittee.
- Any dissension from a member will be included in the final report.

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# Members

- **Chair:** Mark Enders (Stakeholder Committee)
- Rachel Sanborn (Stakeholder Committee)
- Kimberly Meitzen (Stakeholder Committee)
- Kevin Mayes (Stakeholder Committee)
- Jacquelyn Duke (Science Committee)
- Charlie Kreitler (Science Committee)

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# Biological Goals Subcommittee Charge

- Review the current EAHCP biological goals and the HCP Handbook as it pertains to biological goals development and structure.
- Develop initial recommendations for deletions, additions, or other changes to current biological goals.
- Finalize biological goal recommendations to be considered in the next EAHCP.
- Approve a report setting out the biological goal recommendations to be provided to the EAHCP Permit Renewal contractor.

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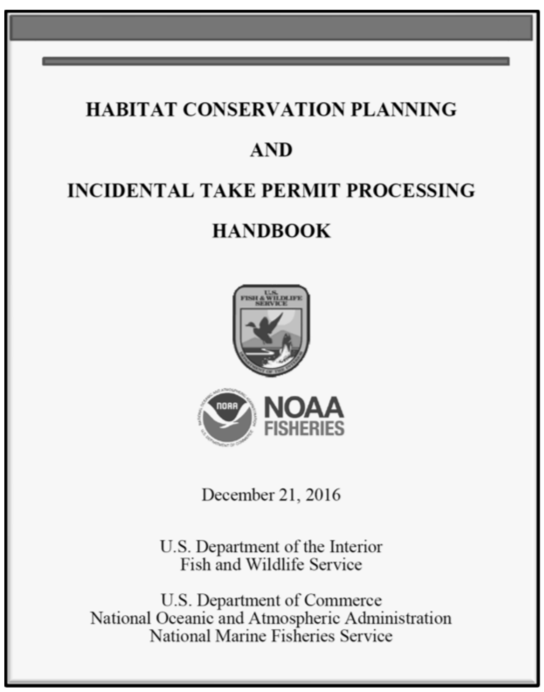

HABITAT CONSERVATION PLANNING

AND

INCIDENTAL TAKE PERMIT PROCESSING

HANDBOOK

NOAA FISHERIES

December 21, 2016

U.S. Department of the Interior
Fish and Wildlife Service

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

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**Figure 9.1e: Hierarchy of Goals and Purposes**


1. Purpose of the HCP: The purposes specified in or derived from law, regulations, agreement, etc. that broadly outlines the need for the HCP to meet regulatory purposes in harmonizing sustainable development with conservation of fish and wildlife.
2. Regional or Landscape Goals: summarize how the HCP conservation program will contribute to regional and landscape conservation goals.
3. HCP Conservation Vision Statement: A concise statement of what the HCP conservation program should be, or what we hope to do, based on the needs of species, and other mandates.
4. HCP Goal. Descriptive, open-ended, and often broad statement of desired future conditions that conveys a purpose, but does not define measurable units.
5. HCP Objective: A concise statement of what we want to achieve, how much we want to achieve, when and where we want to achieve it, and who is responsible for the work. Objectives derive from goals and provide the basis for determining strategies, monitoring effectiveness, and evaluating the success of actions.
6. HCP Conservation Actions: specific actions, tools, techniques used to meet plan objectives.
7. HCP Monitoring Goals: succinct statements of what the monitoring program will achieve.

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# Handbook pg. 9-6

- Biological goals broadly describe the desired future conditions of an HCP in succinct statements.
- Each goal steps down to one or more objectives that define how to achieve these conditions in measurable terms.
- A well-written goal directs work toward achieving the vision and purpose of an HCP.

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# Biological Goals are **not**….

- An HCP is not a recovery plan (but should be consistent with existing recovery plans)
- They are not restatements of the issuance criteria in the ESA or the regulations
- They are not restatements of other regulations, policies, or guidance

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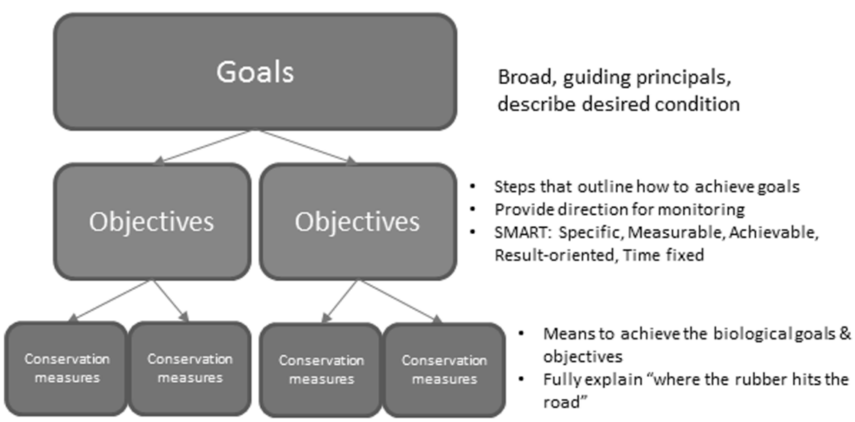
# Biological Goals

**Figure 9.1a: Biological Goals and Objectives**

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# Goals must:

- broadly state desired future condition,
- be descriptive, and
- be clear and understandable to all, not just to those at the table developing them.

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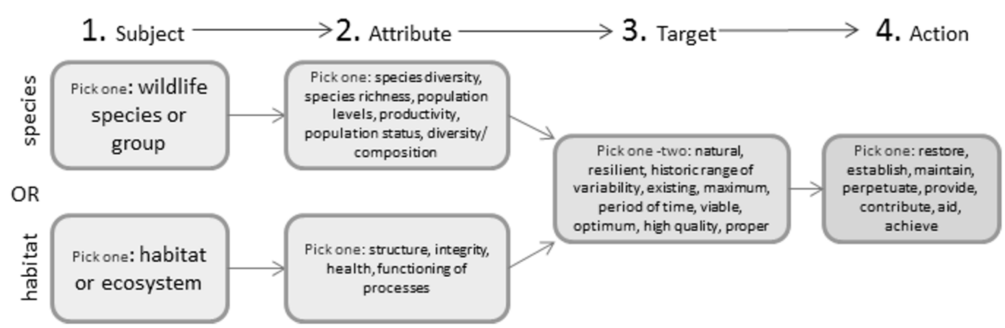
# Elements of a Biological Goal

**Figure 9.1b: Four Elements of a Biological Goal**

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# Example Biological Goals

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# Example: Species Based Goals

Example species-based goal:

Goal: Swainson's hawk: maintain or increase population size and distribution of Swainson's hawk in the inventory area

Goal: foothill yellow-legged frog: protect, maintain, or increase populations of foothill yellow-legged frog

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# BSEACD HCP – Barton Springs Edwards Aquifer

The biological goals of the District HCP are to:

- Minimize drought-related decreases in size and health of the Barton Springs salamander population to the maximum extent practicable,
- Minimize drought-related decreases in size and health of the Austin blind salamander population to the maximum extent practicable, and
- Promote recovery of the populations from those decreases to levels required for their long-term viability.

