

Candidate Conservation Agreement with Assurances for the False Spike and Texas Fawnsfoot in the Brazos River Basin



Developed Cooperatively by:

U.S. Fish and Wildlife Service – Southwest Region

and

Brazos River Authority

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1.0 Introduction

The Brazos River is the third-longest river in Texas, draining approximately 45,000 square miles as it meanders from northwest to southeast across the state. Due to its size and orientation, the Brazos River basin covers multiple ecoregions. From the arid high plains of west Texas, where some Brazos basin tributaries exhibit salinities greater than that of seawater, to the humid gulf prairies and marshes, the basin is home to a diverse array of aquatic fauna. This fauna includes two freshwater mussel species (False spike [*Fusconaia mitchelli*] and Texas fawnsfoot [*Truncilla macrodon*]) which are currently candidates for listing under the Endangered Species Act of 1973 (ESA).

Endangered Species Act (Act) policy allows for non-federal property owners who wish to conduct conservation for non-listed species on non-federal lands the opportunity to voluntarily enter into a Candidate Conservation Agreement with Assurances (CCAA). In return, the U.S. Fish and Wildlife Service (USFWS) may issue a permit under section 10(a)(1)(A) of the Act providing incidental take coverage for the species if listed and regulatory assurances. A property owner is defined as a person with a fee simple, leasehold, or property interest (including owners of water rights or other natural resources), or any other entity that may have a property interest, sufficient to carry out the proposed management activities, subject to applicable state law, on non-Federal land (50 CFR §17.3). A CCAA is an agreement between the USFWS and a property owner that provides a mechanism to implement conservation measures aimed at reducing threats to the candidate species, thereby potentially reducing the need for listing. In the event that the species is listed, the property owner receives assurances, through an Enhancement of Survival Permit, that they will not be required to take additional conservation measures beyond those agreed to in the CCAA (50 CFR §§ 17.22(d) and 17.32(d)).

The Brazos River Authority (BRA) is a special district of the State of Texas responsible for the development and management of the water resources of the Brazos River basin. Today, the BRA's staff develop and distribute water supplies (Figure 1), provide water and wastewater treatment, and monitors water quality. The BRA has over 250 employees, of which 15 are environmental professionals who were involved in the development of this CCAA, and an annual operating budget of \$58.7 million. As such, the BRA has the authority and capacity to properly implement all of the terms of this CCAA.

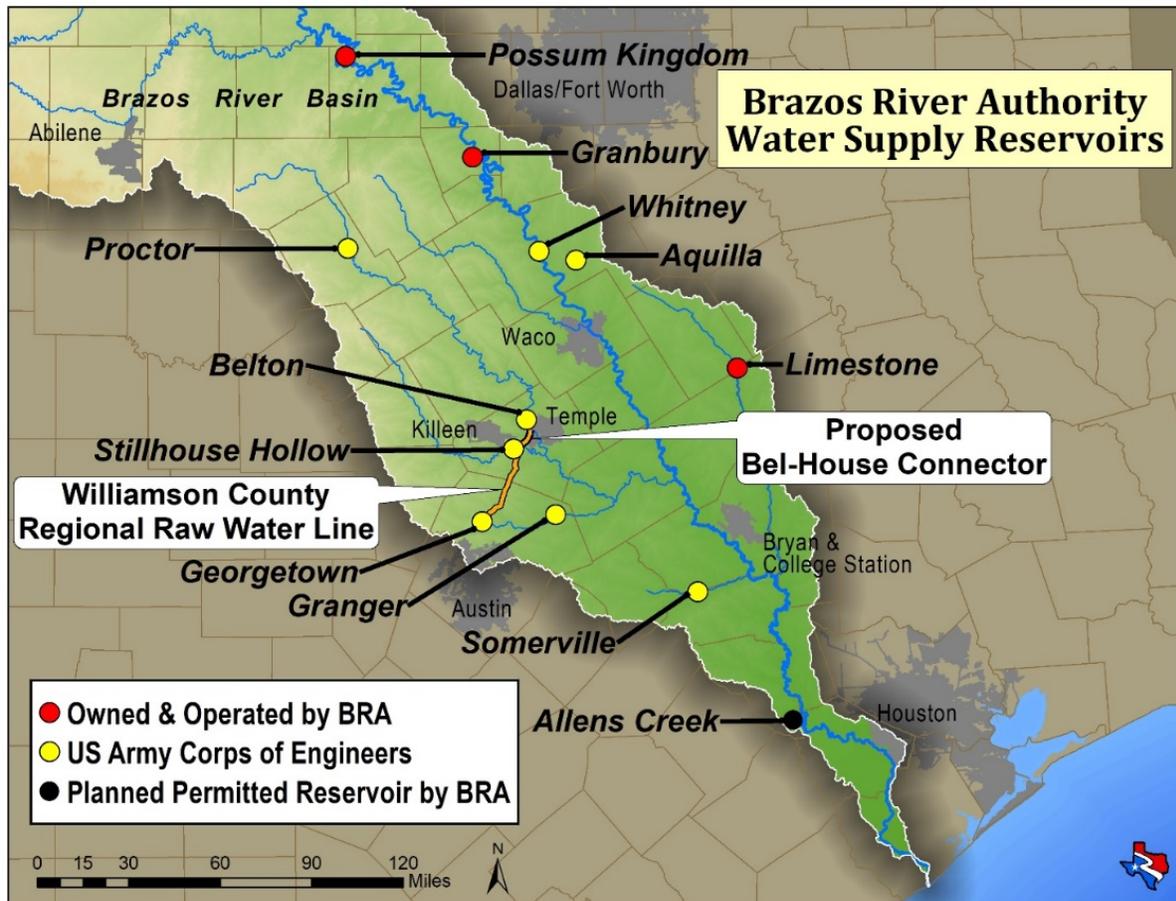


Figure 1. Map depicting Brazos River Authority Water Supply System, “BRA System”.

This document represents a voluntary partnership between the Brazos River Authority (BRA) and the USFWS in the form of a Candidate Conservation Agreement with Assurances (CCAA) to address the conservation needs of two species of freshwater mussels currently under review for ESA listing by USFWS (False spike, *Fusconaia mitchelli*, and Texas fawnsfoot, *Truncilla macrodon*; collectively referred to as the Covered Species). The Conservation Measures proposed address key current and possible future threats to the Covered Species, to the extent to which those threats are under the control of BRA. The BRA is entering into this CCAA voluntarily to cover BRA’s area of influence and does not intend for this agreement to enjoin other property owner’s in the basin. The term of this agreement is for twenty years.

1.1 Benefits of this Agreement

This agreement will provide net conservation benefit to the Covered Species through implementation of a comprehensive conservation strategy based on priorities established by national freshwater mollusk experts (FMCS 2016) and tailored to specific threats and hydrologic conditions in the Brazos River basin. BRA is committed to the implementation and funding of the comprehensive conservation strategy described herein. This strategy includes research and monitoring to gain further knowledge of the Covered Species, avoidance to protect existing populations, education and outreach to engage the public, and employs both collaborative

conservation and adaptive management principles to develop a comprehensive adaptive management program that involves collaboration with partners including TPWD and USFWS. It also includes the development of conservation zones and future hydrology modeling to prioritize areas for implementation of specific conservation measures designed to reduce current and future threats to the Covered Species, including avoidance of areas known to support mussel populations. Current threats to the species are summarized in Section 4.0. The conservation strategy, conservation zones, hydrologic modeling, and specific conservation measures are outlined in detail in Section 6.0, 7.0, 8.0, and 9.0, respectively. Conservation measures include: research into how compliance with existing Texas Administrative Code Title 30, Chapter 298 - Environmental Flow Standards for Surface Water (where applicable) provide for the ecological needs of mussels, and work with TCEQ to refine these standards specifically to provide additional benefit to freshwater mussels; avoidance of specific activities in areas known to harbor key populations of the Covered Species; additional applied research to examine the effects of various stressors to Covered Species; long-term monitoring of Covered Species populations, host fish, water quality, and substrate/channel morphology in key areas; surveys to fill existing data gaps in distributional information; updated hydrologic modeling to evaluate future risk to Covered Species; education and outreach to garner public interest in mussel conservation and habitat enhancements; and supporting development of emergency short-term refugia protocols and captive propagation for the Covered Species. Although this agreement specifically provides net conservation to benefit the Covered Species, many of the implemented conservation measures will result in beneficial impacts to other mussel species (**Appendix A**), fish, and native aquatic biota within the Brazos River basin.

Net Conservation Benefit

The agreement, when fully implemented, is expected to provide a net conservation benefit to the Covered Species by the end of its 20-year term. The conservation measures described in the agreement will reduce the extent and severity of threats to populations of the Covered Species that currently occupy stream reaches identified for protection in the agreement. The identification of avoidance and minimization zones will reduce threats associated with physical disturbance associated with the construction of new water supply and delivery infrastructure. Applied research, long-term monitoring, and an adaptive management program tied to changed circumstances will reduce threats associated with periods of critical low flows by providing the BRA with specific trigger points that consider the ecological needs of Covered Species when BRA makes drought management decisions. The BRA system of reservoirs allows BRA the flexibility to adjust to regional drought conditions and provide downstream water users from multiple reservoirs, and in the process provide for environmental flows that consider the needs of the Covered Species. The combination of reduced threats associated with physical disturbance and critical low flows will allow populations to naturally increase in terms of both number of individuals and extent of physical habitat occupied. Measures to guard against critical low flows will also protect against water quality degradation, as cleansing flows dilute potential toxicants. Twenty years represents approximately 2-5 generations for the Covered Species, and increases in population number and extent are expected to be measurable within 20 years and a long-term monitoring program is implemented to document these increases. Opportunities to accelerate

natural increases in population number and extent are anticipated by this agreement as BRA will provide funding for or otherwise assist TPWD and USFWS with population augmentation and species reintroduction efforts, and identify stream reaches appropriate for restoration of mussels. To that end, the BRA will work directly with TPWD and USFWS to translocate individuals of Covered Species in the event of a catastrophic drought (worse than the drought of record) and to reintroduce the Covered Species within currently occupied or historically occupied stream reaches, assuming those actions are deemed to be appropriate by TPWD and USFWS at that time. BRA, through its own actions and by engaging willing partners, will work to demonstrate that a net conservation benefit has been realized within 20 years of the execution of this agreement.

1.2 Purpose of this Agreement

The purpose of this agreement is to provide a mechanism for BRA to implement a variety of conservation measures to benefit the Covered Species within the Covered Area. The conservation measures chosen are specifically designed to maintain and/or increase resiliency, redundancy, and representation, providing a net conservation benefit for the Covered Species, while allowing for ongoing and continued water supply development activities to meet the growing demands of an increasing population within the Brazos River basin over the term of the CCAA. Implementation of the conservation strategy and its conservation measures are expected to result in population increases and habitat improvements for the Covered Species over the twenty-year term of the agreement.

Species Status Assessment (SSA)

In October 2018, the USFWS made a draft of the Species Status Assessment Report for the Central Texas Mussels (SSA report) available for peer and partner reviewers. BRA staff provided partner review and participated in the SSA Science Expert meeting in June 2017. The SSA report assessed the current condition of known populations of the Central Texas Mussels, including false spike and Texas fawnsfoot, and ranked each population as Healthy, Moderately Healthy, Unhealthy, or Functionally Extirpated (Table 5.2; p. 73). For the Brazos River basin, one population of false spike (the Little River basin population) was identified and that population considered to be Unhealthy, primarily because few individuals were found during population surveys and because a low number of sites had evidence of reproduction (Table 5.3; p. 74). One goal of this CCAA is to improve the false spike population in the Little River to an overall Moderately Healthy condition, where false spike can be found in approximately half of all appropriate habitats with more than 25 individuals detected in each survey, and where about half of sites have evidence of reproduction (Table 5.2; p. 73). The SSA report similarly assessed the current condition of known populations of Texas fawnsfoot (Table 5.6; p. 91) where the Upper Brazos population was ranked as Unhealthy and the Lower Brazos population was ranked as Moderately Healthy (Table 5.7; p. 92). Another goal of this CCAA is to improve the overall condition of the Upper Brazos population of Texas fawnsfoot to Moderately Healthy and to improve the overall condition of the Lower Brazos population of the Texas fawnsfoot to Healthy (Table 5.7; p. 92). BRA will accomplish these goals by reducing threats to the false spike and Texas fawnsfoot in the Brazos River basin, primarily associated with low flows, reduced substrate suitability, and degraded water quality. BRA will also work with the Service to

augment existing populations and reintroduce populations using captive-reared individuals. A third goal of this CCAA is to work with the USFWS to re-establish at least one population each of the false spike and Texas fawnsfoot in the Brazos River basin. These goals are ambitious and while BRA will strive to reach these goals in cooperation with the USFWS, attainment of these goals is not the only way to demonstrate a net conservation benefit by the end of the 20-year term of the CCAA.

2.0 Authority

Sections 2, 7, and 10 of the ESA, along with the Fish and Wildlife Coordination Act, allow USFWS the authority to enter into this agreement. This agreement is prepared in accordance with the USFWS's 1999 CCAA Final Policy (64 FR 32726) and 2016 revisions to the Candidate Conservation Agreements With Assurances Policy (81 FR 95164), which became effective on March 21, 2017 (82 FR 8540). The authority for this action is the Endangered Species Act of 1973, as amended (16 U.S.C 1531 *et seq.*).

3.0 Covered Species

The conservation measures described in this document are designed specifically to provide a net conservation benefit to the Covered Species, and specific details on the distribution and biology of each of these species are provided below. However, the Covered Species often co-occur with other species of native freshwater mussels which will also benefit from this agreement. The other species of native freshwater mussels known to occur in the Brazos River basin are listed in **Appendix A**. In addition to freshwater mussels, this agreement will also benefit other fish and aquatic species in the basin by preserving habitat, maintaining environmental flows, and supporting appropriate water quality conditions for a healthy aquatic community and riverine ecosystem as a whole.

3.1 False Spike

The False spike *Fusconaia mitchelli* (Simpson in Dall 1896) is a freshwater mussel species endemic to the Guadalupe, Colorado, and Brazos River basins of central Texas (Howells et al. 1996; Howells 2014). False spike is a medium-sized species typically observed at lengths ranging from 50 mm to 75 mm (Howells et al. 1996; Randklev et al. 2013a, b; Randklev et al. 2017a). Shell shape varies from elongate-oval to sub-rhomboidal (Howells 2014). The beak is slightly elevated above the hinge ligament and typically sculptured with multiple strong w-shaped or double-looped bars (Howells et al. 1996; Howells 2014). The shell exterior is often sculptured centrally with pustules and grooves, though absence of disk sculpture is common (Howells et al. 1996; Howells 2014). The posterior ridge is broadly rounded and the posterior field may have corrugations (Howells 2014). Shell nacre is white, with heavy pseudocardinal teeth and light lateral teeth (Howells et al. 1996; Howells 2014).

For over 30 years False spike was believed to be extirpated from the majority of its range or possibly extinct, with no live individuals observed from the late 1970's to early 2010's (Howells 2002; Howells 2003; Randklev et al. 2013a). In 2012, live individuals were collected from the San Saba River (Colorado basin) and the Guadalupe River, confirming the species was still

extant (Randklev et al. 2012; Randklev et al. 2013a, b; Sowards et al. 2013). Since then, recent surveys have also observed live individuals in the Little River basin (Brazos basin), confirming that False spike still persists within all three major river basins (Guadalupe, Colorado, Brazos) where it historically occurred (Randklev et al. 2013b; Randklev et al. 2017a). Currently, the species is known to occur in four distinct areas: the lower Guadalupe River, the Llano River (Colorado basin), the San Saba River (Colorado basin), and the Little River basin (a Brazos River tributary; USFWS 2018).

Historically, within the Brazos basin, False spike shells were documented from the Leon River (Bell and Coryell counties; Strecker 1931; Popejoy et al. 2018) and the mainstem Brazos River (Somervell County; Strecker 1931; Randklev et al. 2017a). Recently, False spike has been observed in the mainstem Little River, with a few live individuals also found in nearby lower Little River tributaries, including the San Gabriel River downstream of Granger Lake, and Brushy Creek near the San Gabriel River confluence (**Figure 1**; Randklev et al. 2013b; Randklev et al. 2017a). However, recent surveys (Bonner et al. 2018) failed to find live individuals at ten sites in the mainstem Little River, suggesting that the species' distribution may be restricted in the Little River basin to near the San Gabriel River (a tributary). Gravid females were observed within the Little River, San Gabriel River, and Brushy Creek (Randklev et al. 2017a), and a sub-adult (>30 mm) was found in Brushy Creek, indicating that recruitment occurs at some capacity in the Little River basin (Randklev et al. 2017a). Although present in the lower Little River basin, False spike has not been documented recently from either of the major Little River tributaries (Leon River and Lampasas River). Randklev et al. (2013c) failed to detect False spike in the Leon River, suggesting that this species may be extirpated from this tributary. Although a recently dead specimen was reported from the Lampasas River in 1980 (Randklev et al. 2017a), there are no recent records of live False spike from the Lampasas River basin.

False spike is most frequently associated with fluvial habitats (Howells 2014), and is most commonly observed in riffles and runs with sporadic observations in other habitats (Randklev et al. 2013b; Mabe & Kennedy 2014; Tsakiris & Randklev 2016a, Randklev et al. 2017a).

Like other native freshwater unionids, False spike parasitize on host fish during the glochidial stage, receiving nutrition and transport from the host until dropping off as fully-developed juveniles (Barnhart et al. 2008; Fritts et al. 2012). Like most *Fusconaia* species, False spike is a short-term brooder that releases glochidia via conglutinate packets during a brief period following glochidia maturation (Dudding et al. 2019). False spike in the lower Guadalupe River have been found gravid from February to June (Dudding et al. 2019). Confirmed hosts include Blacktail Shiner *Cyprinella venusta* and Red Shiner *Cyprinella lutrensis* (Dudding et al. 2019).

Limited information is available on physiological responses and tolerance limits of False spike to variations in water quality. A recent study by Bonner et al. (2018) estimated optimal temperatures for organism growth of 28°C for individuals from the lower Guadalupe River, and the divide between sublethal and lethal thermal stress was estimated at 31°C. An additional study from the lower Guadalupe River tested upper thermal tolerances of False spike, estimating the LT₀₅ (i.e., temperature when 5% of the test individuals died) at about 31°C, and the LT₅₀ (i.e.,

temperature when 50% of the test individuals died) at approximately 33°C (Morton et al. 2018). Similar studies have not been conducted in the Brazos River basin.

Molecular evidence supports genetic isolation between Guadalupe River basin, Colorado River basin, and Brazos River basin populations of False spike, suggesting each basin represents a distinct evolutionarily significant unit. Although there is not enough molecular evidence to support splitting these populations into separate species, genetic isolation observed among drainages suggest that False spike in the Brazos basin should be treated as a separate conservation unit (Pfeiffer et al. 2015). Maintaining representation of False Spike across the three river basins is important for ensuring long-term viability of the species (USFWS 2018).

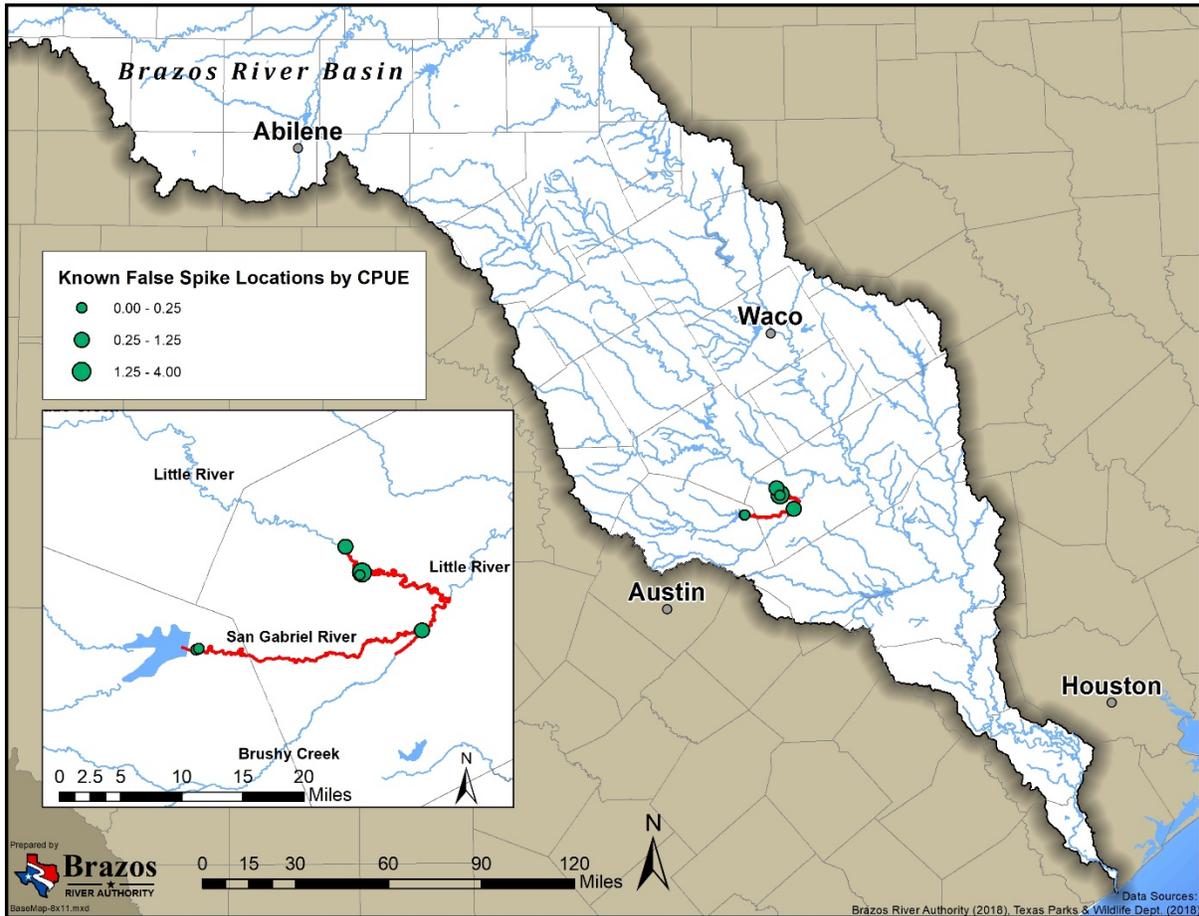


Figure 2. Currently known distribution (occupied stream segments shown in red) and catch-per-unit-effort (CPUE) of False spike within the Brazos River basin.

3.2 Texas Fawnsfoot

The Texas fawnsfoot *Truncilla macrodon* (Lea 1859) is a species of freshwater mussel endemic to the Brazos and Colorado River basins of central Texas (Strecker 1931; Howells et al. 1996; Howells 2014). Recent phylogenetic research suggests that specimens from the Trinity River basin thought to be Fawnsfoot *T. donaciformis* are actually Texas fawnsfoot, extending the species' range further east (Inoue et al. 2017).

Shells are typically small (60 mm or less in length), elongate oval and compressed (Howells et al. 1996; Howells 2014). The beak is above the hinge line with sculpture described as 3-6 single looped concentric ridges, though 1-2 heavier ridges may be present (Howells et al. 1996; Howells 2014). The periostracum is typically light yellow or brown with green rays (Howells et al. 1996; Howells 2014). Similar to other *Truncilla* species, Texas fawnsfoot will often have green rays broken into chevron-like patterns (Howells et al. 1996; Howells 2014). In the shell interior, the nacre is white, pseudocardinal teeth are compressed, and lateral teeth are thin (Howells et al. 1996; Howells 2014).

Within Brazos River basin, historic and zooarchaeological shell records indicate Texas fawnsfoot was widespread (Strecker 1931; Popejoy et al. 2018). The species historically occurred in the mainstem Brazos River (Brazos & Robertson Counties) and in multiple tributaries, including the Leon River (Coryell County), Aquilla Creek (McLennan County), Bosque River (McLennan County), and North Bosque River (McLennan County; Strecker 1931). However, from the time the species was described in 1859 to 2008, only two live specimens were observed, one from the Little Brazos River and one from the mainstem Brazos River. This caused some to question whether viable populations existed (Howells 1996, 1997). However, few extensive surveys were done in this time period and the small size of Texas fawnsfoot allows it to easily go undetected. In 2008, 10 live individuals were observed in the lower Brazos River (Grimes & Washington Counties) and a population was also discovered in the lower Colorado River (Burlakova & Karatayev 2010; Randklev et al. 2010). Since then, the species has been documented at multiple other locations (Johnson and Groce 2012; Randklev et al. 2014a, b; Randklev et al. 2017a, b; TxDOT 2017; Khan et al. 2018; Bonner et al. 2018). Texas fawnsfoot is currently thought to occur in seven distinct areas: the lower Colorado River, the lower San Saba River and nearby stretches of the middle Colorado River, the lower Brazos River and nearby segments of some tributaries (lower Little River, lower Navasota River), the middle Brazos River between Possum Kingdom Reservoir and Lake Granbury, the Clear Fork Brazos River, the middle Trinity River, and the East Fork of the Trinity River (USFWS 2018).

Within the Brazos River basin, recent survey efforts have found Texas fawnsfoot to occur in multiple locations within the three general reaches identified above (**Figure 2**; Karatayev & Burlakova 2008; Randklev et al. 2009; Randklev et al. 2014a, b; Tsakiris & Randklev 2016b; Khan et al. 2018, Bonner et al. 2018). In the Clear Fork Brazos River, 223 recently dead (i.e., nacre still fresh) shells and one live individual were collected during the drought of 2011 near Fort Griffin (HDR 2012). However, surveys at Fort Griffin and two other sites on the Clear Fork in 2017 found only one live mussel and failed to collect any live Texas fawnsfoot, calling into question the status of this population (Bonner et al. 2018). In the middle Brazos River between

Possum Kingdom and Lake Granbury, Khan et al. (2018) observed Texas fawnsfoot as the most abundant mussel species present, although overall abundance and diversity of mussels was rather low. Bonner et al. (2018) found 1 live juvenile in this reach, suggesting that recruitment is occurring in this stretch. In the lower Brazos River between Waco and Sealy, Texas fawnsfoot was sporadically found, but the species was relatively abundant in some locations (Randklev et al. 2014a, b). It was also observed the Little River upstream of the San Gabriel River confluence and the lower Navasota River in close proximity to the Brazos River confluence (Randklev et al. 2017a, Khan et al. 2018).

Habitat utilization of Texas fawnsfoot appears to be variable with individuals found in a variety of habitat types. In the middle Brazos River and Little River, Texas fawnsfoot has been most frequently observed in riffle habitats (Randklev et al. 2014a, b; Randklev et al. 2017a; Khan et al. 2018). In the lower Brazos River, the species is associated with substrates dominated by pebble or gravel and most frequently observed in deep banks, though observations also occurred in point bar and backwater habitats (Randklev et al. 2014a, b). In the lower Colorado River, Texas fawnsfoot were most commonly found in run edge habitats (Bonner et al. 2018). In the Trinity River, this species was observed in bank and riffle habitats (Randklev et al. 2017b).

Little is known regarding the life history requirements of Texas fawnsfoot (Howells 2014). They are presumed to have a similar reproductive cycle to other *Truncilla* species, which are long-term brooders that parasitize solely on Freshwater Drum *Aplodinotus grunniens* to complete their life cycle (Howells 2014; Barnhart et al. 2008).

Molecular evidence indicates genetic isolation among drainages, and the existence of three separate evolutionarily significant units, which supports that Texas fawnsfoot in the Brazos River basin should be considered a separate conservation unit from the Colorado and Trinity River basins (Inoue et al. 2017). Maintaining representation of Texas fawnsfoot across the three river basins is important for ensuring long-term viability of the species (USFWS 2018).

Map showing the currently known distribution of the Texas Fawnsfoot in the Brazos River between Possum Kingdom Reservoir and Lake Granbury, the Brazos River south of the City of Waco to the City of Richmond, the Little River from the FM 1915 crossing downstream to the confluence with the San Gabriel River, and the Navasota River from the confluence with Gibbons Creek to the confluence with the Brazos River.

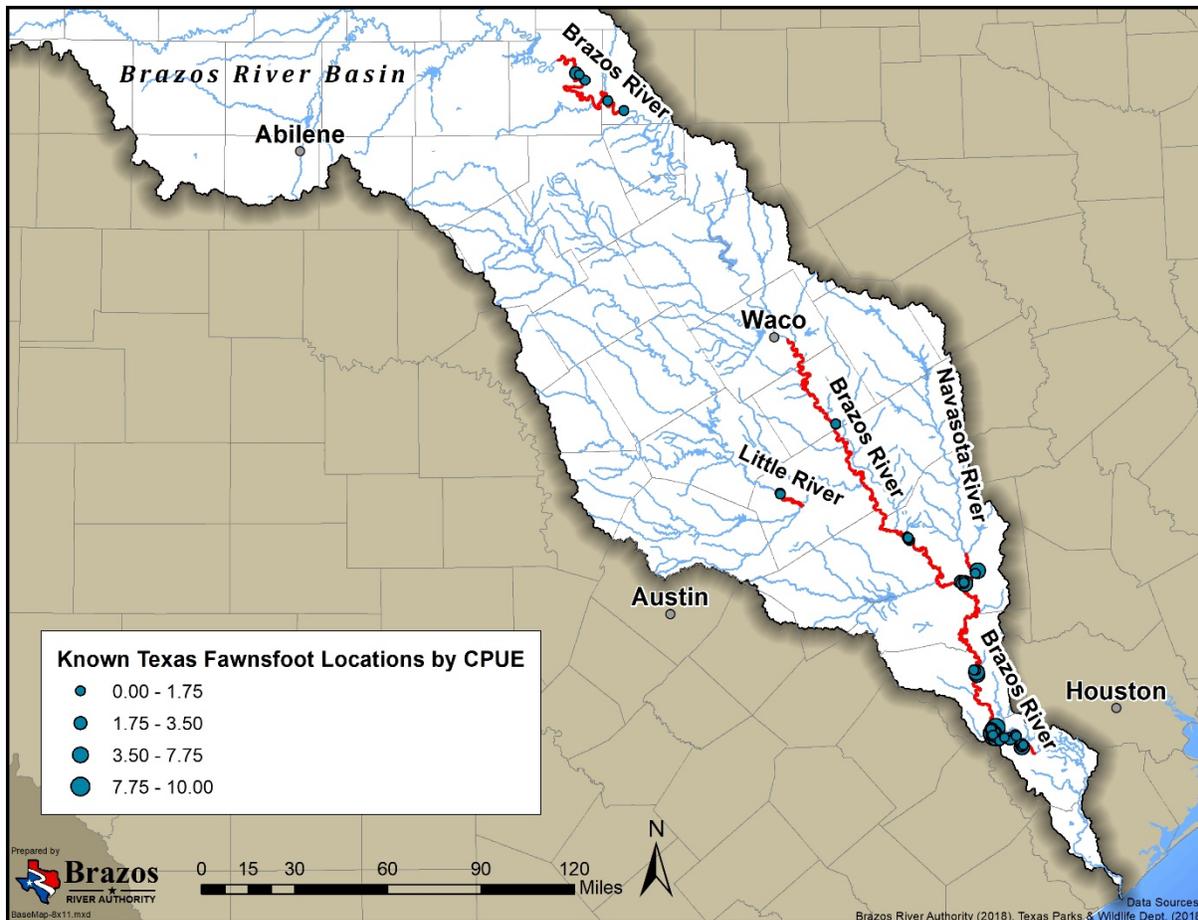


Figure 3. Currently known distribution (occupied stream segments shown in red) and catch-per-unit-effort (CPUE) of Texas fawnsfoot within the Brazos River basin.

4.0 Threats

4.1 Degradation, Loss, and Fragmentation of Habitat

A variety of natural and anthropogenic factors can lead to degradation, loss, or fragmentation of habitat for the Covered Species. Factors influencing water quality and quantity have the potential to degrade mussel habitat, as described in Section 4.2. Sedimentation from runoff and erosion can alter substrate conditions and lead to degradation of mussel habitat. Inundation by reservoirs or desiccation during drought conditions can lead to loss of habitat. Finally, fragmentation can occur as mussel populations become separated by dams or expanses of poor habitat. Such fragmentation can restrict gene flow and result in genetic isolation of previously connected populations.

4.2 Water Quantity

The increase in human demand for water resources has resulted in the modification of riverine systems through groundwater pumping, construction of reservoirs, surface water diversions, and discharges. Resulting alterations to the natural flow regime may change the magnitude, frequency, duration, timing, and flashiness of a river or stream (Poff et al. 1997), thus changing

the temporal and spatial distribution of water quantity and influencing instream organisms such as freshwater mussels.

Large reservoirs typically result in changes to the natural hydrology which include: decreases in peak discharges, increases in minimum flows, increases in base flow levels, and alterations to the timing of low and high flow events (Zhang and Wurbs 2018; Graf 2006; Kondolf and Batalla 2005; Magilligan and Nislow 2005; Wellmeyer et al. 2005). The Brazos basin currently contains 17 major reservoirs for flood control and water supply (Brazos BBEST 2012) and hundreds of surface water diversions, which both influence the distribution and availability of water. As in other areas, post-reservoir hydrology data from the lower Brazos River basin indicate increased base flows, reductions in the duration of extreme low flow events, and reductions in the overall magnitude of high flow pulses (BRA unpublished data). These conditions could potentially have positive influences on mussel communities by preventing desiccation during drought conditions and preventing displacement during extreme high flow events. However, altered hydrology can also negatively impact mussel populations. High water velocities associated with increased base flows can potentially displace settling juveniles before they can establish (Layzer and Madison 1995). Altered hydrology can also lead to changes in bedload movement and sediment scour, displacing juvenile mussels (Layzer et al. 1993). Changes to basic water chemistry, such as temperature, resulting from reservoir releases may also limit mussel reproduction (Layzer et al. 1993). Additionally, deviations to the timing of high and low flows may prevent the presence of the required host fish species during mussel reproductive seasons (Freeman & Marcinek 2006; Gido et al. 2010).

4.3 Water Quality

Anthropogenic activities that alter flow regimes and landscapes may exacerbate natural fluctuations in water quality, and thus influence survival, growth, and reproduction of freshwater mussels (Strayer 2008). Reductions in surface flows have been shown to elevate surface water temperatures and reduce dissolved oxygen concentrations, which may result in high mussel mortality (Gagnon et al. 2004; Golladay et al. 2004; Haag & Warren 2008). Moreover, drought conditions have been shown to cause gravid females to abort immature glochidia, limiting reproductive output, and potentially causing recruitment failure (Aldridge & McIvor 2003).

The input of excess ammonia and nutrients (e.g., nitrate, total phosphorus) also pose a threat to freshwater mussel persistence. In the Brazos basin, the percent of cultivated land at the reach scale and the percent of urban land at the catchment scale have been associated with increased instream nutrient concentrations (Becker et al. 2014). Exposure to elevated levels of ammonia can have lethal and sublethal effects on juvenile mussels and has been implicated as one of the main contributors to the overall decline of mussels throughout North America (Strayer et al. 2004; Newton & Barsch 2007; EPA 2013). This observed sensitivity to ammonia caused the Environmental Protection Agency (2013) to consider the physiological tolerances of mussels when recommending aquatic life criteria for acute (1-hour average: 17 mg TAN/L) and chronic (30-day rolling average: 1.9 mg TAN/L) exposure to ammonia. In addition to surface runoff, return flows from various entities such as waste water treatment plants may result in elevated nutrient loading to rivers and lakes. Elevated levels of ammonia and nitrate directly downstream

of a wastewater treatment plant in the Grand River, Ontario, Canada has been associated with the extirpation of mussel populations in large sections downstream of the treatment plant (Gillis et al. 2017).

Another water quality issue in the Brazos River basin is the presence of Golden algae. Golden algal blooms produce toxins fatal to various aquatic biota and resulted in multiple fish kills from 2000-2012 in the stretch of river from Possum Kingdom Reservoir downstream to Lake Whitney (Patiño et al. 2014). While Golden algae events do occasionally occur within the reservoirs, there have been no documented Golden algae events in the river since 2012. In addition to fish, these toxic algal blooms may influence freshwater mussels in these areas, although specific data on the effects to freshwater mussel populations is lacking.

4.4 Runoff and Erosion

The landscape within a watershed has a strong influence on channel morphology and hydrodynamics of lotic systems (Brim-Box & Mossa 1999; Newton et al. 2008). Alterations to the landscape (e.g., urbanization, agriculture) have been shown to increase runoff and erosion, which are major contributors to excess fine sediment inputs in river systems (Brim-Box & Mossa 1999). Sedimentation has been shown to negatively impact unionids as well as the ecological integrity of streams, including changes in stream geomorphology, water quality, and reductions in substrate complexity (Poff et al. 1997; Brim-Box & Mossa 1999). Much of the landscape in the Brazos River basin has been modified into rangeland (57%), cropland (24%), and urban development (16%; Dahm et al. 2005). Excess fine sediment inputs have been documented in the Brazos River basin (Dunn and Raines 2001) and pose a potential threat to the Covered Species.