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# Example: Habitat Based

Example habitat-based goal:

Goal: Maintain and enhance functional grassland communities that benefit covered species and promote native biodiversity.

Goal: Improve the quality of streams and the hydrologic and geomorphic processes that support them to maintain a functional aquatic and riparian community to benefit covered species and promote native biodiversity.

Goal: Maintain a functional riparian forest and scrub community at a variety of successional stages and improve these communities to benefit covered species and promote native biodiversity.

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# Upper Santa Ana River HCP

The HCP Goals will be accomplished within the HCP Preserve System and are as follows:

**HCP Goal 1:** Conserve Covered Species and manage their habitats to contribute to the recovery of listed species or those that may become listed under the Federal Endangered Species Act.

**HCP Goal 2:** Maintain or simulate natural ecological processes necessary to maintain the functionality of the natural communities and habitats upon which the Covered Species depend within the HCP Preserve System and to the greatest extent possible outside the HCP Preserve System.

**HCP Goal 3:** Maintain or increase habitat connectivity in the HCP Preserve System and to adjacent protected habitat areas to reduce isolation between metapopulations of Covered Species.

**HCP Goal 4:** Actively manage lands within the HCP Preserve System for the benefit of Covered Species to maintain or increase the health of populations.

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# Current Biological Goals

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# Comal System: Fountain Darter

**Fountain Darter**

***Long-term Biological Goals***

The long-term biological goals for the fountain darter at Comal Springs are quantified as areal coverage of aquatic vegetation (habitat) within four representative reaches of the Comal system (Upper Spring run [upstream most portion of the system to Spring Island], Landa Lake [Spring Island to the outflow to Old and New channels], Old Channel, and New Channel) and fountain darter density (population measurement) per aquatic vegetation type. (Figure 4-1). The habitat-based and population measurement goals are presented in Table 4-1 and include proposed aquatic vegetation restoration efforts. The population measurement goal is to maintain the median densities of fountain darters observed per aquatic vegetation type per system at a level greater than or equal to that observed over the past 10 years in the EAA Variable Flow Study monitoring.

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# Comal System: Habitat-based and population measurement goals for the Fountain Darter

**TABLE 4-1[2]**
**TABLE 4-1 FOUNTAIN DARTER HABITAT (AQUATIC VEGETATION) IN METERS SQUARED ($M^2$) AND FOUNTAIN DARTER MEDIAN DENSITY (NUMBER/$M^2$) PER HABITAT TYPE**

| Fountain darter habitat (aquatic vegetation) goal in meters squared ($m^2$) | | | | | | |
|---|---|---|---|---|---|---|
| Study Reach | Bryophytes | *Potamogeton* | *Ludwigia* | *Cabomba* | *Sagittaria* | *Vallisneria* |
| Upper Spring Run Reach | 1,750 | 0 | 25 | 25 | 850 | 0 |
| Landa Lake | 3,950 | 25 | 900 | 500 | 2,250 | 12,500 |
| Old Channel | 550 | 0 | 425 | 180 | 450 | 0 |
| New Channel | 150 | 0 | 100 | 2,500 | 0 | 0 |
| TOTAL | 6,400 | 25 | 1,450 | 3,205 | 3,550 | 12,500 |
| Fountain darter median density goal (number/$m^2$) | | | | | | |
| | Bryophytes | *Potamogeton* | *Ludwigia* | *Cabomba* | *Sagittaria* | *Vallisneria* |
| | 20 | 3.3 | 7 | 7 | 1 | 1 |

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# San Marcos System: Fountain Darter

## Fountain Darter

### *Long-term Biological Goals*

The long-term biological goals for the fountain darter are quantified as areal coverage of habitat within three representative river reaches of the San Marcos system (Figure 4-3) and fountain darter density (population measurement) per aquatic vegetation type. These habitat-based and population measurement goals are presented in Table 4-21. The population measurement goal is to maintain greater than or equal to the median densities observed per aquatic vegetation type per system over the past 10 years of EAA Variable Flow Study monitoring.

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# San Marcos System: Fountain Darter

**TABLE 4-21[5]**
**FOUNTAIN DARTER HABITAT (AQUATIC VEGETATION) IN METERS SQUARED ($m^2$) AND FOUNTAIN DARTER DENSITY (NUMBER/$m^2$) PER HABITAT TYPE**

| Fountain darter habitat (aquatic vegetation) in meters squared ($m^2$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Study Reach | | *Ludwigia* | *Cabomba* | | *Potamogeton* | *Sagittaria* | *Hydrocotyle* | *Zizania* |
| Spring Lake Dam | | 100 | 50 | | 200 | 200 | 50 | 700 |
| City Park | | 150 | 90 | | 1,450 | 300 | 10 | 1,750 |
| IH-35 | | 50 | 50 | | 250 | 150 | 50 | 600 |
| TOTAL | | 300 | 190 | | 1,900 | 650 | 110 | 3,050 |
| Fountain darter median density (numbers/$m^2$) | | | | | | | | |
| | | *Ludwigia* | *Cabomba* | | *Potamogeton* | *Sagittaria* | *Hydrocotyle* | *Zizania* |
| | | 7 | 7 | | 5 | 1 | 4 | 5 |

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# Comal Springs Riffle Beetle

## Comal Springs Riffle Beetle

### *Long-term Biological Goals*

The long-term biological goals for the Comal Springs riffle beetle involve a qualitative habitat component and quantitative population measurement. As with the fountain darter, a representative reach approach was employed. From a habitat perspective, the goal is to maintain silt-free habitat conditions via continued springflow, riparian zone protection, and recreation control throughout each of the three sample reaches (Spring Run 3, Western shoreline, and Spring Island area). (Figure 4-2). Additionally, the population measurement goal is to maintain greater than or equal to the median densities observed over the past six years of EAA Variable Flow Study monitoring..