Along with landscape alterations, in-channel modification can alter flow regimes and thus patterns of sediment deposition and scour (Petts 1980; Ligon et al. 1995; Baxter 1997). The Brazos basin currently contains 39 reservoirs with storage capacities of 5,000 acre-feet or greater (Vogl and Lopes 2009). Elevated base flows from dam releases can cause bed scour, which channelizes the river and decreases habitat diversity (Poff et al. 1997). Channelization can also lower the base level of a river and initiate upstream erosion (i.e., head-cutting; Shields et al. 2000).

4.5 Barriers to Dispersal

Dispersal is dependent on movement of host fish and serves several important functions such as connecting subpopulations within the occupied range of a species or allowing a species to move into formerly uninhabited areas (Strayer 2008). Degradation and loss of habitat due to anthropogenic actions may lead to large sections of unsuitable mussel habitat, thus reducing dispersal success (Strayer 2008). Dams can act as permanent barriers to host fish movement, and hydroelectric dams may impinge or entrain hosts and result in mortality (Watters 1996; Newton et al. 2008; Rytwinski et al. 2017). Barriers to dispersal pose a threat to the Covered Species and may prevent intrapopulation connectivity and range expansion.

4.6 Overutilization

Commercial harvest historically influenced freshwater mussels throughout North America and was common in Texas during the 20th century (Howells et al. 1996; Haag 2012). However,

currently minimal commercial harvest occurs in Texas. Additionally, harvest is prohibited in some areas identified as mussel sanctuaries by TPWD (Howells 2014). One of these mussel sanctuaries occurs in the Brazos River basin and includes the Brazos River from the dam at Possum Kingdom Reservoir in Palo Pinto County downstream to FM 2580 in Parker County (31 TAC 57.157), a reach of river included in this CCAA. Recreational fishermen sometimes use the soft tissues of mussels as bait. Although the exact level of harvest for bait is unknown (Howells 2014), it is expected to be minimal. The collection of mussels for scientific studies has also been suggested as contributing to the threat of overutilization of freshwater mussels in Texas (USFWS 2018).

4.7 Exotic Species

In the Brazos River basin, the Asian clam *Corbicula fluminea* has been well established for an extended period of time (Fontanier 1982; Karatayev et al. 2005). This species competes with native mussels for space and food (Strayer 1999; Vaughn & Spooner 2006; Ferreira-Rodriguez et al. 2018). Moreover, Asian clams are sensitive to rapid increases in temperature, resulting in mass die offs which have been shown to cause spikes in ammonia concentrations, a known stressor to native mussels (Cherry et al. 2005; Cooper et al. 2005; Newton & Barsch 2007).

The Zebra mussel *Dreissena polymorpha* has been recently introduced to Texas and is currently found in 5 river basins, including the Brazos (TPWD 2019). In the Brazos basin, this invader was first discovered in Lake Belton (Leon River) in 2013 and has since been found in Lake Georgetown, Stillhouse Hollow Lake, and Granger Lake. It is also present in the river systems downstream of these lakes including the Lampasas, Leon, and Little River (TPWD 2019; Bonner et al. 2018). Dreissenid mussels can cause major abiotic alterations in freshwater ecosystems and have had large impacts on aquatic organisms such as freshwater mussels (Baker & Levinton 2003; Burlakova et al. 2014). Like Asian clams, Zebra mussels compete for space and food with native mussels and also has been found aggregated on the posterior end of mussels, preventing the ability of the native mussel to filter, leading to mortality (Nichols & Wolcox 1997; Baker & Levinton 2003). Typically, dreissenid mussels densely colonize slow moving areas of lakes and reservoirs, but do not form dense aggregations in swift flowing river environments. As a result, Zebra mussels are not currently considered a major threat to riverine systems (Karatayev et al. 2017) because they are generally not found in flowing water habitats characteristic of the Covered Species. Since Zebra mussels have invaded certain areas occupied by the Covered Species, continued monitoring is important to evaluate the long-term impacts of this invasive species.

4.8 Climate Change

The ramifications of climate change are expected to intensify several of the threats mentioned above (Wuebbles et al. 2013). Future climate projections predict an increase in annual temperatures throughout the Southwestern United States, with the number of hot days (> 95° F) in Texas expected to double by 2050 (Kinniburgh et al. 2015). Additionally, precipitation patterns are expected to become more variable, with more intense precipitation events and longer dry periods in between (Kloesel et al. 2018). This will result in more soil moisture stress and influence both surface water and groundwater recharge (Loaiciga et al. 2000; Mace & Wade

2008; Taylor et al. 2012; Kloesel et al. 2018). Climate change combined with expected increased utilization of groundwater resources may result in increased drought frequency and intensity within the Brazos basin (Wuebbles et al. 2013).

5.0 Covered Area

As a Special District of the State of Texas, the BRA is tasked with developing, managing, and protecting the water resources of the Brazos River Basin. For the purposes of this CCAA, the Covered Area is defined as properties owned by the BRA along with areas of the BRA's water supply system (System) within the Brazos River basin (**Figure 3**). The current System includes the three reservoirs BRA owns and operates, Possum Kingdom Lake, Lake Granbury, and Lake Limestone, and conservation storage space in eight U.S. Army Corps of Engineers (USACE) reservoirs, Lakes Proctor, Belton, Stillhouse Hollow, Georgetown, Granger, Somerville, Whitney, and Aquilla. Infrastructure currently associated with BRA's raw water supply operations include the System reservoirs, the East Williamson County drinking water intake structure on Lake Granger, and the Williamson County Regional Raw Water Line (WCRRWL) connecting Lake Stillhouse Hollow to Lake Georgetown. A currently proposed water supply pipeline (Bel-House Connector) will also connect Lake Belton to Lake Stillhouse Hollow. Additionally, BRA has only just recently incorporated groundwater into its formerly all surface water-based System, with the completion of a well into the Trinity Aquifer in east Williamson County.

The Covered Area will include the stream reaches below System reservoirs and associated infrastructure described above (**Figure 4**). Possum Kingdom Reservoir represents the upstream-most BRA-operated infrastructure in the Brazos River basin, and the current Water Management Plan (WMP) focuses on operations of the water supply infrastructure from this point downstream. Brazos River Authority has no infrastructure and limited interests above Possum Kingdom reservoir, and therefore, has no way to directly influence freshwater mussel populations or their habitats in this portion of the basin.

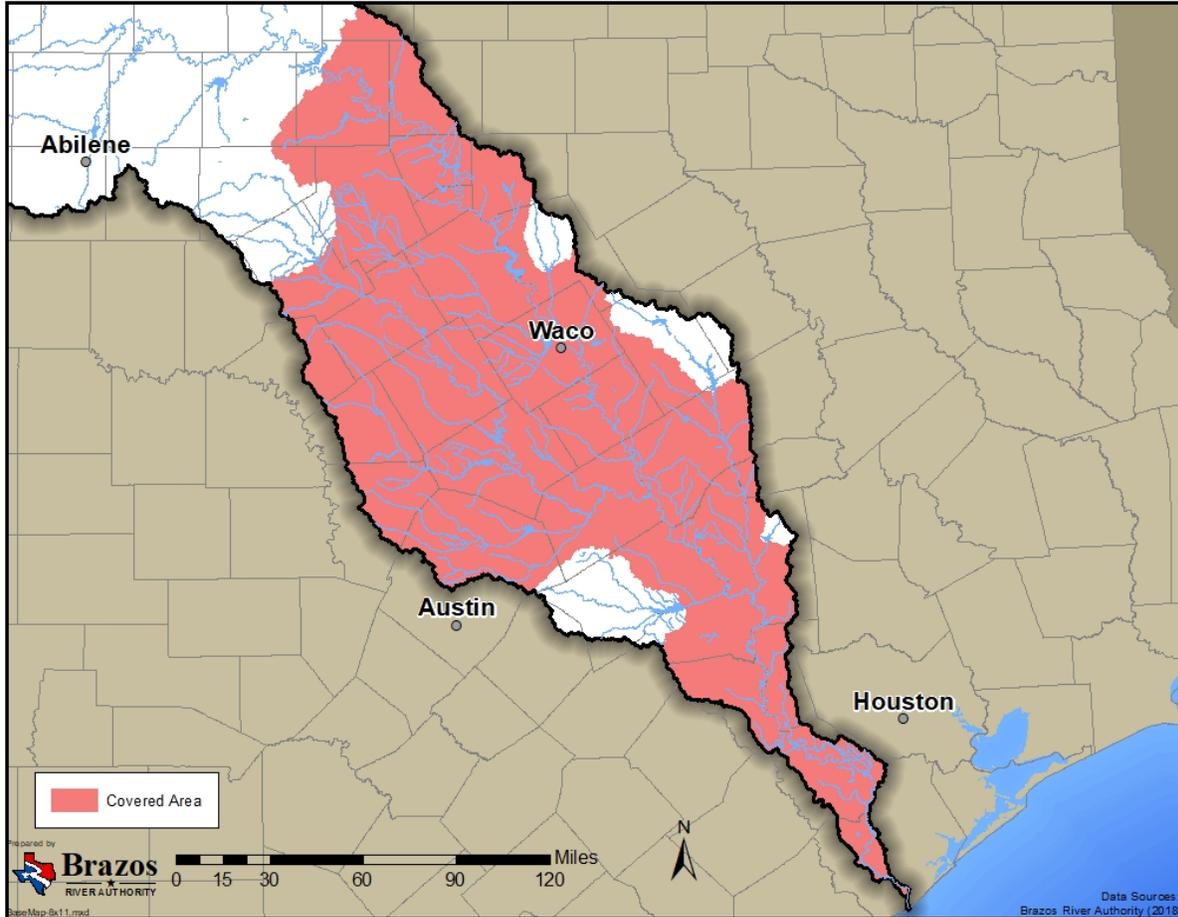


Figure 4. Covered Area.

6.0 Conservation Strategy

The conservation strategy used in this document is based on the Freshwater Mollusk Conservation Society’s National Strategy for the Conservation of Native Freshwater Mollusks (FMCS 2016). This publication outlines 10 issues considered as top priorities for freshwater mollusk conservation. **Table 1** provides a list of the 10 issues outlined in the national strategy, a summary of the goals provided in the strategy, and a summary of how the specific conservation measures outlined in this document address each goal, with respect to the Covered Species and their habitats as they occur in the Covered Area.

Although the conservation measures outlined below correspond well with each of the 10 issues identified in the national conservation strategy, they were further refined to address specific threats to the Covered Species in the Brazos River basin. These threats are summarized in Section 4.0. **Table 2** provides a list of the threats identified, the conservation measures that address each threat, and the anticipated results. Additional details on specific conservation measures can be found in Section 9.0.

To assist in guiding implementation of conservation measures, the Covered Area was split into Mussel Conservation Zones based on the current occurrence and abundance of freshwater

mussels, as outlined in Section 7.0. Resulting Mussel Conservation Zones allowed for prioritizing specific conservation activities to target key mussel populations. This prioritization, along with future refinements made during the adaptive management process, will help ensure efficient and effective contributions to achieving a substantial net conservation benefit for the Covered Species over the 20-year term of the CCAA and permit.

Lastly, as summarized in Section 8.0, hydrologic modeling was conducted to evaluate future risk of low-flow impacts throughout the Covered Area. The hydrologic modeling approach considers multiple future water-use scenarios defined by regional water planning groups and the BRA, and represents the best estimated projection of water management during the permit period. This allowed for further refinement of conservation measures to prioritize conservation activities in areas of greatest future risk based on projected future water availability. Thus, hydrologic modeling critically informs the BRA in managing its conservation measures and other activities to offset possible future threats to the Covered Species in the Covered Area. Hydrologic modeling will inform conservation actions to be implemented as part of a comprehensive adaptive management program designed to reduce threats associated with critical low flows during times of drought over the 20-year term of the CCAA. The hydrologic modeling will inform how BRA manages its system of reservoirs to supply surface water to downstream customers, while providing for environmental flow needs of the Covered Species.

Table 1. Issues and conservation goals identified in the Freshwater Mollusk Conservation Society’s National Strategy for the Conservation of Native Freshwater Mollusks (FMCS 2016), along with a brief description of how conservation measures from the Brazos River basin CCAA address identified conservation goals.

Issues	Goals	Conservation Measure	How Measure Addresses Goals
1. Increase knowledge of the distribution and taxonomy of mollusks at multiple scales over time and make that information available.	Understand the status and trends of mollusk populations to better manage and conserve.	Informative Field Investigations and Modeling	Surveys will help fill data gaps in distributional information.
		Long-term Monitoring	Long-term monitoring will assess trends in existing populations over time.
2. Address the impacts of past, ongoing, and newly emerging stressors on mollusks and their habitats.	Minimize threats to mollusks and their habitats.	Informative Field Investigations and Modeling	Future drought scenario modeling will identify spatial and temporal patterns in drought risk to mussel populations and assist in prioritizing conservation actions.
		Environmental Flow Protection	Promotes flow conditions adequate for survival and long-term persistence of Covered Species and strives to assure water quantity.
		Avoidance	Avoids detrimental activities in areas of optimal habitat for Covered Species and prevents further fragmentation.
		Applied Research	Aids in identifying habitat, water quality, and flow-related stressors important in structuring populations of Covered Species and will be used to guide adaptive management.
3. Understand and conserve the quantity and quality of suitable habitat for mollusks over time.	Increase understanding of physical, chemical, and biological characteristics of habitat to support sustainable assemblages of mollusks.	Informative Field Investigations and Modeling	Future drought scenario modeling will identify spatial and temporal patterns in drought risk to mussel populations and assist in prioritizing conservation actions.
		Applied Research	Aids in identifying habitat, water quality, and flow-related stressors important in structuring populations of Covered Species. This information will be used to guide adaptive management.
		Long-term Monitoring	Habitat utilization surveys will assist in understanding habitat requirements of the Covered Species. This data will be essential to the adaptive management process.
		Avoidance	Conserves habitat through avoidance of detrimental activities in areas of optimal habitat.

Table 1. Continued.

Issues	Goals	Conservation Measure	How Measure Addresses Goals
4. Understand the ecology of mollusks at the individual, population, and community levels.	Increase fundamental knowledge of the biology of mollusks so managers can more effectively conserve them.	Applied Research	Proposed applied research studies will increase the knowledge on the biology of Covered Species at the individual and population level.
		Long-term Monitoring	By evaluating population trends in response to various environmental factors, long-term monitoring will provide data on the ecology of Covered Species.
5. Restore abundant and diverse mollusk populations until they are self-sustaining.	Conserve and restore viable populations and communities of mollusks.	Long-term Monitoring	Population demographic data from long-term monitoring will assist in determining if populations are self-sustaining.
		Applied Research	Reintroduction cage studies will evaluate areas suitable for reintroduction of Covered Species.
		Captive Propagation	Should restoration or supplementation of existing populations be desired, successful captive propagation of Covered Species is necessary to supply organisms.
6. Identify the ecosystem services provided by mollusks and their habitats.	Improve science-based consideration of the social and economic values of mollusk communities and functioning aquatic systems.	Communication / Education / Outreach	Education and outreach activities will highlight the ecosystem services of freshwater mussels and the social and economic value of functioning aquatic systems.
7. Strengthen advocacy and build support for the conservation of mollusks and their habitats.	Increase information sharing and communication among citizens and decision-makers at multiple levels regarding conserving mollusk resources.	Communication / Education / Outreach	Information sharing will occur with state and federal agency personnel through an interagency workgroup, and communication with the public will occur through education and outreach opportunities.
8. Educate and train the conservation community and future generations about the importance of mollusks to ensure conservation efforts continue into the future.	Provide a suite of training opportunities to the greater conservation community, and inspire future generations to work on the conservation of mollusks.	Communication / Education / Outreach	Education and outreach activities will include presentations of conservation accomplishments to the greater conservation community and will also focus on educating youth and young professionals about mussel conservation through social media and other avenues.

Table 1. Continued.

Issues	Goals	Conservation Measure	How Measure Addresses Goals
9. Seek consistent, long-term funding to support mollusk conservation efforts.	Increase funding for mollusk conservation.	Commitment of long-term funding provided by BRA to support this CCAA.	This agreement represents an example of long-term funding by BRA to support mollusk conservation.
10. Coordinate a national strategy for the conservation of mollusk resources.	Increase coordination and information sharing among local, state, national, and international partners in conserving mollusk resources.	Communication / Education / Outreach	Coordination with state and federal agency personnel will occur through and interagency workgroup. Conservation successes of the program will be communicated to national partners in mollusk conservation.

Table 2. Threats to the Covered Species, conservation measures, and a description of how each measure addresses threats.

Threats	Conservation Measures	How Measures Address Threats
Degradation, Loss, and Fragmentation of Habitat	Field Investigations and Modeling	Ongoing survey work will fill data gaps and better define occupied habitat. Hydrologic modeling will identify areas at risk of habitat loss and or fragmentation under future water management scenarios. This information will be used in the adaptive management process to guide on the ground management activities.
	Environmental Flow Protection	Meeting environmental flow standards will preserve available habitat and decrease fragmentation. Flow balancing and flood releases will be evaluated to reduce impacts to mussel habitat, where possible.
	Avoidance	Avoidance of key areas will preserve high quality habitat.
	Applied Research	Habitat quantification tool will aid in identifying key habitat requirements. Studies to evaluate reintroduction opportunities expected to promote expansion of occupied habitat and increases in population numbers.
	Long-term Monitoring	Long-term monitoring of mussels, host fish, water quality, and sediment/channel morphology will assist in identifying trends in habitat availability and population numbers.
Water Quality and Quantity	Field Investigations and Modeling	Drought scenario modeling will identify areas at risk of water quantity issues under future scenarios.
	Environmental Flow Protection	Meeting environmental flow standards will support adequate water quality and quantity, thereby supporting maintenance and expansion of populations and habitats.
	Applied Research	Physiological tolerance research will identify water quality thresholds for Covered Species important in managing water quality. Development of environmental flow methodologies specific to mussels will assist in managing water quantity. Groundwater-surface water interaction studies will assist in understanding the interaction between alluvium and surface flows. This information will help inform management to offset possible risks to populations and habitats and identify opportunities for restoration.
	Long-term Monitoring	Long-term monitoring of water quality conditions, in combination with physiological tolerance studies, will assist in managing water quality to support Covered Species and habitats.
	Communication / Education / Outreach	Educating customers and the public about water conservation through outreach opportunities will assist in maintaining water security into the future.