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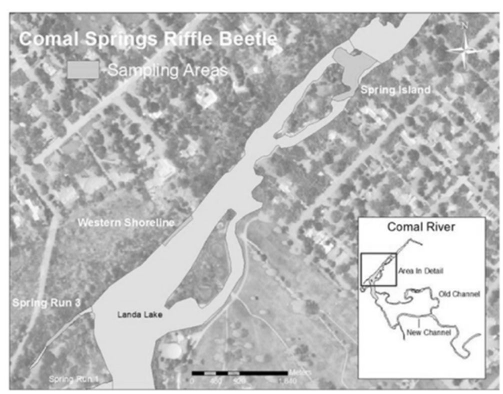
# Comal Springs Riffle Beetle: Goals

**TABLE 4-7**
**COMAL SPRINGS RIFFLE BEETLE LONG-TERM BIOLOGICAL GOALS**

| | Spring Run 3 | Western Shoreline | Spring Island Area |
|---|---|---|---|
| Habitat | Silt-free gravel and cobble substrate ≥ 90% of each study area | | |
| Density (# of CSRB/ Lure) | ≥20 | ≥15 | ≥15 |

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# Comal Springs Dryopid Beetle and Peck's Cave Amphipod

**Comal Springs Dryopid Beetle and Peck's Cave Amphipod**

***Long-term Biological Goal***

The Comal Springs dryopid beetle and Peck's Cave amphipod are subterranean species inhabiting the Comal system. The subterranean nature and restricted range of the Comal Springs dryopid beetle (to the headwaters of the springs and spring upwelling areas) suggests that it does not require substantial surface discharge from springs to survive and presumes that springflow (of sufficient water quality) that continually covers the spring orifice should prevent long-term detriment to the population. EARIP (2009). Similarly, the Peck's Cave amphipod requirements include sufficient springflow covering the spring orifices and adequate water quality to prevent long-term adverse impacts to the species. (*Id.*).

As such, the long-term biological goal for these subterranean species focuses on Aquifer water quality as well as a springflow component. The water quality goal is:

- to not exceed a 10 percent deviation (daily average) from historically recorded water quality conditions (long-term average) within the Edwards Aquifer as measured issuing from the spring openings at Comal Springs.

This includes all water quality constituents currently measured in the EAA Variable Flow Study. This goal assumes that a 10 percent deviation would be acceptable; however, more extensive work to evaluate and assess water quality tolerances of these species will be addressed as part of the AMP.

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# Texas wild-rice

***Long-term Biological Goal***

The long-term biological goal for Texas wild-rice has been determined by an evaluation of: (1) the maximum occupied area of Texas wild-rice that has been present in the San Marcos system over time; (2) TPWD analysis of the Hardy (2010) physical habitat modeling; and (3) the 1996 USFWS recovery plan goals.

The long-term biological goal for Texas wild-rice is presented in Table 4-10 and subsequent discussion.

***Flow-related Objectives***

The long-term biological goals for Texas wild-rice are defined as areal coverage over a spatial extent of the San Marcos River (*see* Table 4-10). However, because of the uncertainty associated with the long-term biological goals, the associated management objectives necessitate the flow-related objectives presented above in Table 4-13.

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SERVATION PLAN

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# Texas wild-rice

**TABLE 4-10**
**LONG-TERM BIOLOGICAL GOAL FOR TEXAS WILD-RICE**

| River Segment | Areal Coverage ($m^2$) | Reach Percentage of Total Areal Coverage |
|---|---|---|
| Spring Lake | 1,000 – 1,500 | n/a |
| Spring Lake Dam to Rio Vista Dam | 5,810 – 9,245 | 83 – 66 |
| Rio Vista Dam to IH-35 | 910 – 1,650 | 13 – 12 |
| Downstream of IH-35 | 280 – 3,055 | 4 – 22 |
| TOTAL | 8000 – 15,450 | 100 |

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# San Marcos salamander

**San Marcos Salamander**

***Long-term Biological Goals***

The long-term biological goals for the San Marcos salamander include a qualitative habitat component and a quantitative population measurement. As with the fountain darter and riffle beetle, a representative reach approach was employed. From a habitat perspective, the goal is to maintain silt-free habitat conditions via continued springflow, riparian zone protection, and recreation control throughout each of the three representative reaches (Hotel area, Riverbed area, and eastern spillway below Spring Lake Dam) (Figures 4-3, 4-4). Additionally, the population measurement goal is to maintain greater than or equal to the median densities observed over the past 10 years of monitoring. Table 4-25 summarizes long-term biological goals.

**TABLE 4-25**
**SAN MARCOS SALAMANDER LONG-TERM BIOLOGICAL GOALS**

| | Hotel Area (Spring Lake) | Riverbed Area (Spring Lake) | Eastern Spillway below (Spring Lake) |
|---|---|---|---|
| Habitat | Silt-free gravel and cobble substrate ≥ 90% of each study area | | |
| Density (# of salamanders/$m^2$) | ≥15 | ≥10 | ≥5 |

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# Texas Blind-Salamander

## Texas Blind Salamander

***Long-term Biological Goal***

Similar to the Comal Springs dryopid beetle and Peck's Cave amphipod, the Texas blind salamander is a subterranean species. An assumption of the HCP is that as subterranean species, mechanisms exist for these species to retreat into the Aquifer should springflows cease at the spring outlets at San Marcos Springs. As such, the long-term biological goal for this subterranean species relates to Aquifer water quality. The water quality goal for the Texas blind salamander is:

- Not to exceed a 10 percent deviation (daily average) from historically recorded water quality conditions (long-term average) within the Aquifer as measured issuing from the spring openings in Spring Lake.

This includes water quality constituents currently measured in the EAA Variable Flow Study. (*See* Section 5.7.2). To be conservative, the long-term goal assumes that a 10 percent deviation would be acceptable; however, more extensive work to evaluate and assess the validity of that assumption and the water quality tolerances of the Texas blind salamander will be considered in the AMP.

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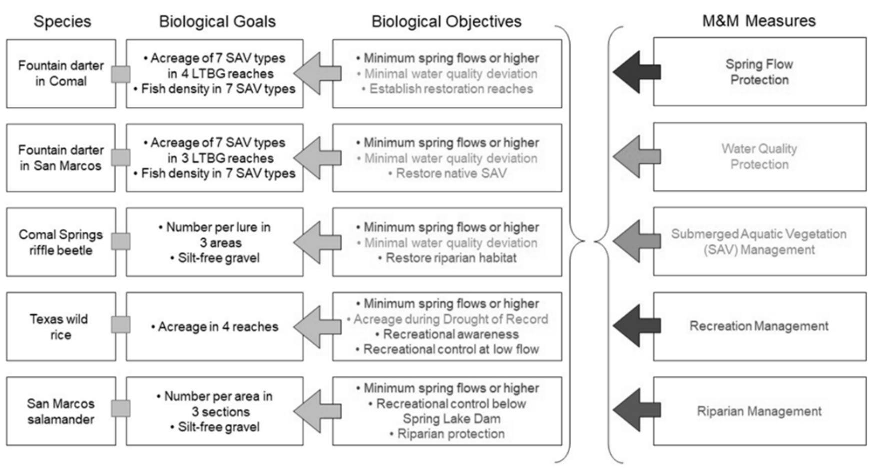
# NAS Report 3

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# Biological Goals Subcommittee