Table 2. Continued

Threats	Conservation Measures	How Measures Address Threats
Runoff and Erosion	Environmental Flow Protection	Flood releases will be evaluated to reduce excessive erosion and bank-sloughing downstream.
	Avoidance	Any necessary intake structures will be designed and operated to minimize hydraulic/river bed disturbance.
	Long-term Monitoring	Long-term monitoring of substrate and channel morphology transects will aid in identifying and managing erosion issues.
	Communication / Education / Outreach	Outreach opportunities to educate landowners about best management practices will help reduce runoff and erosion from upland areas.
Barriers to Dispersal	Environmental Flow Protection	Meeting environmental flow standards will minimize fragmentation of habitats and promote population expansion.
	Avoidance	Additional dams will be avoided on the mainstem Brazos, Navasota, and Little Rivers to prevent additional barriers to dispersal.
	Captive Propagation	For populations separated by barriers, developing captive propagation techniques can eventually provide organisms to augment existing populations and/or expand the distribution of the Covered Species. BRA will support and assist TPWD and USFWS with reintroductions of the Covered Species, assuming such actions are deemed to be appropriate by TPWD and USFWS at that time.
Overutilization	Communication / Education / Outreach	Coordinating with Interagency Workgroup will prevent overexploitation of key populations, and encourage collaboration among researchers.
Exotic Species	Communication / Education / Outreach	Outreach will educate the public about the negative impacts of zebra mussels and the proper techniques to prevent their transportation. An established education and outreach program will help prevent future invasions of exotic species.
	Long-term Monitoring	Long-term monitoring of zebra mussel occurrence, in streams, will assist in understanding their current distribution in relation to the Covered Species, and help determine what threats, if any, are posed by zebra mussels to Covered Species. Identified threats will be addressed in coordination with USFWS through the adaptive management program.

7.0 Conservation Zones

To prioritize specific portions of the Covered Area in relation to the current status and distribution of Covered Species and other freshwater mussels, Mussel Conservation Zones were developed. These zones were developed in coordination with USFWS biologists and are based on the best currently available data on occurrence and abundance of freshwater mussels within the Covered Area. Five zones (A-E) were delineated to categorize conservation priority for the Covered Species and other freshwater mussels (**Figure 4**). Boundaries were selected to encompass known occurrences and zones were stratified by abundance in some instances. The metrics used in classification of Mussel Conservation Zones, and exact boundaries of each zone, are outlined in detail below. In application, activities near zone boundaries will include consideration of impacts to downstream zones, where appropriate. Applying adaptive management principles, conservation zones will be updated as additional data collection informs our understanding of Covered Species distributions.

Zone A

Zone A is defined as all stream reaches where False spike is currently known to be present within the Covered Area. False spike has a limited distribution within the Brazos River basin and is relatively rare where it occurs. Therefore, areas where this species occur are of highest conservation priority and will be included in avoidance/minimization zones as outlined in Section 9.4. It should be noted that Texas fawnsfoot is also present in portions of this zone within the mainstem Little River.

Zone A includes portions of the Little River, San Gabriel River, and Brushy Creek in Milam and Williamson counties (**Figure 5**). In the Little River mainstem, Zone A extends for approximately 20.7 stream miles from the FM 1915 crossing on the Little River in Milam County downstream to the confluence of the Little River and San Gabriel River in Milam County. In the San Gabriel River, it extends for 32.8 stream miles from Granger Lake Dam in Williamson County downstream to the confluence of the San Gabriel River and Little River in Milam County. In Brushy Creek, Zone A extends for 3.0 stream miles from the FM 908 crossing downstream to the confluence of Brushy Creek and the San Gabriel River, all within Milam County. In total, Zone A covers approximately 56.4 stream miles within these three streams.

Zone B

Zone B is defined as stream reaches where Texas fawnsfoot is most abundant. Since Texas fawnsfoot is more widely distributed within the Covered Area, abundance was used to stratify conservation priority within the species' range.

Zone B includes portions of the mainstem Brazos River and Navasota River in Brazos, Grimes, Washington, Waller, Austin, and Fort Bend counties (**Figure 6**). In the mainstem Brazos River, Zone B extends 153.9 stream miles from the confluence of Yegua Creek in Washington County downstream to the FM 723 crossing in Fort Bend County. In the Navasota River, Zone B includes 27.7 stream miles from the confluence with Gibbons Creek in Brazos/Grimes County to the confluence with the mainstem Brazos River in Washington/Grimes County.

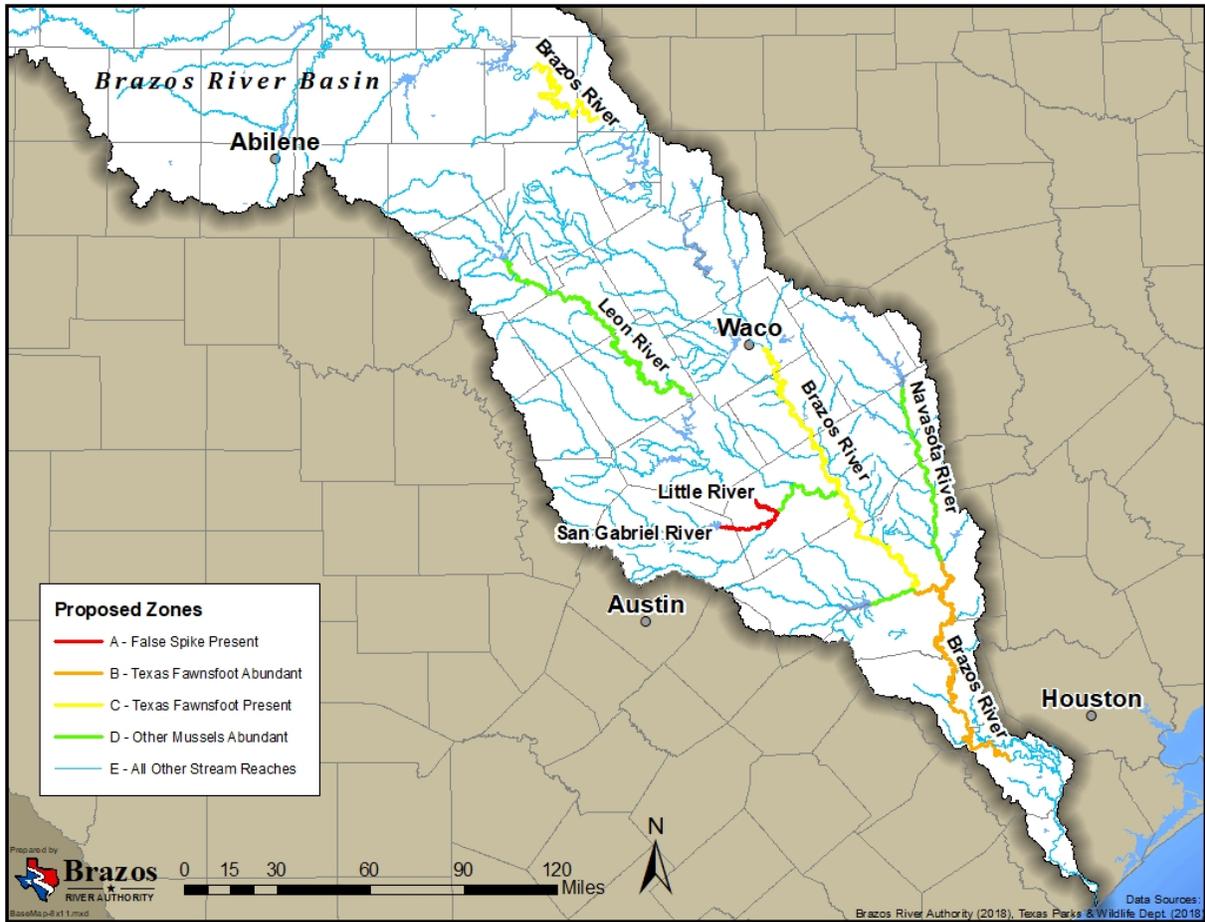


Figure 5. Map of the five proposed Mussel Conservation Zones within the Covered Area.

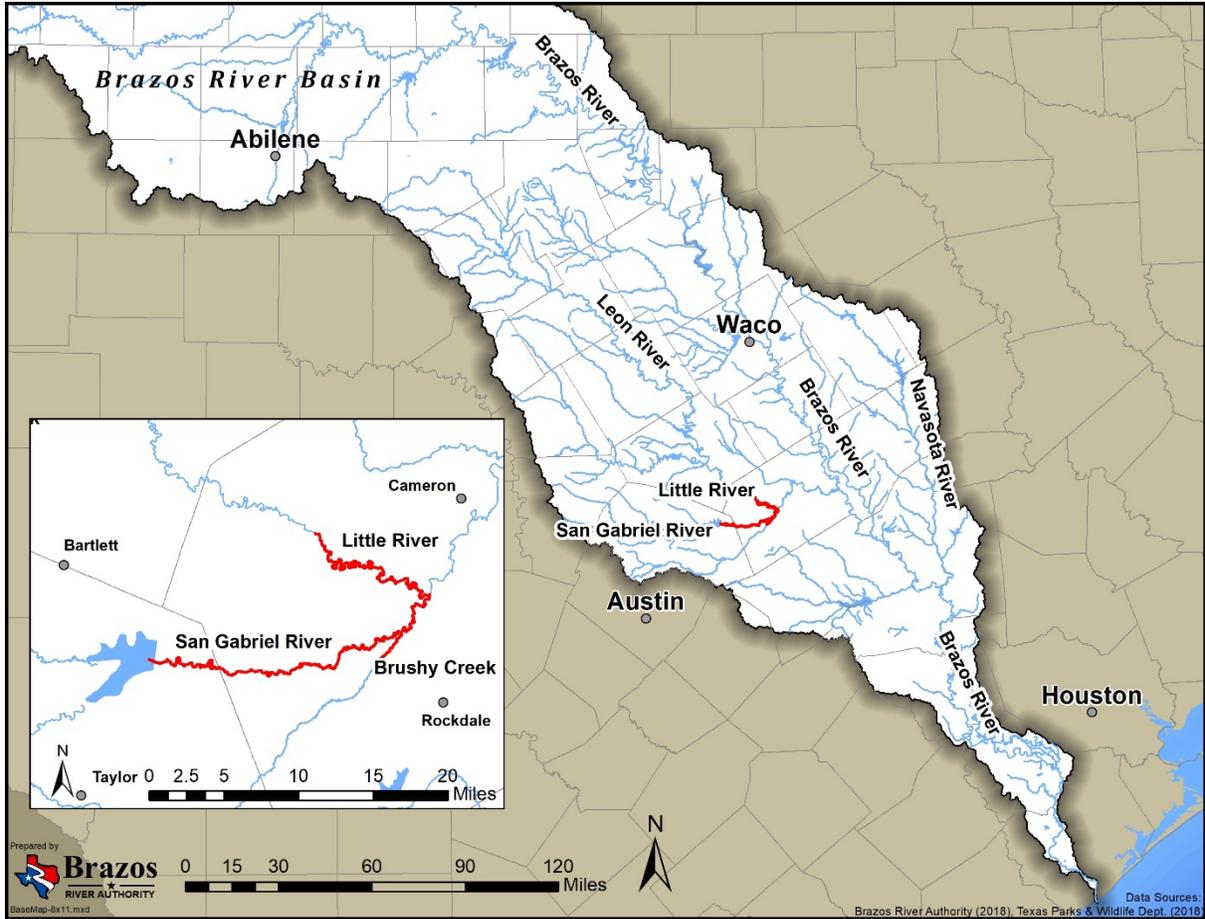


Figure 6. Mussel Conservation Zone A, defined as areas where False spike is present.

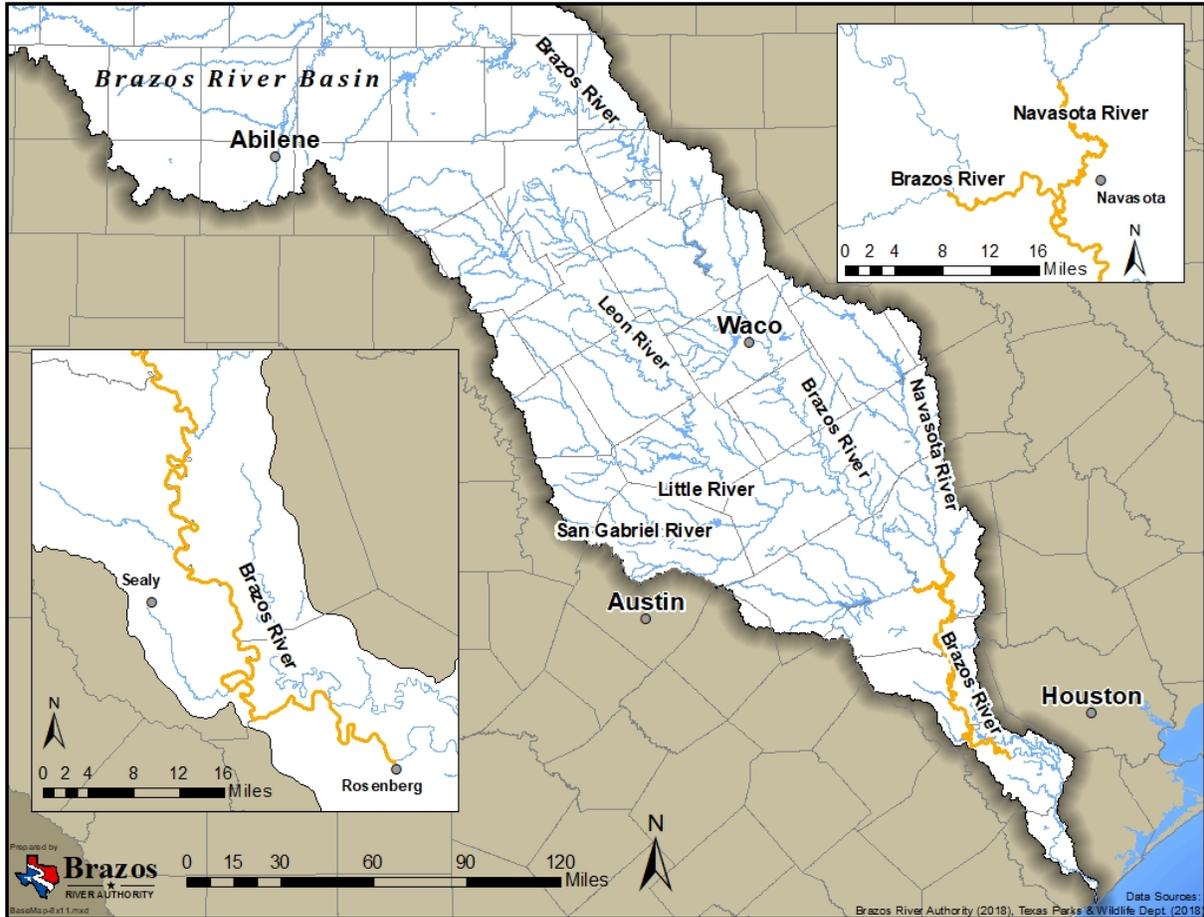


Figure 7. Mussel Conservation Zone B, defined as areas where Texas fawnsfoot is most abundant.

Zone C

Zone C is defined as stream reaches where Texas fawnsfoot is present, but not as abundant as in Zone B, or where abundance data is lacking. Portions of Zone C include Texas fawnsfoot populations which are isolated by reservoirs, and therefore, are of high conservation concern. Given differences in population abundance and isolation, conservation actions may differ between Zone B and Zone C.

Zone C includes portions of the lower Brazos River mainstem in McLennan, Falls, Milam, Robertson, Burleson, and Brazos counties, as well as portions of the middle Brazos River mainstem in Palo Pinto and Parker counties (**Figure 7**). In the lower Brazos River, Zone C extends 166.3 stream miles from the SH 6 crossing in McLennan County downstream to the confluence of Yegua Creek and the Brazos River mainstem in Burleson/Brazos counties. In the middle Brazos River mainstem, Zone C extends 79.9 stream miles from FM 4 in Palo Pinto County downstream to FM 1189 in Parker County.

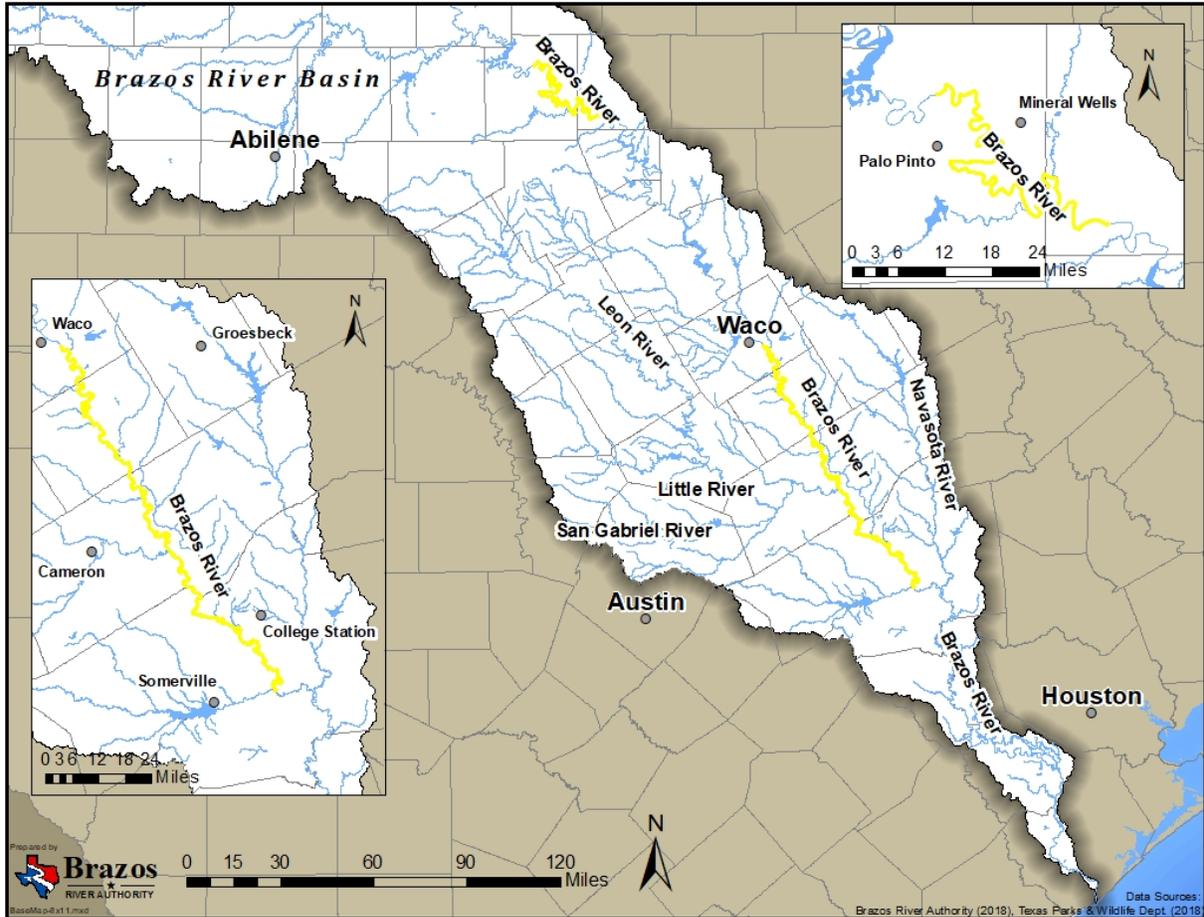


Figure 8. Mussel Conservation Zone C, defined as areas where Texas fawnsfoot is present but not abundant, or where abundance data is lacking.