Meeting 1 Agenda
February 2, 2023
2:00pm – 4:00pm

1. **Confirm attendance**
2. **Meeting logistics**
   a. Virtual meeting logistics
   b. Meeting POCs
   c. Subcommittee logistics
3. **Overview of the Biological Goals Subcommittee Charge and meeting process.**
4. **Presentation on the USFWS Habitat Conservation Planning and Incidental Take Permit Processing Handbook – Chapter 9.1: Biological Goals.**
5. **Review and discussion of the current EAHCP Biological Goals.**
6. **Discussion to identify the type of Biological Goal(s) to proceed with.**
7. **Questions from the public**
8. **Future meetings**
9. **Adjourn**

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# Covered Species

- Fountain Darter
- Comal Springs riffle beetle
- Comal Springs dryopid beetle
- Peck's Cave Amphipod
- Texas wild-rice
- ~~San Marcos gambusia~~
- ~~Comal Springs salamander~~
- Texas blind salamander
- San Marcos salamander
- Edwards Aquifer diving beetle
- Texas troglobitic water slater

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# Suggestion: Group by Species Type

Macroinvertebrates

- Peck's Cave amphipod
- Edwards Aquifer diving beetle
- Texas troglobitic water slater
- Comal Springs riffle beetle
- Comal Springs dryopid beetle

Salamanders

- Texas blind salamander
- San Marcos salamander

Texas wild-rice

Fountain darter

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# Suggestion: Group Species by Habitat

Subterranean Species (Aquifer Dwelling)

- Edwards Aquifer diving beetle
- Texas troglobitic water slater
- Texas blind salamander

Spring/River Dwelling

- Texas wild-rice
- Fountain darter

Both Subterranean and Spring/River Dwelling

- Peck's Cave amphipod
- Comal Springs riffle beetle
- Comal Springs dryopid beetle
- San Marcos salamander

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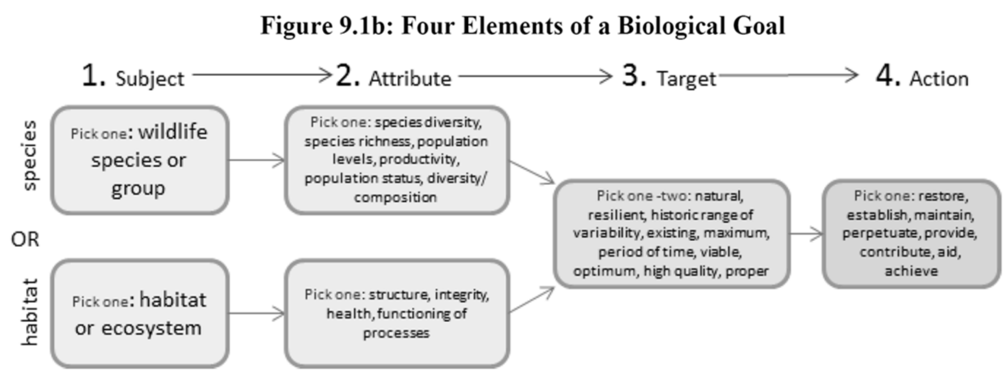
# Elements of a Biological Goal




35

# Questions?

36

# Suggestions from the Listen & Learn Report

- Maintain springflow conducive to the protection of **Covered Species**.
- Extend the area of habitat restoration for the **Covered Species** further downstream.
- Maintain or create informed users of the Comal and San Marcos Springs.

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# Suggestion: Goal(s) per group

- Maintain genetically diverse populations of **Texas wild-rice** in the San Marcos River.
- Provide and maintain a diverse native aquatic vegetation community to support viable **fountain darter** populations in the spring systems.
- Maintain adequate water quality standards and springflow for **macroinvertebrate** and **salamander** populations in the spring systems.
- Contribute to the education of Comal and San Marcos River recreators on the importance of habitat conservation in relation to the **Covered Species**.
- Support land conservation over the Edwards Aquifer recharge zone.

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HABITAT CONSERVATION PLAN

# Biological Goals Subcommittee – Meeting #2

February 16, 2023

Meadows Center for Water and the Environment & Microsoft Teams

1

## Meeting Logistics

**This meeting is being recorded**

- Meeting Materials available on the EAHCP website under – Biological Goals Subcommittee
- Contact Olivia Ybarra for more info: oybarra@edwardsaquifer.org
- IT Support: Jesus Hinojosa: jhinojosa@edwardsaquifer.org

2

## Overview of Meeting #1

- Subcommittee introductions
- Current Biological Goals
- HCP Handbook – Chapter 9 and other meeting materials.
- Discussion on proposed Biological Goals and species categories.

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3

## Biological Objectives Work Group

- Fountain Darter/ Texas wild-rice:
  - Tom Arsuffi
  - Megan Bean
  - Jason Martina
  - Tim Bonner
- Salamanders:
  - Justin Crow
  - Pete Diaz
  - Nate Bendik
- Macroinvertebrates:
  - Butch Weckerly
  - Chad Norris
  - Randy Gibson

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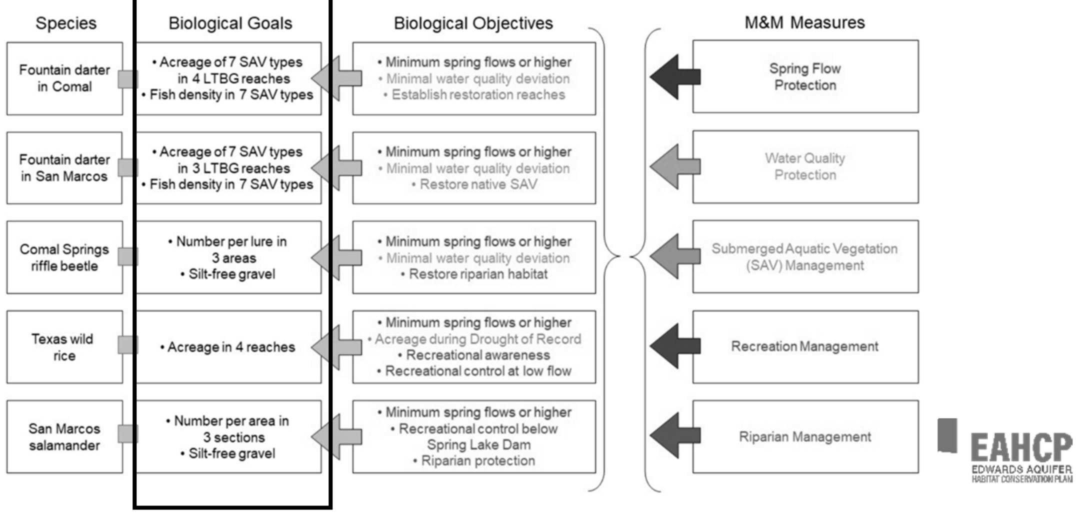
# NAS Report 3




5

# Action Item:

**Consider staff recommendation to develop new biological goals for the next EAHCP.**

6

# Developing Biological Goals



# Handbook pg. 9-6

- Biological goals **broadly describe** the desired future conditions of an HCP in **succinct statements**.
- Each goal steps down to one or more **objectives that define how to achieve** these conditions in measurable terms.
- A well-written goal directs work toward achieving the **vision and purpose of an HCP**.

# Examples

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# Thurston County HCP (updated 2022)

## 5.2 Biological Goal and Conservation Objectives

The Biological Goal, Conservation Objectives, and Conservation Measures are intended to illustrate the vision and commitments of the Conservation Program. The Biological Goal describes what the Conservation Program will accomplish by the end of the incidental take permit duration. The Conservation Objectives serve as benchmarks by which to measure progress in achieving goals for each Covered Species, across temporal and spatial scales. Conservation Measures are specific measurable actions that will be implemented to meet the Conservation Objectives and achieve the Biological Goal.

The Biological Goal of the HCP is to:

> Maintain, in perpetuity, populations of each of the Covered Species within Thurston County, through strategic habitat acquisition, conservation, enhancement, and management in advance of, unavoidable impacts to the Covered Species from the Covered Activities.

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# Maricopa Sun Solar Complex Project HCP (2021)

The goals and objectives developed for each of the Covered Species are similar, as is the rationale for their importance as part of the conservation strategy. The Project's primary biological goals are to preserve Covered Species and provide Covered Species habitat within the Permit Area by:

1. Preserving populations of Kern mallow within the Permit Area.
2. Increasing the ability of San Joaquin kit fox to disperse through the Permit Area and providing habitat within the region.
3. Preserving existing populations of the Tipton kangaroo rat within the Permit Area and providing habitat for the Tipton kangaroo rat within the Permit Area.
4. Preserving existing populations of Nelson's antelope squirrel within the Permit Area and providing habitat for Nelson's antelope squirrel within the Permit Area.
5. Preserving existing populations of the western burrowing owl within the Permit Area and providing habitat for the western burrowing owl within the Permit Area.
6. Providing habitat for the blunt-nosed leopard lizard within the Permit Area.

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# Bitter Ridge Indian Bat and Northern Long-Eared Bat HCP (2020)

**5.1 Biological Goals and Objectives**

These biological goals are the guiding principles for this HCP's conservation program. The biological objectives are meant to clarify the purpose and direction of the conservation measures through specific, measurable, achievable targets. While measures to conserve or recover an endangered or threatened species are not required under § 10 of the ESA, the biological goals and objectives of this HCP are consistent with actions to promote the recovery of the Indiana bat and northern long-eared bat.

**Goal 1**: Contribute to maintaining the integrity of the populations of the Covered Species in Indiana by minimizing mortality of the Covered Species in the Permit Area.

**Objective 1**: Implement an operational strategy in each permit year that will decrease Covered Species' fatality rates by at least 60% compared to levels of projected take without minimization for the Project, as well as implementing a monitoring and adaptive management strategy (with potential for additional minimization measures to be put in place) in order to maintain take at or below the permitted levels over the 35-year term of the ITP (Sections 4.1 through 4.3).

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## HCP for the Hine's Emerald Dragonfly, Blanding's Turtle, Spotted Turtle, Leafy Prairie Clover, and Lakeside Daisy (2021)

The biological goals for this HCP are:

- To meaningfully contribute to the conservation of the Covered Species found in the Permit and Planning Area;
- Protect Covered Species and habitat by avoiding and minimizing take of Covered Species and impacts to their habitat to the maximum extent practicable; and
- To restore, enhance, and preserve Covered Species habitat as mitigation for impacts to habitat.

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## Aera Block 12 Development Project – HCP (2020)

**Goal 1.** Avoid or minimize disturbance to or loss of Covered Species habitat within the Project Area to the maximum extent practicable, emphasizing avoidance of habitat occupied by Covered Species.

**Objective 1.1.** Minimize disturbance of suitable habitat during project construction, production O&M, and well plugging and abandonment by implementing best management practices.

**Objective 1.2.** Minimize disturbance of suitable habitat occupied by Covered Species by conducting preconstruction surveys for Covered Species and implementing species-specific avoidance measures to protect occupied habitat to the maximum extent practicable.

**Objective 1.3.** Reclaim areas of temporary disturbance after construction activities are completed to reestablish suitable habitat conditions for the Covered Species.

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# Lake States HCP (2023)

| | | |
|---|---|---|
| Biological Goal 3: Promote stewardship on other nonfederal lands. | Objective 3.1: Increase bat conservation by providing the Landowner Enrollment Program on eligible lands throughout the permit term. | • Provide opportunity to eligible forest owners to receive take authorization through the Lake States HCP in exchange for improving bat conservation on their lands. [a] |
| | Objective 3.2: Develop and implement a communication plan for educating the public on covered bats and their conservation. | • Develop a communication plan about bats.<br>• Implement the communication plan through publication of press releases, development and publication of web content, development of a brochure, speaking engagements, webinars, and other public outreach. |

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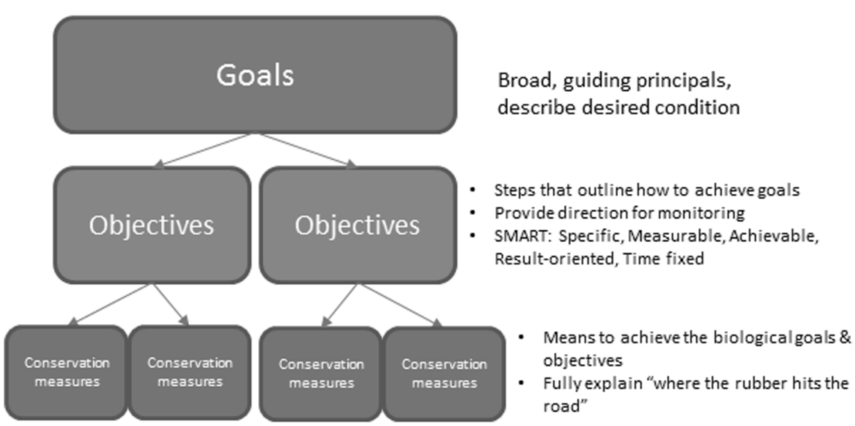
# Biological Goals

**Figure 9.1a: Biological Goals and Objectives**

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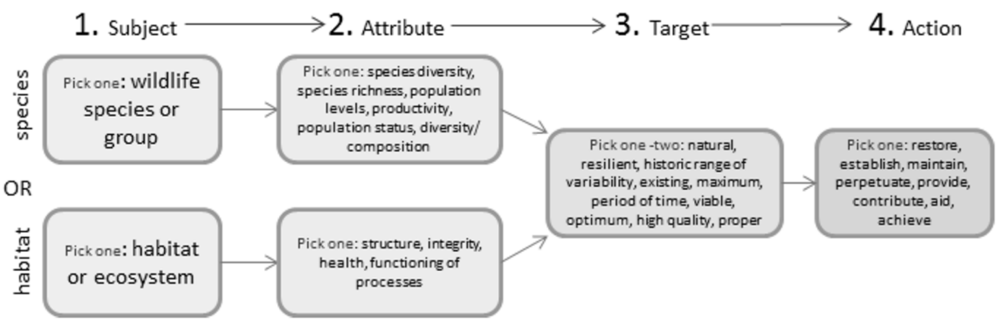
# Elements of a Biological Goal

Figure 9.1b: Four Elements of a Biological Goal

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# Suggested Biological Goals

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## Covered Species

- Fountain Darter
- Comal Springs riffle beetle
- Comal Springs dryopid beetle
- Peck's Cave Amphipod
- Texas wild-rice
- ~~San Marcos gambusia~~
- ~~Comal Springs salamande~~r
- Texas blind salamander
- San Marcos salamander
- Edwards Aquifer diving beetle
- Texas troglobitic water slater

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## Suggested Goals

Goal 1: Maintain resilient **Texas wild-rice** populations in the San Marcos River and Spring Lake.