Zone D

Zone D is defined as stream reaches where Covered Species are absent, but substantial freshwater mussel populations currently exist. Although these mussel populations are of lower conservation priority because the Covered Species are not known to occur in them, they are of conservation significance since abundant mussel populations are known in these areas. Although currently unoccupied, some of the areas in Zone D were historically occupied by the Covered Species and they represent potential areas for habitat restoration and natural population expansion depending on habitat conditions and future hydrologic risk assessment. Additional information will be needed to make those determinations in coordination with USFWS and TPWD. BRA will assist USFWS and TPWD in evaluating potential areas for reintroduction of Covered Species, solely at the discretion of USFWS and TPWD. If USFWS and/or TPWD determine that reintroduction is warranted, then BRA will provide support for logistics and monitoring. Repatriation of Covered Species in Zone D would result in the establishment of new populations, and expansion of existing populations, resulting in significant conservation benefit. BRA has worked with its partners in the basin to improve water quality in several stream reaches identified in Zone D (i.e., Leon and Navasota rivers).

Zone D includes portions of the Leon River in Comanche, Hamilton, and Coryell counties; portions of the Navasota River in Robertson, Leon, Brazos, Madison, and Grimes counties; portions of Yegua Creek in Burleson and Washington counties; and portions of the Little River in Milam County (**Figure 8**). Within the Leon River, Zone D extends 187.5 stream miles from the Lake Proctor Dam in Comanche County to the SH 236 crossing in Coryell County. In the Navasota River, Zone D extends 99.3 stream miles from Lake Limestone Dam in Robertson/Leon counties downstream to the confluence with Gibbons Creek in Brazos/Grimes counties. In Yegua Creek, Zone D extends 20.5 stream miles from Lake Somerville Dam downstream to the confluence with the mainstem Brazos River, all in Burleson/Washington counties. In the Little River, Zone D extends 47.8 stream miles from the confluence with the San Gabriel River to the confluence with the mainstem Brazos River, all in Milam County.

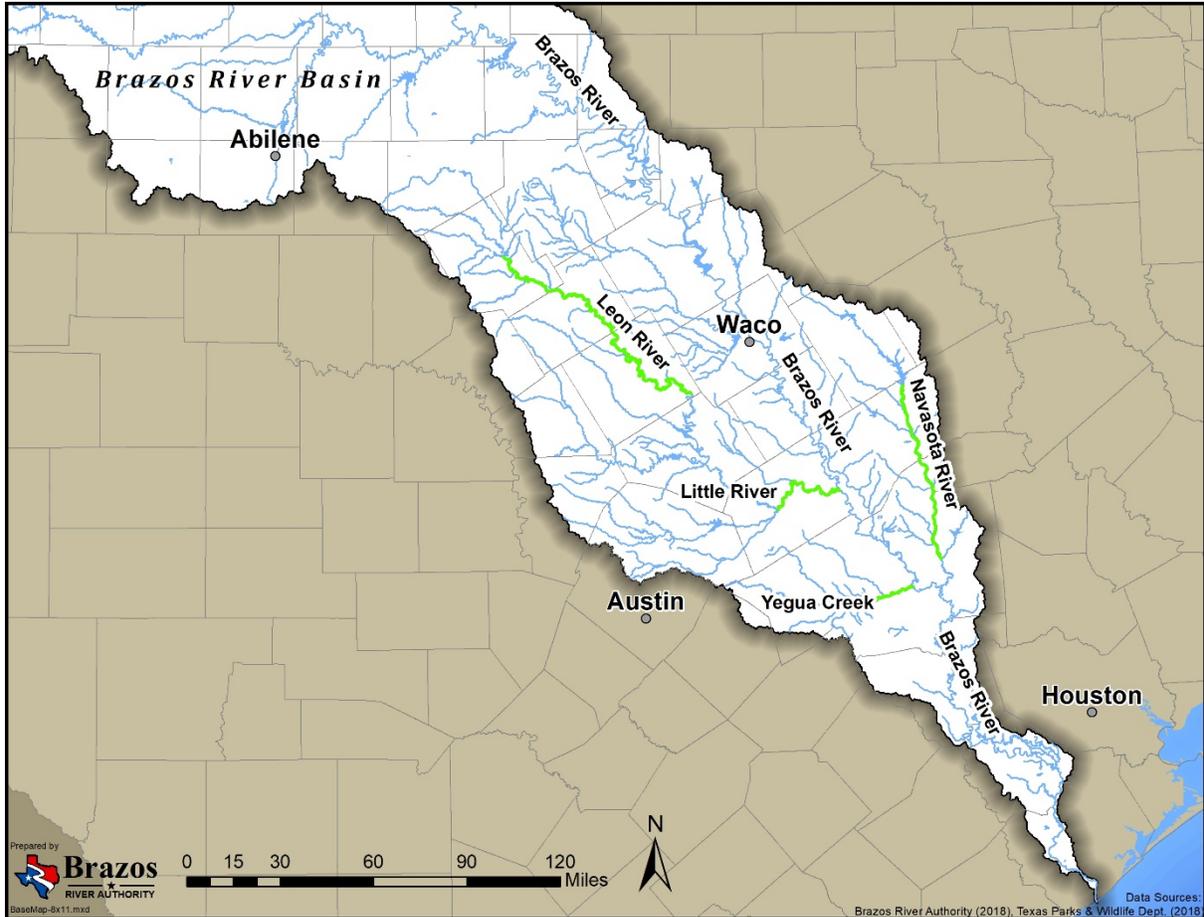


Figure 9. Mussel Conservation Zone D, defined as areas where freshwater mussels are abundant, but Covered Species are not known to occur.

Zone E

Zone E is defined as stream reaches where no substantial mussel populations exist based on currently available data. These areas are currently of lowest conservation priority. It should be noted that not all of Zone E has been surveyed for mussels. Under this CCAA, BRA will perform additional surveys to fill in data gaps. Freshwater mussels may occur in these areas, but at lower abundance.

Zone E includes all of the Covered Area not already assigned to Zone A-D (**Figure 4**).

8.0 Hydrologic Modeling

The Covered Area represents a large portion of the Brazos River basin covering the mainstem Brazos River and multiple tributaries. Hydrologic conditions within this large area are variable and will fluctuate under future scenarios depending on location within the basin, local climatic and geologic conditions, proximity to infrastructure, and local land and water use patterns. Modeling was used to evaluate future hydrologic conditions within portions of the Covered Area, based upon the most current version of TCEQ approved Water Management Plan dated April 2, 2018 (<http://www.brazos.org/About-Us/Water-Supply/SysOps>). The hydrologic information was overlaid with mussel distributional information to evaluate the frequency of extreme low-flow events in portions of the Covered Area occupied by the Covered Species. This analysis was used as a component of the conservation strategy to evaluate future hydrologic risk within the Covered Area during the permit period, and to guide prioritization of Mussel Conservation Zones, with consideration of streamflow conditions in the future. This hydrologic analysis is summarized below, with specific details presented in **Appendix B**. The intent of this modeling is to provide BRA with the best available information for proactively managing its system of reservoirs to provide surface water to downstream users, while providing for the environmental flow needs of freshwater mussels, including the Covered Species, over the 20-year term of this agreement.

Surface water in Texas is owned by the state and regulated by the Texas Commission on Environmental Quality (TCEQ). Along with hundreds of other water users, the BRA holds permits to divert, store and manage water in the Brazos River basin. To determine specific permit limits on diversion, storage and water management patterns, a computer-based model known as a Water Availability Model (WAM) is used to predict the amount of water that would be in a river or stream under a specified set of conditions. The modeling system used by TCEQ consists of two parts: the modeling program, Water Rights Analysis Package (WRAP), and specific hydrologic input parameters with specified water management. Water use amounts and limits are determined on a month-average basis by analyzing historical climate conditions, including the drought of record, and also including environmental flow conditions. The inputs to the WAM model include “naturalized” flows (that is streamflow that would have been in the river during historical periods in the absence of any water management), and historical precipitation and evaporation. In the Brazos River basin, the BRA was required to extend the hydrology used in the WAM model from 1997 to include the recent drought period, as a condition of the approval of the System Operation Permit. This extended WAM, that incorporates two major drought periods, was approved by TCEQ staff for the period of 1940 through 2015 to evaluate the impact of the recent drought period on the Systems Operation Permit. A version of the WAM does not exist with hydrology extending from 2015 to the present. Although the extended WAM is used for this CCAA hydrologic analysis, it should be noted that TCEQ continues to use the version of the WAM with 1940-1997 hydrology for review of current or pending water right permit applications in the Brazos basin.

Assessing projected water patterns in the Brazos River basin is difficult because of the complexity of the infrastructure and uncertainty of water use patterns. For the 20-year CCAA

time frame, assumptions are necessary on how much water each water rights user will use each month, how much water is returned to the river after it is used (i.e., waste water discharges), and how much storage is available in existing and proposed reservoirs (considering sedimentation which lowers storage capacity over time). For this analysis, conservative assumptions have been used consistent with those approved by TCEQ for recent water rights permitting activities.

Using the modeling tools and underlying assumptions referenced above, projected flow levels were determined under various scenarios and compared to historical gaged conditions to evaluate changes to water quantity patterns within the basin and future risk to freshwater mussel populations. Monthly-average model results were evaluated in relation to occurrence of subsistence flows (the minimum streamflow needed during critical drought periods to maintain tolerable water quality conditions and to provide minimal aquatic habitat space for the survival of aquatic organisms [NAS 2005]) and zero flows, as these flow conditions were considered to be most relevant to freshwater mussel persistence and most relevant to BRA's management ability. Based on historical gaged conditions, the percentage of months at or below subsistence for each stream segment varied across the basin (**Figure 9**). Under the modeled 2060 scenario, percentage of time at or below subsistence increased in some segments and decreased in others (**Figure 10**). Similar patterns are evident for modeled zero flow months with additional details of hydrologic modeling documented in **Appendix B**.

Although this modeling is complex and based on a variety of inputs, available data and assumptions, some general mechanisms for these projections are apparent. In general, stream segments which show increased frequency of subsistence and zero flows are in areas with predicted increases in local use. Decreased frequency of low flows is typically associated with increased reservoir releases to meet demands of downstream water rights or increased return flows. Understanding such future water use scenarios is critical as a conservation strategy to aid in identification of appropriate conservation activities or restoration projects that could be implemented within each segment. For example, based on this analysis, stream segments with documented Covered Species populations exhibiting increased frequencies of subsistence or zero flow months under future conditions (e.g., San Gabriel River) were prioritized with respect to the proposed conservation measures. These segments are included in Zone A and future infrastructure and development will be avoided in these stream segments as outlined in Section 9.4. In contrast, stream segments with decreased frequency of low flows under future conditions (e.g., Yegua Creek) represent potential areas for population restoration and habitat enhancement projects.

It is important to recognize that results of this analysis represent future combined use by all surface water users within the basin, and that BRA only manages a portion of the combined total. Modeled use of BRA water rights comprised less than 50% of total combined surface water use in the basin, although the degree of BRA's water management varies spatially across the basin and varies in time according to hydrologic conditions. During high flow periods, BRA has limited ability to manage water in the basin because BRA does not control flood storage in any reservoirs. During low flow periods under a full utilization scenario, BRA releases of stored water generally account for between 20-85% of water in covered stream reaches, with less

management and influence in the lower basin. Thus, BRA releases during critical low flow periods would provide substantial increases in flow and water quality, directly benefitting downstream mussels.

These hydrologic modeling efforts inform the BRA about current and future threats associated with altered hydrology (low flows and flooding) to the Covered Species in the Covered Area. This information will be used to inform an adaptive management program, in coordination with the USFWS, to prioritize, define and implement appropriate conservation actions necessary to provide a net conservation benefit to the Covered Species over the 20-year term of the CCAA and permit. These actions include, but are not limited to, strategic water releases as identified above to increase flows, improve water quality, and restoration of instream and adjacent riparian habitats.

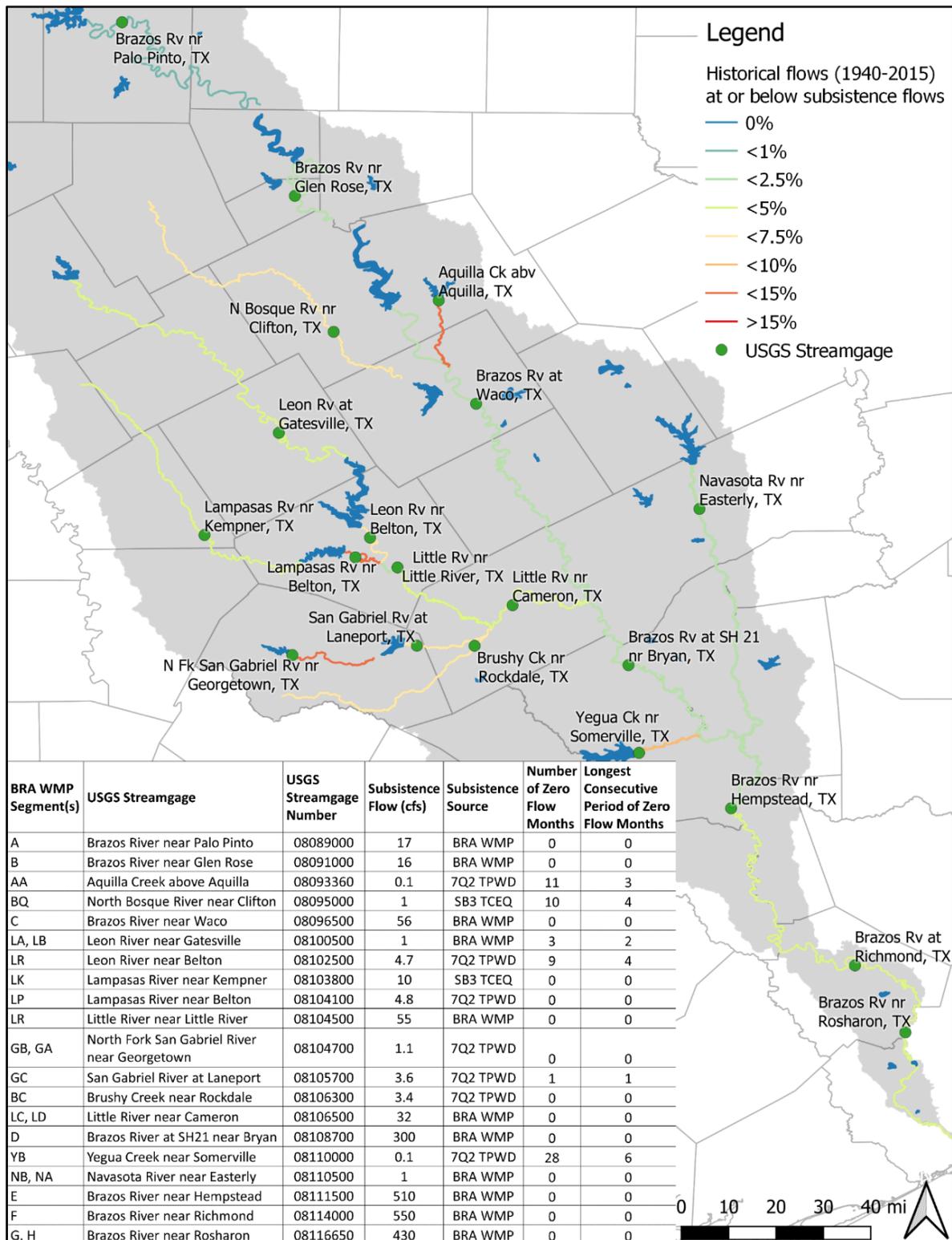


Figure 10. Map showing percent of months below subsistence flows based upon historical gage data for stream segments in the Brazos River basin.

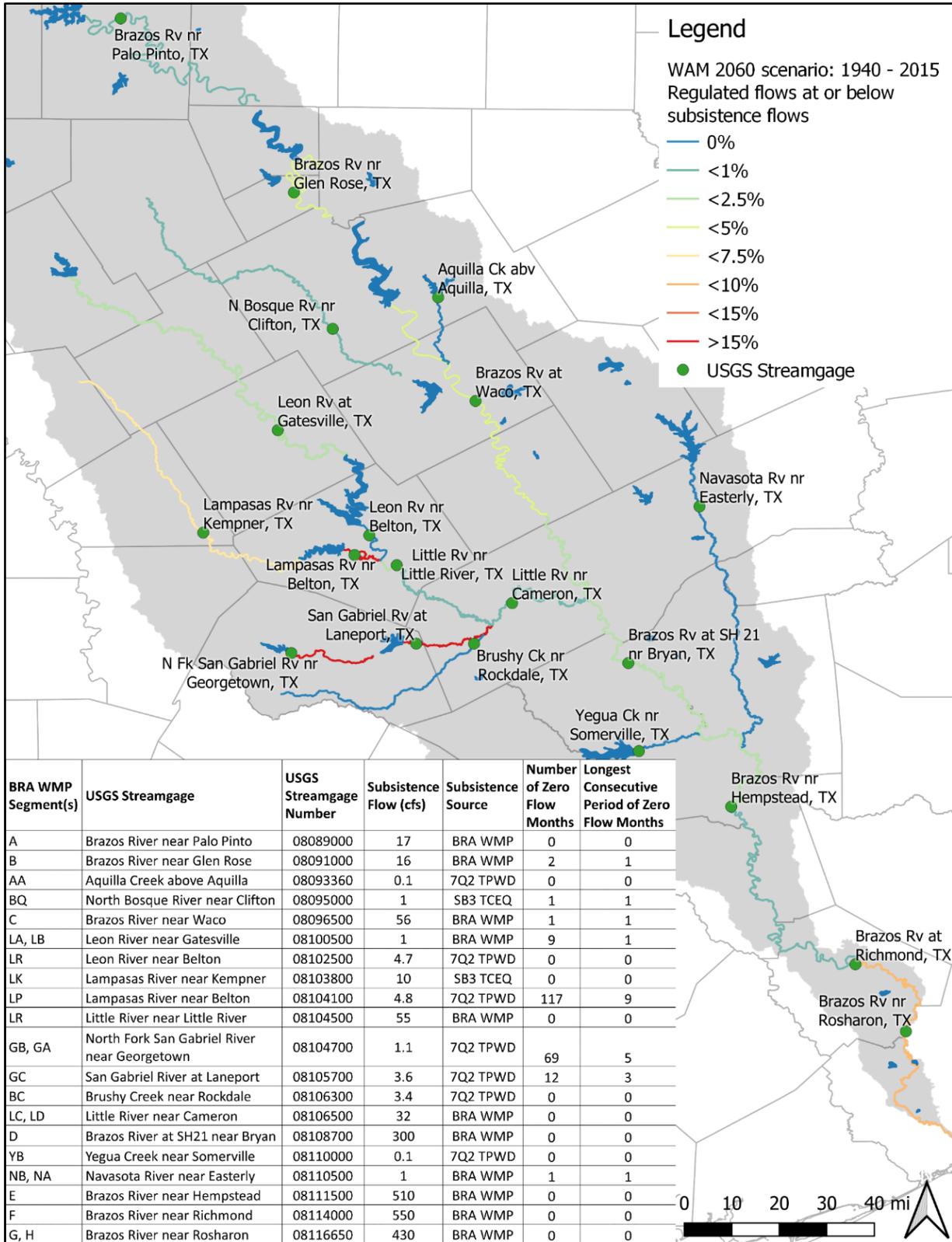


Figure 11. Map showing percent of months below subsistence flows based upon hydrologic modeling for the 2060 scenario.