Goal 2: Provide and maintain native habitat to support **fountain darter** populations in the Comal and San Marcos spring systems.

Goal 3: Maintain covered **macroinvertebrate** species populations in the Edwards Aquifer, and the Comal and San Marcos spring systems. (Comal Springs riffle beetle, Comal Springs dryopid beetle, Peck's Cave Amphipod, Edwards Aquifer diving beetle, and Texas troglobitic water slater)

Goal 4: Maintain healthy **salamander** populations in the Edwards Aquifer and San Marcos spring systems. (San Marcos salamander and Texas blind salamander)

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## Suggested Goals

Goal 5: Maintain healthy populations of each of the **Covered Species**, within the **Permit Area**, through habitat conservation, enhancement, and management.

Goal 6: Contribute to maintaining springflow in the Comal and San Marcos spring systems for the **Covered Species**.

Goal 7: Maintain good water quality in the Comal and San Marcos spring systems for the **Covered Species**.

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## Suggested Goals

Goal 8: Promote the importance of **habitat conservation** in the Edwards Aquifer region.

Goal 9: Support **land conservation** in the Edwards Aquifer region.

Goal 10: Manage **recreational impacts** to the Covered Species and their habitat.

EAHCP

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# Thank You!

- Public Comment
- Next Meeting:
  - Date: March 2, 2023
  - Time: 2:00PM – 4:00PM
  - Location: Pauline Espinosa Community Hall – San Marcos, TX and Microsoft Teams
- Adjourn

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# Biological Goals Subcommittee – Meeting #3

March 2, 2023

Pauline Espinosa Community Hall & Microsoft Teams

1

## Meeting Logistics

**This meeting is being recorded**

- Meeting Materials available on the EAHCP website under – Biological Goals Subcommittee
- Contact Olivia Ybarra for more info: oybarra@edwardsaquifer.org
- I.T. Support: Jesus Hinojosa: jhinojosa@edwardsaquifer.org

2

# Approval of Meeting Minutes

- February 2, 2023
- February 16, 2023

3

# Overview of Meeting #2

- Introduction of the Biological Objectives Subcommittee members.
- Continued discussion on biological goals per the HCP Handbook and examples from other HCPs.
- Motion to revise existing and develop new biological goals.
- Discussion on suggested biological goals.

4

# Next Steps

- **March 6:** Draft Biological Goals Subcommittee Report sent to members for review.
- **March 6 – 9:** Report review and comment period.
- **March 10:** EAHCP staff addresses report comments/edits.
- **March 13:** Final report sent to Subcommittee Members
- **March 16:** Consideration to approve the Biological Goals Subcommittee Report.

EAHCP

5

# Thank you!

- Public Comment
- Next Meeting:
  - Date: March 16, 2023
  - Time: 2:00PM – 4:00PM
  - Location: Meadows Center and Microsoft Teams

EAHCP

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# Biological Goals Subcommittee – Meeting #4

March 16, 2023

Meadows Center for Water and the Environment & Microsoft Teams

1

## Meeting Logistics

**This meeting is being recorded**

- Meeting Materials available on the EAHCP website under – Biological Goals Subcommittee
- Contact Olivia Ybarra for more info: oybarra@edwardsaquifer.org
- I.T. Support: Jesus Hinojosa: jhinojosa@edwardsaquifer.org

2

# Approval of Meeting Minutes

- March 2, 2023

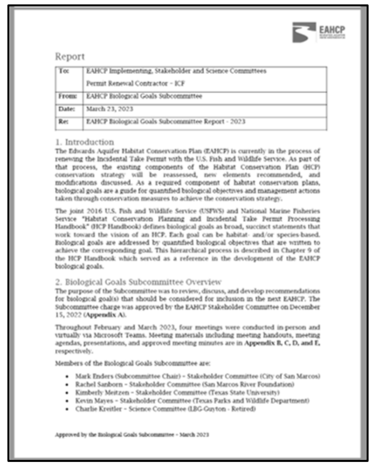
3

# Overview of Meeting #3

- Motion to approve meeting minutes from February meetings.
- Continued discussion on Biological Goals.

4

# Final Review of Biological Goals Subcommittee Report



Report

| | |
|---|---|
| To: | EAHCP Implementing, Stakeholder and Science Committees<br>Permit Renewal Contractor – ICF |
| From: | EAHCP Biological Goals Subcommittee |
| Date: | March 23, 2023 |
| Re: | EAHCP Biological Goals Subcommittee Report - 2023 |

1. Introduction

The Edwards Aquifer Habitat Conservation Plan (EAHCP) is currently in the process of renewing the Incidental Take Permit with the U.S. Fish and Wildlife Service. As part of that process, the existing components of the Habitat Conservation Plan (HCP) conservation strategy will be reassessed, new elements recommended, and modifications discussed. As a required component of habitat conservation plans, biological goals are a guide for quantified biological objectives and management actions taken through conservation measures to achieve the conservation strategy.

The joint 2016 U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service "Habitat Conservation Planning and Incidental Take Permit Processing Handbook" (HCP Handbook) defines biological goals as broad, succinct statements that work toward the vision of an HCP. Each goal can be habitat- and/or species-based. Biological goals are addressed by quantified biological objectives that are written to achieve the corresponding goal. This hierarchical process is described in Chapter 9 of the HCP Handbook which served as a reference in the development of the EAHCP biological goals.

2. Biological Goals Subcommittee Overview

The purpose of the Subcommittee was to review, discuss, and develop recommendations for biological goal(s) that should be considered for inclusion in the next EAHCP. The Subcommittee charge was approved by the EAHCP Stakeholder Committee on December 15, 2022 (**Appendix A**).

Throughout February and March 2023, four meetings were conducted in person and virtually via Microsoft Teams. Meeting materials including meeting handouts, meeting agendas, presentations, and approved meeting minutes are in **Appendix B, C, D, and E**, respectively.

Members of the Biological Goals Subcommittee are:

- Mark Enders (Subcommittee Chair) – Stakeholder Committee (City of San Marcos)
- Rachel Sanborn – Stakeholder Committee (San Marcos River Foundation)
- Kimberly Meitzen – Stakeholder Committee (Texas State University)
- Kevin Mayes – Stakeholder Committee (Texas Parks and Wildlife Department)
- Charlie Kreitler – Science Committee (LBG-Guyton - Retired)

Approved by the Biological Goals Subcommittee – March 2023

5

## Consideration to approve the final Biological Goals Subcommittee Report.

- Motion:
  - Move the Biological Goals Subcommittee approve the Biological Goals Subcommittee Report and submittal to the EAHCP Committees (Stakeholder, Implementing, and Science), Permit Renewal Contractor (ICF), and the Biological Objectives Subcommittee.

6

Thank you, Subcommittee!

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# APPENDIX E

Approved Meeting Minutes

# Biological Goals Subcommittee

**Meeting #1**
**Meeting Minutes**
February 2, 2023

1. **Confirm attendance**

   All Subcommittee members were in attendance via Microsoft Teams.

2. **Meeting logistics**
   Mark Enders, Biological Goals Subcommittee Chair, provided an overview of meeting logistics, points of contact and introduced the members of the Subcommittee.

3. **Overview of the Biological Goals Subcommittee Charge and meeting process.**
   Mark Enders presented the charge and the major elements of the Subcommittee. The primary focus of this Subcommittee is to: 1) Review the current EAHCP Biological Goals and the HCP Handbook; 2) Develop initial biological goal recommendations; 3) Finalize biological goal recommendations and 4) Approve the Biological Goals Subcommittee Report for the EAHCP Permit Renewal Contractor (ICF) and the EAHCP Committees.

4. **Presentation on the USFWS Habitat Conservation Planning and Incidental Take Permit Processing Handbook – Chapter 9.1: Biological Goals.**

   Olivia Ybarra, HCP Coordinator, provided an overview of the HCP Handbook as it pertains to the development of biological goals. Olivia highlighted the hierarchy of biological goals, biological objectives, and conservation measures in the context of the EAHCP. Additionally, Olivia noted that, in accordance to the HCP Handbook, biological goals should be broad, succinct statements that reflect the purpose and vision of the EAHCP. Examples of species and habitat based biological goals were also provided.

5. **Review and discussion of the current EAHCP Biological Goals.**

   The Subcommittee received a summary of the current EAHCP Biological Goals. It was noted that the current goals are very quantified, measurable, and specific. According to the HCP Handbook, the current biological goals reflect the elements of a biological objective rather than a goal. Chad Furl, EAHCP Chief Science Officer, reminded the Subcommittee that the details of the biological objectives will be discussed at a subsequent Biological Objectives Work Group. Myron Hess asked if there were any specific recommendations on the Covered Species that will be included in the renewed Incidental Take Permit. Chad Furl responded that, for the purpose of the biological goals development exercise, the current

Covered Species will be the primary focus, with the exception of the San Marcos Gambusia and the Comal Springs salamander. If additional species are added to the Covered Species list after the biological goals are developed, the Biological Goals Subcommittee may reconvene to consider those species as they relate to the biological goals.

EAHCP staff provided suggested biological goals developed using the guidelines from the HCP Handbook and several biological goals that were provided during the Listen and Learn Workshop series. Olivia Ybarra noted that Covered Species can be grouped into categories to help develop broad biological goal statements.

Chad Furl added that the HCP Handbook does not specify the number of goals an HCP should contain. Grouping species, rather than developing a goal per species, may be a more efficient and effective approach. The Biological Objectives Work Group will then review these goals and expand on the approach to achieve each goal.

6. **Discussion to identify the type of Biological Goal(s) to proceed with.**

The HCP Handbook suggests biological goals can be habitat or species based. Olivia Ybarra presented examples of each type of goal that are currently being implemented in other HCPs.

Jacquelyn Duke noted that the recommendations of "genetically diverse population of Texas wild-rice" might be too specific. Chad Furl reminded the group that the Biological Objectives Work Group will add the details of how to achieve the Biological Goals.

Kevin Mayes suggested adding a geographic component to a biological goal statement. For example, "maintaining Texas wild-rice in the San Marcos River from Spring Lake to the confluence with the Guadalupe River". Kevin also noted that when using words like "adequate" in reference to water quality standards, it is important to reference the TCEQ water quality guidelines.

Kimberly Meitzen noted the successes of the fountain darter and Texas wild-rice and suggested goals that go beyond the current geographic range for the Covered Species and suggested that future biological goals acknowledge the current long-term biological goal reaches.

The Subcommittee was reminded that the current biological goals that were originally approved by the USFWS do not align with the structure of a biological goal as described in the most up to date HCP Handbook. In summation, the current biological goals are written closer to what biological objective statement.

7. **Questions from the public**

There were no questions from the public.

## 8. Future meetings

Meeting #2 will be held on February 16, 2023, from 2:00PM – 4:00PM at the Meadows Center for Water and the Environment.

## 9. Adjourn

# Biological Goals Subcommittee

**Meeting #2**
**Meeting Minutes**
February 16, 2023

1. **Confirm attendance**

   Mark Enders, Charlie Kreitler, Rachel Sanborn, Kimberly Meitzen and Kevin Mayes attended the meeting in-person. Jacquelyn Duke attended virtually via Microsoft Teams.

2. **Meeting logistics**

   Mark Enders, Biological Goals Subcommittee Chair, noted that the meeting materials are available online and acknowledged EAA I.T. support should anyone need technical assistance.

3. **Overview of Meeting #1 discussion.**

   Mark Enders provided a review of the first meeting's discussion regarding subcommittee introductions, the current biological goals, and the HCP handbook.

4. **Consider staff recommendation to develop new biological goals for the next EAHCP.**

   Charlie Kreitler noted that since the current biological goals were approved by USFWS, was there a need to change them. USFWS staff responded that it is recommended that the EAHCP biological goals be updated to reflect lessons learned and reiterated that the current goals are written as objectives.

   Kevin Mayes suggested adding "revise current biological goals" to the action item. A revision was made to the action item presented to the subcommittee.

   A motion was made by Rachel Sanborn, seconded by Charlie Kreitler, to approve of the revision of current biological goals and/ or the development of new biological goals for the next EAHCP. The Subcommittee approved this upon consensus. There were no objections.

5. **Discussion on the development of Biological Goals.**

   Olivia Ybarra reminded the Subcommittee of the HCP Handbook guidelines on the elements of a biological goal and provided examples of broad biological goals from HCPs that were recently approved by USFWS.

   Kevin Mayes noted that although San Marcos Gambusia was not included in the list of species to consider in the development of the biological goals, it should be noted it was not included due to its pending delisting from the Endangered Species Act (ESA). The Comal Springs salamander was also not considered due to the recent removal of the petition for the species to be added to the ESA.