9.0 Conservation Measures

The conservation measures described in this section will be planned and executed in close coordination with USFWS and other key partners. Timing and frequency of conservation measures is discussed in the Implementation Schedule provided in Section 10.0.

9.1 Distributional Freshwater Mussel Surveys and Hydrologic Modeling

9.1.1 Freshwater Mussel Surveys to Fill Data Gaps

To develop a better understanding of the current distribution of the Covered Species, the BRA has commenced mussel surveys in areas throughout the Brazos basin that have either not been surveyed or were previously surveyed without the use of conventional survey methodologies. BRA will use survey methods approved by USFWS. Initial survey efforts in the Fall of 2018 were conducted in the Lampasas River sub-basin, which included the mainstem Lampasas River, Sulphur Creek, and Salado Creek. Additional survey locations are planned and may include, but are not limited to, the Little Brazos River, North Bosque River, Gibbons Creek, and Palo Pinto Creek.

9.1.2 Additional Hydrologic Modeling

As described in Section 8.0, hydrologic modeling was conducted by BRA to support preparation of this agreement and identify areas of the basin at highest risk under future drought and management scenarios. To keep pace with changing water planning and water use projections within the basin, this analysis will be updated every five years for the life of the permit to guide the adaptive management process (see Section 12.0).

9.2 Communication / Education / Outreach

9.2.1 Coordinate with Agencies through Interagency Workgroup

To promote efficient and effective communication of conservation activities and results of applied research, BRA will engage other agencies including USFWS, TPWD, TCEQ, TXDOT, NRCS and scientists including university researchers and environmental consultants working on freshwater mussel issues in the Brazos River basin through an interagency workgroup. Annual meetings of this group will allow scientists from various agencies and universities to share research and monitoring plans and prevent overutilization of existing populations for scientific research. These meetings will coincide with USFWS' annual Mussel Research and Coordination Meeting. Data sharing will allow all parties to stay up-to-date on ongoing research and assist in making sound conservation and management decisions.

Additionally, to facilitate data sharing, the BRA plans to collaborate with other USFWS conservation partners including TPWD, TXDOT, USACE, and other River Authorities on the Mussels of Texas Project. The Mussels of Texas Project collates and displays available mussel distribution information, and is planned to be made available to help inform entities whose actions could result in harm to mussels. Thus, the Mussels of Texas Project helps inform BRA, and others, in their efforts to minimize and avoid adverse effects to freshwater mussels, including the Covered Species. The BRA plans to contribute data to the Mussels of Texas Project when the database platform is publicly available. TXDOT is currently the lead agency for the Mussels of Texas Project.

9.2.2 Increase Awareness of Freshwater Mussels and Foster Community Engagement

Public outreach and education are critical for successful implementation of any conservation strategy for cryptic species like freshwater mussels. The general public in the Brazos Basin is not largely aware of freshwater mussels, their value, the implications of their decline, activities that may negatively impact them, or the supporting science. To address this knowledge deficit, BRA will establish a comprehensive communication program within two years of final execution of this CCAA that includes freshwater mussels and their habitats.

A multi-media approach will be utilized including in-person presentations and exhibits at community events across the basin, a freshwater mussel-specific informational page on BRA's website, and mussel content on social-media outlets.

Topics to be covered in this multi-media approach will include: general mussel awareness and life cycle needs, ecosystem services, threats to mussel persistence, water quality, water conservation, and riparian restoration.

In addition to the items above, outreach staff will develop a web-based toolbox, within four years of final execution of this CCAA, where landowners can find information on resources to assist them in overcoming barriers to implementing more mussel friendly practices on private property. BRA will work with our partners to help direct interested landowners and others to existing state and federal technical and financial assistance programs, to encourage voluntary habitat and species restoration on private lands in the Covered Area.

9.3 Environmental Flows Protection

9.3.1 Environmental Flow Management

To protect environmental flows in the basin, BRA will manage water supply operations according to the System Operation Permit and associated Water Management Plan (BRA 2018, <http://www.brazos.org/About-Us/Water-Supply/SysOps>) (WMP) for the life of this CCAA. The System Operation Permit, issued by the TCEQ in 2016, represents a unique, cost-effective, and environmentally-conscious approach by BRA to address current and future water supply needs in the basin. The WMP describes how BRA implements the System Operation Permit and allows BRA to use naturally occurring flows, return flows from wastewater treatment plants, and water supply in 11 existing reservoirs to manage water supply demands in the basin. The WMP incorporates environmental flow standards adopted by the TCEQ in compliance with the Senate Bill 3 process to mimic the natural hydrology of the basin and protect the seasonal distribution of dry, average, and wet conditions. BRA will continue to provide for environmental flows in the Brazos River basin through implementation of the WMP even if TCEQ no longer requires BRA to meet minimum flow standards (see Section 13. Changed Circumstances).

As part of the WMP, diversions of water under the System Operations Permit include prohibitions on diversion when flows are not compliant with TCEQ environmental flow standards. Furthermore, operations under the System Operation Permit and WMP, as with other existing water rights, are conducted in compliance with TCEQ's rules governing watermaster operations (Chapter 304 of Title 30 of the Texas Administrative Code). Prior to the diversion of water under the System Operation Permit and WMP, the BRA and the TCEQ Brazos

Watermaster Office ensures operations are compliant with TCEQ environmental flow standards. By maintaining operations in compliance with the WMP for the life of this CCAA BRA is able to manage water use under all of its permits to support water supply needs in the basin, while accounting for existing environmental flow requirements. Additional details of the WMP can be found in the Conformed Technical Report in Support of the Water Management Plan for Water Use Permit No. 5851, accessible online at the BRA website (<https://www.brazos.org/About-Us/Water-Supply/SysOps>).

Many of the Senate Bill 3 based environmental flow conditions implemented by TCEQ are based on historical hydrology or fish habitat considerations and do not specifically address the environmental flow requirements of freshwater mussels. To address this, as part of applied research activities described below, additional studies are planned to develop assessment methodologies that will help identify the environmental flow needs of freshwater mussels and their host fishes. Thus, BRA's current and future water management activities that meet TCEQ environmental flow standards, combined with proposed applied research and adaptive management, are expected to provide substantial conservation benefit to the Covered Species in the Covered Area.

As new information related to the flow needs of mussels is identified during the execution of applied research, the BRA will collaborate with the TCEQ to integrate this information into future updates of the Texas Environmental Flow Standards for Surface Water (30 TAC §298). Additionally, the BRA will incorporate technical guidance based on the results of applied research studies regarding environmental flow needs of mussels into future updates of the WMP. The incorporation of this technical guidance into the WMP and new environmental flow standards that are protective of mussels by TCEQ could provide a conservation benefit as minimum flows are protected.

9.3.2 Allen's Creek Reservoir Management to Support Environmental Flows

The proposed 9,500-acre Allen's Creek Reservoir is an off-channel reservoir in the lower Brazos River basin (**Figure 11**), meaning that it will not be built on the Brazos River, but rather a tributary (Allen's Creek) that does not provide habitat for the Covered Species (Randklev et al. 2014, p.2) . It is permitted by the Texas Commission on Environmental Quality to capture water during high flow events for release to downstream customers during lower flows, and when full, will provide approximately 100,000 acre-feet of firm water supply per year. The water use permit contains several special conditions dictating how water may be moved into and out of the reservoir that are designed to protect instream uses, water quality and aquatic habitat. These conditions include a maximum diversion rate from the Brazos River, a maximum release rate, and detailed diversion restrictions based on naturalized flows and ambient flow conditions. A copy of the permit can be located at:

https://www15.tceq.texas.gov/crpub/index.cfm?fuseaction=iwr.viewdocument&doc_name=Permit%202925B%2Epdf&doc_id=573521202011249&format_cd=pdf.

While the reservoir is permitted by TCEQ and the necessary land has been purchased, before construction the BRA must also complete reservoir design and USACE permitting, which will occur concurrently. Timing of the USACE permitting process is difficult to predict, but BRA

anticipates that the permitting process will be complete and construction will begin within the next 15 years and that the reservoir will be operational during the term of this permit. By adding water storage capacity at the bottom of the Basin, near to major downstream water users, BRA gains additional flexibility to deliver water and maintain environmental flow conditions appropriate for Covered Species through implementation of the System Operations Permit and WMP. That is, adding Allen's Creek Reservoir as part of BRA's system of reservoirs affords BRA additional flexibility to maintain wetted habitats and suitable water quality, benefitting mussels including the Covered Species.

By delivering water to senior water rights holders and customers in the lower Brazos River basin during periods of low flow, via the bed and banks of the Brazos River, this reservoir would contribute to meeting subsistence and base environmental flow requirements in the river, and thus reduce potential drought impacts to freshwater mussels in this area. Note that the initial construction of the Allen's Creek Reservoir is beyond the scope of this CCAA and does not represent a Covered Activity; however, future management and operations of the Allen's Creek Reservoir are Covered Activities expected to reduce the future threat of low flows to Covered Species downstream, thus contributing to a net conservation benefit over the 20-year term of the CCAA and permit. As part of BRA's system of reservoirs, the operation of Allen's Creek Reservoir, will allow BRA greater capacity to deliver surface water to downstream users, and provide for the environmental flow needs of Covered Species and avoid critical low flows during times of severe drought. Thus, the future operation of Allen's Creek Reservoir contributes to, and supplements BRA's existing capability to deliver a net conservation benefit to the Covered Species within the 20-year term of this agreement.

Additionally, this reservoir will increase the resiliency of the BRA water supply system by increasing total water storage available for release during drought conditions. Increased drought resiliency of the water supply system will also have the benefit of reducing potential drought impacts to freshwater mussels downstream of the project since water will be transported via the bed and banks of the Brazos River. The resiliency and the flexibility of the BRA system of reservoirs affords BRA the ability to provide for the resource needs of mussel by delivering surface water through the bed and banks of the Brazos River.

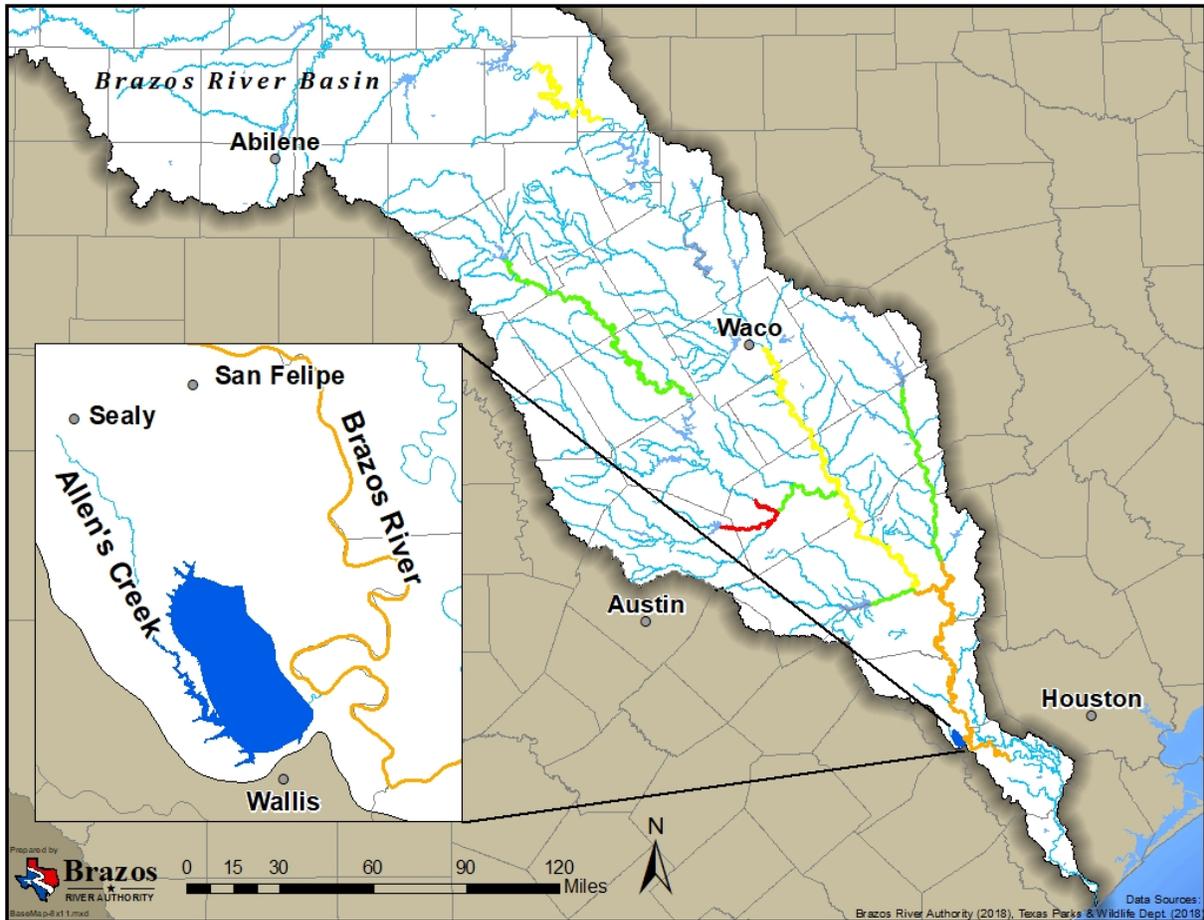


Figure 12. Location of proposed Allen’s Creek Reservoir in the lower Brazos River basin in relation to Conservation Zones.

9.3.3 Evaluate Controlled Releases to Minimize Erosion

Extended controlled releases at bank-full discharge can result in erosion of stream banks and scouring of river beds. Such conditions can displace freshwater mussels and damage important habitats. Depending on how controlled releases are concluded, they can result in post-event bank sloughing, which can also degrade instream habitat.

Within the BRA’s System, the eight reservoirs owned and operated by the USACE have the ability to capture water during periods of high streamflow and flooding, and release this water gradually to minimize flooding in downstream areas. The release of floodwater stored in these eight USACE reservoirs is determined by USACE. The three reservoirs owned and operated by BRA do not have the ability to store water in order to prevent flood impacts downstream.

The BRA’s Operations Procedures for Controlled Releases from its three reservoirs establishes procedures and guidelines for BRA staff to conduct release operations during high inflow events in order to minimize threats to the safety of the dam, impacts to downstream property, and impacts to the downstream river channel. Controlled releases are increased incrementally over time to maintain reservoir levels protective of the dam structure. This may or may not result in

bank-full discharge downstream of the reservoir. Conversely, when the release event is coming to its conclusion, decreases in release rates are also performed incrementally to minimize downstream bank sloughing.

BRA will continue to work to minimize scouring flows from BRA-system reservoirs, when and where possible, by studying ways to manage releases from BRA-owned reservoirs and how managed releases may affect downstream sediment dynamics and mussel beds. BRA will also coordinate with the USACE to evaluate potential modifications to flood releases from USACE-owned reservoirs to minimize scouring flows and thus protect mussels, when possible. BRA will work with its conservation partners to help identify state- and federal- funding sources and private landowners interested in implementing habitat restoration projects below these dams, but does not commit any BRA funds at this time.

9.4 Avoidance and Minimization

To assist in maintaining key populations of the Covered Species, the following avoidance and minimization measures are proposed. Although avoidance and minimization could result in significant costs to BRA during the permit term, these measures were designed to maintain existing populations of the Covered Species, particularly in areas with higher probabilities of drought-related impacts.

- The BRA will not construct additional dams on the mainstem Brazos River, mainstem Navasota River, or mainstem Little River.
- The BRA will not sponsor additional BRA infrastructure or diversion projects that impact the stream bed in Zone A.
- Within Zones B and C, the BRA will conduct mussel surveys to guide placement of any necessary infrastructure/diversions, and they will be sited to minimize disturbance to Covered Species populations.
- In all zones, the BRA will encourage design and construction of infrastructure not owned by BRA to minimize disturbance to the riverbed and minimize hydraulic disturbance.

Active efforts to avoid and minimize disturbances to Covered Species and their habitats, combined with other conservation measures, such as providing appropriate environmental flow conditions and identifying habitat and water quality requirements of the Covered Species, all applied in an adaptive management framework, will allow populations and occupied habitats to expand naturally, contributing to a substantial net conservation benefit for the Covered Species in the Covered Area. Additionally, if new populations of the Covered Species are identified through ongoing or future surveys, Conservation Zones and resulting avoidance and minimization measures will be reevaluated through the adaptive management process in Section 12.0.

9.5 Applied Research

As part of the proposed conservation measures, BRA will conduct a variety of applied research to supplement the available knowledge on the Covered Species. Details of each applied research

activity are discussed below. This applied research will be conducted in coordination with other agencies/researchers and will include substantial involvement from FWS and TPWD staff biologists. The goal of this research is to better define habitat and water quality requirements of the Covered Species to inform future management decisions and support on-the-ground conservation activities.