EAHCP staff provided ten suggested biological goals for the Subcommittee to review and discuss. Olivia Ybarra noted that these suggested goals were based on the current biological goals and lessons learned throughout ten years of EAHCP implementation.

**Goal 1:** Maintain resilient Texas wild-rice populations in the San Marcos River and Spring Lake.

**Goal 2:** Provide and maintain native habitat to support fountain darter populations in the Comal and San Marcos spring systems.

**Goal 3:** Maintain covered macroinvertebrate species populations in the Edwards Aquifer, and the Comal and San Marcos spring systems. (Macroinvertebrates: Comal Springs riffle beetle, Comal Springs dryopid beetle, Peck's Cave Amphipod, Edwards Aquifer diving beetle, and Texas troglobitic water slater)

**Goal 4:** Maintain healthy salamander populations in the Edwards Aquifer and San Marcos spring systems. (San Marcos Salamander and Texas blind salamander)

**Goal 5:** Maintain healthy populations of each of the Covered Species, within the Permit Area, through habitat conservation, enhancement, and management.

**Goal 6:** Contribute to maintain springflow in the Comal and San Marcos spring systems for the Covered Species.

**Goal 7:** Maintain good water quality in the Comal and San Marcos spring systems for the Covered Species.

**Goal 8:** Promote the importance of habitat conservation in the Edwards Aquifer region.

**Goal 9:** Support land conservation in the Edwards Aquifer region.

**Goal 10:** Manage recreational impacts to the Covered Species and their habitat.

In their discussions, the Subcommittee considered grouping several suggested goals into one broad goal. Another Subcommittee consideration was to develop a very broad goal that reflects the vision of the EAHCP and could potentially encompass several biological objectives that would not be appropriate in a goal focused on a specific species. Kevin Mayes noted that goals that reflect human mediated concepts and have recreation components should be considered as a biological goal. The general purpose of the Subcommittee was to develop an overarching, broad goal with several additional goals related to each species or habitat grouping.

The Subcommittee discussed doing some homework to revise the suggested biological goals or develop new proposed goals to email out or bring to the next subcommittee meeting for further discussion.

The Subcommittee will continue their discussion on revisions and groupings of the suggested biological goals at the next meeting.

**6. Questions from the public**

There were no questions from the public.

**7. Future meetings**

Meeting #3 will be held on March 2, 2023, from 2:00PM – 4:00PM at the Pauline Espinosa Community Hall.

**8. Adjourn**

# Biological Goals Subcommittee

**Meeting #3**
**Meeting Minutes**
March 2, 2023

1. **Confirm attendance**

   Mark Enders, Charlie Kreitler, Rachel Sanborn, Kimberly Meitzen, Jacquelyn Duke and Kevin Mayes attended the meeting in-person.

2. **Meeting logistics**

   Mark Enders, Biological Goals Subcommittee Chair, noted that meeting materials are available online and acknowledged EAA I.T. support should anyone need technical assistance.

3. **Approval of meeting minutes from February 2 and February 16, 2023.**

   A motion was made by Rachel Sanborn and seconded by Charlie Kreitler, to approve the meeting minutes from the February 2 and February 16, 2023 Biological Goals Subcommittee meetings. There were no objections.

4. **Overview of Meeting #2 discussion.**

   Olivia Ybarra provided a review of the second meeting's discussion including an introduction to the Biological Objectives Subcommittee, continued discussion on biological goals per the HCP Handbook and additional examples from other HCPs.

5. **Continued discussion on suggested biological goals.**

   The Biological Goals Subcommittee was provided draft goals that were submitted to EAHCP staff. The Subcommittee reviewed and revised the draft goal submissions. Key terms were defined to reduce ambiguity. The Subcommittee agreed to define "Conserve" as a means to protect, restore, and enhance the Covered Species and their habitats. Additional key terms were described and intended to be included in the Biological Goals Subcommittee Report. The following are the biological goals the Biological Goal Subcommittee generated as a product of their discussion.

   **Goal 1:** Conserve the quantity and quality of springflow and ecosystem characteristics within the Plan Area to provide for the resiliency of the Covered Species.

**Goal 2:** Promote environmental outreach, support land and water conservation, and mitigate anthropogenic and environmental disturbances within the Plan Area for the benefit of the Covered Species.

**Goal 3:** Conserve habitats and diverse native aquatic vegetation assemblages to support resilient fountain darter populations in the Comal and San Marcos spring and river systems.

**Goal 4:** Conserve and manage a resilient Texas wild-rice population in the San Marcos spring and river system.

**Goal 5:** Conserve habitats to support resilient Texas blind salamander, Comal Springs dryopid beetle, Peck's cave amphipod, Edwards Aquifer diving beetle, and Texas troglobitic water slater populations in the Plan Area.

**Goal 6:** Conserve habitats to support resilient Comal Springs riffle beetle populations in the Plan Area.

6. **Next steps of the Biological Goals Subcommittee.**

   Olivia Ybarra described the next steps of the Subcommittee. A draft report will be prepared by EAHCP staff and submitted to the Subcommittee on March 6 for review and comment. The fourth and final meeting will include the consideration to approve the Biological Subcommittee Report.

7. **Questions from the public**

   There were no questions from the public.

8. **Future meetings**

   Meeting #4 will be held on March 16, 2023, from 2:00PM – 4:00PM at the Meadows Center for Water and the Environment.

9. **Adjourn**

# Biological Goals Subcommittee

**Meeting #4**
**Meeting Minutes**
March 16, 2023

1. **Confirm attendance.**
   Mark Enders, Charlie Kreitler, Rachel Sanborn, Kimberly Meitzen and Kevin Mayes attended the meeting in-person. Jacquelyn Duke attending the meeting virtually via Microsoft Teams.

2. **Meeting logistics.**
   Mark Enders noted that meeting materials were available online on the EAHCP website under Biological Goals Subcommittee and I.T. support for virtual attendees.

3. **Approval of meeting minutes from March 2, 2023.**
   A motion was made by Kevin Mayes and seconded by Rachel Sanborn to approve the meeting minutes from the March 2, 2023 Biological Goals Subcommittee meeting. There were no objections.

4. **Review of final Biological Goal recommendations and Subcommittee Report.**
   The Biological Goals Subcommittee reviewed and edited the draft Subcommittee Report. The final report contains all edits, comments, and suggestions provided by the Subcommittee members.

5. **Consideration to approve the Biological Goals Subcommittee Report.**
   A motion was made by Jacquelyn Duke, seconded by Kimberly Meitzen, to approve the Biological Goals Subcommittee Report and submittal to the EAHCP Committees (Stakeholder, Implementing, and Science), Permit Renewal Contractor (ICF), and all relevant Subcommittees. There were no objections.

6. **Questions from the public.**
   There were no questions from the public.

7. **Future meetings.**
   None.

8. **Adjourn.**