9.5.1 Development of a Habitat Quantification Tool

To evaluate the mechanisms influencing occurrence and abundance of the Covered Species in the Covered Area, BRA will develop a freshwater mussel habitat quantification tool within the first three years of implementation of this agreement. The goal of this desktop analysis is to synthesize all available freshwater mussel survey and habitat utilization data within the Covered Areas for evaluating spatial trends and resulting mechanisms that affect mussel occurrence and density. This tool will provide data necessary for identifying landscape-scale mechanisms in explaining mussel occurrence and evaluating reach-scale habitat suitability. Results will aid in prioritizing areas for implementation of various conservation and/or restoration actions. This tool will be extremely helpful in an adaptive management context, and will better position BRA to inform future conservation activities in the Brazos River basin.

9.5.2 Development of Environmental Flow Methodologies Specific to Freshwater Mussels

With the passage of Senate Bill 3, the Texas legislature recognized the importance of maintaining the ecological integrity of Texas river systems. Recent analyses stemming from this legislation have been conducted to determine flow conditions necessary to maintain a sound ecological environment in Texas rivers. This process led to the establishment of environmental flow standards by the TCEQ. However, the majority of the biologically-focused environmental flow research conducted to date has assessed the influence of various flow tiers on instream fish and riparian vegetation communities. Only recently have environmental flow studies begun to evaluate instream flow requirements of freshwater mussels. To provide additional information on instream flow requirements of freshwater mussels in the Covered Area, the BRA will work in conjunction with USFWS staff to develop environmental flow methodologies specific to freshwater mussels in years 3 to 5 and to identify patterns in habitat utilization, availability, and persistence under various flow conditions. This information will be useful in determining flow conditions necessary to support existing and future populations of the Covered Species and to determine if amendments to the State of Texas' Environmental Flow Standards are warranted. This understanding, applied in an adaptive management framework, will reduce current and future threats associated with low flow events, contributing to a substantial net conservation benefit for the Covered Species. Future, revisions to the State of Texas' Environmental Flow Standards will be addressed under Section 13.0 - Changed Circumstances. BRA will provide information about the instream flow requirements of freshwater mussels to TCEQ and others and inform future revisions to the flow standards.

9.5.3 Evaluate Reintroduction Techniques and Opportunities

To evaluate opportunities for reintroduction of Covered Species into areas of their historic range where they are not currently present, a cage study is planned. This designed experiment will initially use common mussel species as surrogates and compare survival, growth, and

reproductive potential in areas currently devoid of mussels to areas that are currently occupied. Common mussel species known to occupy the same areas as Covered Species (e.g., Yellow sandshell *Lampsilis teres*, Threeridge *Amblema plicata*, Pimpleback *Cyclonaias pustulosa*) will be collected from areas of the basin where they are abundant, relocated to unoccupied areas, and placed in experimental cages. A control treatment will consist of an equal number of caged mussels deployed at the original collection site. Experimental cages will be partially filled with native substrate material from the area to allow the mussels to naturally burrow. Transplanted and control mussels will be periodically monitored to evaluate survival, growth, and gravidity.

Habitat data including continuous water temperature and water level data will be recorded at each site. Patterns in growth, survival, and gravidity between the control and treatment will be used to evaluate the potential for reintroduction in the transplant area. Habitat data collected at each location may help elucidate mechanisms behind patterns in mussel occurrence and inform development of the Habitat Quantification Tool (Section 9.5.1) and mussel-specific environmental flow methodologies (Section 9.5.2). Should these techniques prove successful for evaluating reintroduction potential of common species, it is anticipated that results and/or trials could be expanded to Covered Species. The BRA will coordinate closely with TPWD and USFWS on these research activities and any possible reintroductions or augmentations, which applied in an adaptive management framework, are ultimately expected to contribute to population increases for the Covered Species. BRA will support and assist TPWD and USFWS with reintroductions of the Covered Species, assuming such actions are deemed to be appropriate by TPWD and USFWS at that time. TPWD and USFWS will ultimately need to determine the appropriateness of reintroductions, and judge the efficacy of any future reintroductions of Covered Species.

9.5.4 Analyze Physiological Tolerances of Covered Species

To advance the current science on physiological tolerance of the Covered Species, laboratory studies on water quality tolerance limits will be conducted. If available, this analysis will focus on test organisms produced via captive propagation, rather than specimens collected from the wild. Also, where possible, opportunities will be explored to collaborate with other partners and expand these studies to include populations of the Covered Species outside the Brazos basin. These studies will focus on the influence of water quality parameters believed to pose the highest risk to Covered Species such as water temperature, dissolved oxygen, salinity, turbidity, and ammonia concentrations. Information from these studies will be used in conjunction with water quality monitoring outlined below to evaluate and manage potential water quality stressors in the basin as well as inform development of the Habitat Quantification Tool (Section 9.5.1) and mussel-specific environmental flow methodologies (Section 9.5.2).

9.5.5 Groundwater-Surface Water Interaction Studies

Understanding the hydrologic connection between surface water and groundwater becomes integral to developing strategies to effectively manage these two resources. There is a need for improved science regarding surface water-groundwater interactions as there are thousands of shallow wells in Texas near streams that can affect surface water flow or may be diverting stream water through underflow (Young, et. al, 2018).

The Brazos River Alluvium Aquifer (Alluvium) is an unconfined aquifer that runs from Bosque and Hill Counties in the middle Brazos River Basin through Fort Bend County in the lower Brazos River basin. Previous studies in the northern half of the aquifer (Bosque, McLennan, and Falls Counties) have revealed that there is compartmentalization in some areas of the aquifer, where the aquifer is not influenced by river flows, and in other areas the aquifer is directly recharged by the Brazos River (Jarvis, 2017). To date similar studies have not been conducted in the lower half of the Brazos River Alluvium.

Starting in fiscal year 2020, the BRA will participate with local universities, local groundwater conservation districts, and other interested parties in a planned three-year study. These studies will seek to better understand the interaction between the Brazos River and the Alluvium in Brazos, Grimes and Waller Counties. The team will perform geospatial analysis using Texas Water Development Board's (TWDB) groundwater database and data submitted in Drillers Reports from the area, conduct cross-section monitoring to record changes in bank material and identify possible connectivity between the river and the alluvium. Current and historical water chemistry data of both the Brazos River and Alluvium will be examined for similarities or differences in specific conductance, temperature, cations and anions, and the ratio of hydrogen and oxygen isotopes. Finally, data loggers will be installed to monitor changes in the water table elevation. The goal of the studies is to provide scientific data and improved understanding on if there is interaction between the river and Alluvium, how any identified interaction impacts water quality and flow in the river, and how the aquifer responds to rainfall events and changing river stages.

A better understanding of these interactions will help TCEQ, TWDB, BRA and groundwater conservation districts make more informed decisions regarding groundwater pumping, implementing environmental flow recommendations, water availability, and water quality. Improved understanding on the above items will also contribute to conservation of freshwater mussels through identification of potential reintroduction areas and future hydrological persistence as managers will be able to make knowledgeable decisions on the interface between the river and aquifer and reduce threats to the long-term viability of freshwater mussels.

9.6 Long-term Monitoring

9.6.1 Key Mussel Populations

Long term monitoring will focus on four key reaches within Zones A, B, and C known to have existing populations of the Covered Species:

- 1) Little River basin near the San Gabriel River confluence (Zone A);
- 2) Lower Brazos River near the confluence of Allen's Creek (Zone B);
- 3) Lower Navasota River near the confluence with the Brazos River (Zone C); and
- 4) Mainstem Brazos River between Possum Kingdom Reservoir and Lake Granbury (Zone C).

Both site-specific and reach-scale monitoring approaches will be employed to monitor changes in populations of Covered Species through time. For site-specific monitoring, one area with high

densities of the Covered Species will be identified within each of the four key reaches above and monitored over the life of the permit. Monitoring will be conducted annually and as streamflow conditions allow for safe and effective sampling. To avoid harming sensitive mussel populations, monitoring will be conducted in close coordination with USFWS and TPWD and may include mark-recapture techniques to evaluate capture probability, survival probability, immigration/emigration rates, local population size, longevity, and mussel growth rates. Additionally, quantitative quadrat-style sampling may be employed to ensure capture of small-bodied mussels such as Texas fawnsfoot, to assess recruitment, and to analyze patterns in mussel density. Monitoring protocol development will be coordinated with and approved by USFWS prior to implementation of any mussel sampling plan.

Reach-level habitat utilization surveys will also be employed within each key reach to examine broader-scale patterns in population abundance and habitat utilization, and to evaluate population expansion/contraction. Sampling locations will be spaced longitudinally throughout the reach and data will be collected by timed searches at multiple mesohabitat types within each sampling location. Detailed habitat data (depth, velocity, substrate, shear stress, etc.) will also be collected at each mesohabitat. This sampling approach will allow for quantification of habitat utilization data and assessment of broader-scale trends in the occurrence and abundance of Covered Species. This information will be invaluable in supporting several aforementioned conservation measures (Sections 9.5.1 [Habitat Quantification Tool], 9.5.2 [environmental flow methodologies]), and 9.5.3 [reintroduction evaluation]). Results of monitoring will be summarized in annual reports to USFWS. The BRA will coordinate closely with USFWS and other key partners on these monitoring efforts. The long-term monitoring efforts will provide the foundation for an adaptive management program that informs and directs the implementation of conservation measures that are ultimately expected to contribute to increasing population numbers and extent, thus providing a net conservation benefit for the Covered Species.

9.6.2 Host Fish Populations

For the covered species to persist, host fish populations must exist in adequate numbers to ensure survival of early life stages. To monitor host fish populations, BRA will continue fish assemblage monitoring throughout the basin as part of ongoing work with the Clean Rivers Program and ongoing environmental flow standard validation assessments. Data from ongoing monitoring will be evaluated for trends in occurrence and abundance of mussel host species (i.e., Freshwater Drum, Red Shiner, Blacktail Shiner). Annual accounting of host fish monitoring results will be provided to TPWD and USFWS.

9.6.3 Water Quality

Even though there are stream reaches in the Brazos River basin that do not meet state water quality standards, overall trends are positive and the need for additional monitoring remains. Most of Conservation Zones A and B identified in Section 7.0 have experienced significant decreasing trends ($p < 0.001$) in ammonia levels since the 1970s. The only Zone B reach not to show a statistically significant trend in ammonia levels is the Navasota River. Seventy-eight percent of the basin's impairments are bacteria-related and 91% are on small prairie streams not currently known to support mussels and 11% of the basin's bacteria impairments are currently

proposed by TCEQ to be de-listed, pending approval by the EPA. There are currently, no impairments other than bacteria in any of the Conservation Zones A, B, C or D for any of water quality parameters identified as threats in Section 4.3.

Water quality improvements in the basin can be attributed to the protections afforded in the federal Clean Water Act and the state of Texas' Clean Rivers Act which have resulted in improved regulation of septic systems, sanitary sewer collection systems, and wastewater treatment facilities. While natural habitat preservation around the waterways of the Brazos basin has historically been poor; this tide is changing with the addition of stormwater retention ponds, increased education of the value of riparian vegetation and the promotion of riparian restoration projects, development requirements to limit impervious cover, etc. Additionally, heightened awareness of water quality concerns by basin residents has resulted in the adoption of best management practices (i.e., stormwater improvements, appropriate application of pesticides, disposal of contaminants, etc.) at the local and individual level.

Water quality monitoring conducted by BRA throughout the Brazos River basin as part of the Clean Rivers Program will continue for the 20-year term of the agreement, even if the Clean Rivers Program becomes defunct. Specific to the Covered Species, 15 water quality assessment sites (**Figure 12**) in reaches known to be inhabited by mussels will be evaluated for water temperature, dissolved oxygen, salinity, and ammonia, in particular. The BRA's annual Basin Highlights report (<http://www.brazos.org/About-Us/Water-Quality/Clean-Rivers-Program/Reports-Presentations-and-Meeting-Minutes>) summarizes water quality status in the basin, will be included in BRA's annual reporting to USFWS. Additionally, the BRA produces a basin-wide water quality trend analysis report at 5-year intervals. The most current water quality trend analysis can be found in the Brazos River Basin Summary Report 2017, accessible online at: <http://brazos.org/About-Us/Water-Quality/Clean-Rivers-Program/Basin-Summary-Report>. This water quality trend report for the Brazos River basin will be provided to USFWS every five years, starting in 2023.

BRA's comprehensive water quality monitoring program implemented in support of this CCAA provides information about whether or not water quality is improving or worsening, and how changes in water quality either benefit or harm freshwater mussels. BRA has initiatives and projects, and is able to partner with U.S. Environmental Protection Agency, Texas Commission on Environmental Quality, Texas Parks and Wildlife, Natural Resources Conservation Service (among others) who can fund the development and implementation of water quality improvement programs like Watershed Protection Plans that have been demonstrated to result in positive changes to water quality. Because monitoring information can sometimes be lacking, BRA and partners will be positioned to undertake meaningful projects to improve water quality throughout the Brazos River basin by having a comprehensive water quality monitoring program in place, with a new focus on mussels through this CCAA.

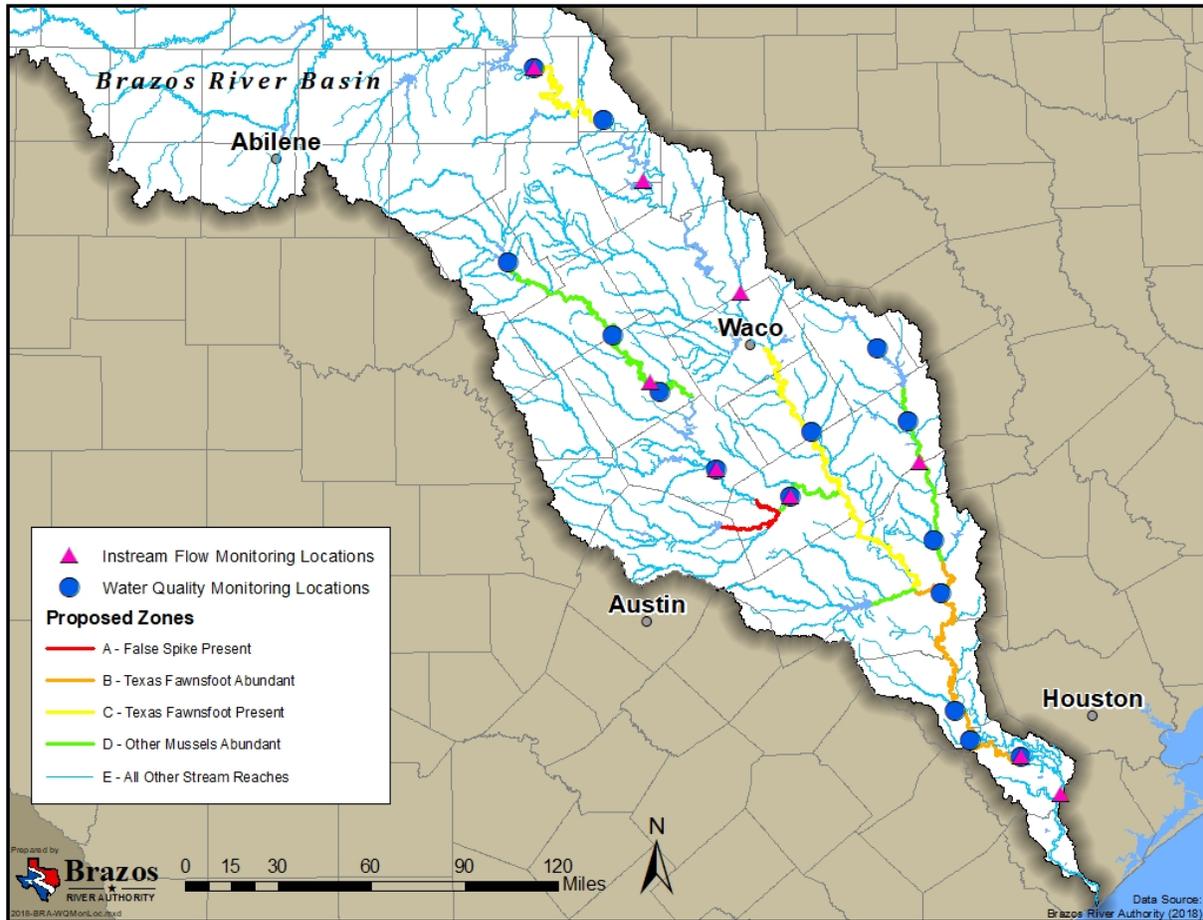


Figure 13. Water quality and instream flow monitoring locations.

9.6.4 Substrate and Channel Morphology

At defined transects within nine instream flow monitoring locations (**Figure 12**), long-term monitoring of substrate composition and channel morphology will be conducted once every five years. Mussel surveys will also be conducted at these transects to determine if mussels are present in the area. If so, long-term monitoring of mussel populations will coincide with channel morphology monitoring.

Four additional transects to monitor substrate and channel morphology will be placed immediately upstream of the four key mussel populations describe in 9.6.1. Transects will be located as close to the instream flow monitoring location as possible, with consideration to where landowner permission can be established.

Data on substrate composition and channel morphology will be collected at these stations, annually the first two years and subsequently every five years. Sampling may be conducted more frequently if high flow events that have the potential to induce channel and sediment movement have occurred. This sampling will be performed when the river is in base flow condition not during periods of elevated flows and will only be conducted when BRA Field Team staff determines conditions are safe to do so.

These surveys will be performed incrementally with the start date to coincide with the key mussel population monitoring detailed in 10.6.1. A section describing these activities will be incorporated into the annual report submitted to USFWS. The section will focus on observed and documented changes in substrate composition and channel morphology over time and the relationship to existing mussel communities. This important component of habitat monitoring, applied in an adaptive management framework and with other conservation measures, will reduce current and future threats associated with habitat degradation, contributing to a substantial net conservation benefit for the Covered Species.

9.6.5 Invasive Species Monitoring

During all monitoring and research activities conducted as part of this agreement TPWD protocols to prevent spread of Aquatic Invasive Species (AIS) will be followed. This includes cleaning, draining, and drying all boats and equipment when moving between sites on different systems. To prevent the possible spread of exotic or otherwise invasive species or disease, BRA will transport freshwater mussels and host fish only under an approved Hazard Analysis Critical Control Points (HACCP¹) plan.

Additionally, presence/absence monitoring for invasive species will coincide with the water quality monitoring events at the 15 sites identified in Section 9.6.3. If invasive species are identified at any monitoring site, the size of the initial infestation will be estimated and then monitored using repeat photography methods. Infestations of invasive species will also be reported to TPWD and a Sighting Report will be submitted to the USGS Nonindigenous Aquatic Species database.

9.7 Short-term Refugia and Captive Propagation

9.7.1 Contingency Plan for Short-term Refugia

Long-term maintenance of captive mussel populations is not a goal of this agreement. However, to assist in conserving existing key populations of the Covered Species under an extreme drought or other stochastic event, the BRA will work with USFWS to develop a Drought Contingency Plan similar to the USFWS Discussion Paper for Drought Contingency Planning for Freshwater Mussels in the Southeast U.S. This contingency plan will be completed by the end of the first full year of the CCAA and will describe the exact methods and facilities to be used to collect and temporarily maintain a refuge population of Covered Species in the event that an extreme event occurs and both parties agree that it threatens to extirpate an existing population. The BRA will implement the contingency plan in coordination with USFWS when needed to salvage mussels in the event of an extreme drought or other event. Under such a scenario, BRA and USFWS will work together to collect remaining live individuals, transport them to a temporary off-site holding location or relocate them to an *in situ* holding location, and potentially restock the original location upon return of appropriate conditions. Development of this contingency plan will be initiated as soon as this agreement is finalized, so that appropriate methodologies will be in place for short-term refugia should the need arise.

¹ Additional information and training is available at: <https://www.fws.gov/fisheries/ANS/ANS-HACCP.html>

9.7.2 Captive Propagation

Captive propagation of the Covered Species is useful in providing organisms for research purposes, and after further research and evaluation, may eventually be used to supplement existing populations or to reintroduce the species into historically occupied but currently unoccupied habitats. The BRA plans to provide partial funding to support ongoing efforts by USFWS hatcheries to establish captive propagation for the Covered Species. Beginning at year six following approval/execution of this CCAA, BRA will provide \$25,000/year through year ten, and then will provide \$15,000/year for years 11 through 20. The first five years of funding for this conservation measure will be to support applied research activities necessary prior to propagation and reintroduction (reintroduction techniques and opportunities [Section 9.5.3] and physiological tolerances investigations [Section 9.5.4]).

This work developing contingency plans, short-term holding strategies, and developing captive propagation techniques will be planned and implemented in close coordination with USFWS and TPWD. Efforts to develop short-term and long-term contingency plans for restoring Covered Species in the event of a natural disaster or other event outside of BRA's control, will bolster resiliency, redundancy, and representation of the Covered Species, contributing to a substantial net conservation benefit. The efforts of BRA will result in additional conservation for the Covered Species, such that in the event of a catastrophic event, BRA will consult with TPWD and USFWS to determine what remedies may be appropriate and partner with TPWD and USFWS to implement those remedies. Investment in a captive propagation program will facilitate future opportunities to reintroduce populations of candidate mussels, ultimately resulting in a net conservation benefit to the species. These efforts coordinated and in collaboration with TPWD and USFWS, to design and implement and a strategy to respond to catastrophic events beyond the control of BRA will enhance the long-time survival of the Covered Species.

10.0 Implementation Timeline

BRA commits to the implementation and funding of the conservation measures described above and listed in Table 3. These measures were strategically planned to maximize usefulness of the resulting data. Many of the conservation measures outlined above have already begun to be implemented. For example, ongoing surveys to fill data gaps in mussel distribution information were initiated in fall 2018, and hydrology modeling has already been initiated to inform development of this CCAA. Additionally, environmental flow management, host fish population monitoring, and water quality monitoring are currently being conducted by BRA and will continue on an annual basis. Substrate and channel morphology monitoring is also ongoing, with surveys conducted on a five-year time step once baseline data is established (**Table 3**). BRA will meet with USFWS annually or more frequently, if necessary, to discuss accomplishments from the previous year, planned activities for the coming year, and identify any needs to adjust the implementation schedule as informed by monitoring and adaptive management program review and other necessary coordination.

Table 3. Implementation timeline demonstrating when each specific conservation measure is to be conducted.

Measure Number	Conservation Measure	Preparation for Implementation	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11-20	Year15
9.1.1	Mussel Surveys to Fill Data Gaps													
9.1.2	Hydrologic Modeling													
9.2.1	Interagency Workgroup													
9.2.2	Education and Outreach													
9.3.1	Environmental Flow Management													
9.3.2	Allens Creek Environmental Flows													
9.3.3	Evaluate Controlled Releases													
9.4	Avoidance and Minimization													
9.5.1	Development of Habitat Quantification Tool													
9.5.2	Environmental Flow Methodologies Development													
9.5.3	Reintroduction Techniques Evaluation													
9.5.4	Physiological Tolerance Studies													
9.5.5	Groundwater Surface-water Interaction Studies													
9.6.1	Mussel Population Monitoring													
9.6.2	Host Fish Population Monitoring													
9.6.3	Water Quality Monitoring													
9.6.4	Substrate and Channel Morphology													
9.7.1	Development of Contingency Plan for Short-term Refugia													
9.7.2	Captive Propagation													
	Monitoring and Adaptive Management Discussions with USFWS													

The conservation measures identified in Table 3 and outlined below will also be initiated upon the effective date of this CCAA. A staggered approach to implementation will be necessary, as some conservation measures will provide information necessary for completion of others. A contingency plan for short-term refugia will be developed during Year 1, so that this protocol is in place in the event that an emergency refugia event is triggered. The contingency plan will define emergency events and identify response actions as appropriate. Habitat utilization data collected during the first two years of reach-scale mussel monitoring and development of the habitat quantification tool will be used to inform environmental flow methodology development in Years 3-5. Additional data on environmental flow requirements of freshwater mussels will then be used to evaluate controlled releases in Year 6. Physiological tolerance studies conducted in Years 1-2 will help inform the reintroduction evaluation studies in Years 3-5, by defining important water quality parameters for Covered Species. Similarly, BRA will contribute to USFWS captive propagation in years 6-20, after physiological tolerance information is available and reintroduction evaluations have been conducted. Groundwater-Surface water interaction studies will be complete by Year 5. Because Allen's Creek Reservoir is expected to be completed in approximately 10 – 15 years, associated conservation measures are applied in years 10-20 of the proposed timeline. Other measures will begin upon implementation of the CCAA and be conducted annually for the entirety of the permit. These measures include coordination with the interagency workgroup, education and outreach activities, and ongoing avoidance and minimization measures. For planning and reporting purposes, Year 1 will begin on October 1 following USFWS approval of the CCAA and issuance of 10(a)(1)(A) enhancement of survival permit.

11.0 Monitoring and Reporting

A variety of conservation measures will be conducted on the Covered Species and their habitats as part of this CCAA. This information will be summarized in an annual report which will be submitted by BRA to USFWS each year. The annual report will include, but not be limited to, information on the following items:

- Summary of conservation, research, and monitoring activities conducted for the year (Annually)
- Results of freshwater mussel surveys designed to fill data gaps in the basin (Years 1-2)
- Results of hydrologic modeling (Years 5, 10, 15)
- Summary of community outreach activities (Annually)
- Summary of Environmental Flows Achievement Report (Annually)
- Summary and results of applied research studies (Years 1-5)
- Results of long-term monitoring (Section 9.6) to include key mussel populations, host fish, and water quality annually; and substrate and channel morphology in designated years (1, 5, 10, 15)
- Summary of captive propagation accomplishments (Years 6-20)
- Any mortality/injury to Covered Species observed during the year (Annually)
- Any other necessary interim updates or interesting findings (Annually)
- Compliance and lack of compliance, with lessons learned to avoid issues in the future

- Copies of monitoring plans, HAACP plans, and other required plans (annually)

Annual reports will be due to the appropriate USFWS Ecological Services Field Office on March 15 of each year, and will include at a minimum, a summary of accomplishments and monitoring results from the past year, and plans for the coming year, as described above.

12.0 Adaptive Management Plan and Program

Adaptive management is an important component of any successful conservation agreement, and this agreement will be adaptively managed with collaborative and substantial involvement from both parties. The conservation measures described herein are designed to further refine our knowledge of the current status of Covered Species populations within the Covered Area; avoid and minimize impacts to known populations of the Covered Species; monitor Covered Species and invasive species populations through time; provide additional information on habitat, flow, and water quality requirements of the Covered Species; and simultaneously monitor habitat, flow, host fish, and water quality conditions within the Covered Area. Since some conservation measures center around monitoring and applied research, a robust adaptive management program is particularly essential in this agreement, to allow modification of conservation measures as new data becomes available. To facilitate the adaptive management process, the following adaptive management procedure is proposed.

Approximately one month following submittal of each annual report, or upon the request of either party, both BRA and USFWS will meet to discuss results from CCAA conservation measures that year and discuss any potential modifications to this conservation agreement. Several of the aforementioned conservation measures will play an essential role in adaptive management discussions. Applied research and survey data will aid in identifying habitat, water quality, and water quantity factors important in structuring Covered Species populations. Additionally, long-term monitoring data and updated hydrologic modeling will aid in identifying if and when such stressors occur, or are predicted to occur, in the Covered Area. Together, these conservation measures will provide the basis for adaptive management into the future. It should also be noted that the long-term monitoring program (habitat, mussels, host fish, water quality, and water quantity) will serve as the baseline for evaluation as the CCAA moves forward.

Specific conservation measures which will be systematically reviewed and discussed, along with potential adaptive actions, are provided in **Table 4**. Each of these measured could directly influence potential management adjustments as new information is acquired through time.

Table 4. Conservation measures and examples of potential adaptive actions.

Conservation Measure	Potential Adaptive Action
Distributional Surveys to Fill Data Gaps	New information on Covered Species distributions will be used to facilitate changes to Mussel Conservation Zones and related avoidance/minimization measures.
Updated Hydrologic Modeling	Updated water use projections or climate change forecasts will influence hydrologic modeling and result in changes to expected future risk of key mussel populations that require reevaluation of avoidance and minimization zones.
Communication / Education / Outreach	Newly available or more efficient methods and newly emerging media outlets will be utilized for education and outreach opportunities.
Applied Research	Increased knowledge of physiological tolerances and flow-ecology relationships related to mussels will guide the development of freshwater mussel specific environmental flow criteria for potential consideration in TCEQ environmental flow standards reevaluation.
Long-term Monitoring	Long-term trends in habitat, water quality, fish host, or Covered Species populations in a certain reach will inform adjustment to avoidance and minimization measures within that reach.
Short-term Refugia	The contingency plan for short-term refugia will be modified through time as new information, facilities and technologies become available.
Captive Propagation	Should successful captive propagation of the Covered Species become a reality, management decisions will be made regarding the best use of propagated individuals.

During this annual meeting, each party shall present any modifications to the agreement that they propose and the justification for those modifications. If mutually agreed upon, minor amendments are possible as described in Section 17.3. It is understood that adaptive management is a program and not an instantaneous event that relies on a solid baseline understanding and strong science. As such, it is recognized that several of the conservation measures informing these potential modifications will not be substantially completed until year 6 following execution of this agreement.

13.0 Changed and Unforeseen Circumstances

In the case of changed or unforeseen circumstances, assurances listed in this document apply to BRA where the CCAA is being properly implemented. “Changed circumstances” as defined in 50 CFR § 17. are, “changes in circumstances affecting a species or geographic area covered by a conservation plan or agreement that can reasonably be anticipated by plan or agreement developers and the USFWS and that can be planned for (e.g., the listing of new species, or a fire or other natural catastrophic event in areas prone to such events).” “Unforeseen circumstances” are changes in circumstances that could not reasonably have been anticipated by BRA and FWS at the time of the CCAA’s negotiation and development, and result in a substantial and adverse change in the status of the species.

13.1 Changed Circumstances

If additional Conservation Measures (including conservation measures and actions as described in this CCAA) are necessary to respond to changed circumstances and the measures were set forth in this CCAA, BRA will implement the measures specified herein. The BRA and the USFWS agree that a changed circumstance will have occurred if, at any time during the course of this agreement, the following conditions apply:

1. Another freshwater mussel or other aquatic species becomes listed within the Covered Area. If so, then conservation zones will be updated to include the distribution of this species, and conservation measures will be evaluated to account for the additional listing. If both parties agree that existing conservation measures are adequate for the newly listed species or agree on additional conservation measures to account for the newly listed species, then this agreement can be amended, preventing the need for a completely new agreement to be developed. Any change in the permit due to the listing of a new species will result in an amendment to the permit. This amendment will be focused only on the amendments proposed, such as, new species and modifications to the conservation measures; but not to any existing conservation measures not affected by the amendment.
2. Critical habitat is designated for covered species or for newly listed aquatic species within the Covered area. If so, then conservation zones will be updated to include the critical habitat, if not already covered, and conservation measures will be evaluated to account for the protection of the critical habitat. If both parties agree that existing conservation measures are adequate for protecting critical habitat or agree on additional conservation measures to protect critical habitat, then this agreement can be amended, preventing the need for a completely new agreement to be developed. Any change in the permit due to the designation of critical habitat for a new species will result in an amendment to the permit. This amendment will be focused only on the amendments proposed, such as modifications to the conservation measures; but not to any existing conservation measures not affected by the amendment.
3. Delisting of a Covered Species. Should USFWS publish a decision to delist a covered species, USFWS will notify BRA once the Final Rule is published in the Federal Register. In response to this changed circumstance, USFWS agrees that BRA may amend the CCAA and related documents to remove the delisted species from the list of Covered

Species and remove some or all the provisions related solely to the delisted species. Any change in the permit due to the delisting of a covered species will result in an amendment to the permit. This amendment will be focused only on the amendments proposed, such as, modifications to the conservation measures; but not to any existing conservation measures not affected by the amendment. BRA acknowledges that if the agreement and permit are amended to remove a covered species, then BRA will no longer receive assurances associated with that species.

4. Special Rules for Threatened Species. In the event that USFWS issues a Special Rule for threatened species, USFWS shall notify BRA of the changed circumstance. In the event of this Changed Circumstance, BRA may amend the CCAA and related documents to incorporate any applicable provisions of the Special Rule into the CCAA. Any change in the permit due to the publication of a special (i.e., 4(d)) rule for a covered species will result in an amendment to the permit. This amendment will be focused only on the amendments proposed, such as, modifications to the conservation measures; but not to any existing conservation measures not affected by the amendment. The net conservation benefit standard for issuance of a CCAA will remain in effect as the USFWS decides whether or not to issue an amended permit.
5. Taxonomic Changes. If taxonomic changes alter the known range, distribution or abundance of a Covered Species in ways that impact the incidental take authorized under this CCAA, BRA will coordinate with USFWS to amend the CCAA and any related documents, as appropriate.
6. TCEQ Environmental Flow Standards are substantially revised. If so, then BRA will coordinate with USFWS to evaluate if revision has the potential to negatively or positively impact Covered Species. If impacts are likely to be positive, no amendment to CCAA will be necessary. If revision has potential to be negative, BRA and USFWS will determine if revision to conservation measures is necessary and feasible and amend CCAA accordingly.
7. TCEQ Environmental Flow Standards are abolished. If so, then BRA agrees to operate following the WMP for the life of this agreement.
8. Invasive species are determined to be threatening the persistence of the Covered Species in the Covered Area. If so, BRA will work with USFWS and TPWD to conduct research or investigate potential removal and control efforts. Further, BRA will implement invasive species removal and control efforts that would not exceed 10 percent increase in the total annual operating costs of implementing the CCAA at the time. BRA will seek to cost share or secure matching grants if costs exceed the 10% spending cap for this Changed Circumstance. TPWD and USFWS may contribute funds or in-kind support for invasive species control efforts, at their sole discretion at the time and depending on availability of funds and other resources.
9. Fish host populations are determined to be in decline in the Covered Area. If so, BRA will work with USFWS and TPWD to conduct research or investigate what has led to the decline and what can be done to reverse or prevent further decline. Further, BRA will implement host fish population augmentation efforts that would not exceed 10 percent increase in the total annual operating costs of implementing the CCAA at the time. BRA

will seek to cost share or secure matching grants if costs exceed the 10% spending caps for this Changed Circumstance. USFWS may contribute funds or in-kind support for host fish restoration efforts, at their sole discretion at the time and depending on availability of funds and other resources.

10. Additional hydrologic modeling activities identifies new areas of the basin known to be occupied by the Covered Species to be at risk under future drought and management scenarios. BRA will evaluate measures to maintain subsistence flows in these newly identified areas and incorporate this new technical guidance information into the WMP to provide for the ecological needs of the Covered Species.
11. Allen's Creek Reservoir does not become operational during the term of this CCAA. If Allen's Creek Reservoir is not available as part of BRA's system of reservoirs to deliver surface water and flows for Covered Species, then BRA will evaluate other measures to maintain subsistence flows in areas occupied by the Covered Species downstream from Allen's Creek confluence. BRA will implement those measures in close coordination with USFWS.
12. If a catastrophic natural event such as wild fire, tornado, flood, toxicant or contaminant spill, dam failure, water treatment plant failure, or other event or disaster where adverse effects would be expected to temporarily reduce or degrade habitat, USFWS will hold BRA harmless for those impacts that are not a result of BRA's gross negligence. However, consistent with BRA's intent to provide a meaningful net conservation benefit to the Covered Species, BRA will coordinate with TPWD and USFWS and assist those agencies in habitat and population restoration efforts, at the sole discretion of TPWD and USFWS. BRA will make funds and in-kind resources available (not to exceed 10 percent increase in the total annual operating budget of the CCAA at the time) to assist in those efforts. USFWS may contribute funds or in-kind support for restoration efforts, at their sole discretion at the time and depending on availability of funds and other resources.
13. The total costs to implement additional conservation measures associated with a combination of Changed Circumstances will not exceed a total of 20 percent increase in the total annual operating budget of the CCAA at the time, and USFWS will help BRA prioritize which actions would be expected to result in the greatest conservation benefit. USFWS may contribute funds or in-kind support for restoration efforts, at their sole discretion at the time and depending on availability of funds and other resources.

13.2 Unforeseen Circumstances

If additional Conservation Measures (including conservation measures and actions as described in this CCAA) are necessary to respond to unforeseen circumstances, FWS may require additional measures of BRA, but only if such measures are limited to modifications within the CCAA's conservation strategy for the Covered Species, as described in Section 6 of this CCAA, and only if those measures maintain the original terms of the CCAA to the maximum extent possible. These additional Conservation Measures (including conservation measures and actions as described in this CCAA) will not involve the commitment of additional land, water, financial compensation, or additional restrictions on the use of land, water, or other natural resources

available for development or use under the original terms of the CCAA without the consent of BRA.

The FWS will demonstrate if unforeseen circumstances exist, using the best scientific and commercial data available. These findings must be clearly documented and based upon reliable technical information regarding the status and habitat requirements of the Covered Species. The FWS will consider, but is not limited to, the following factors:

- Size of the current range of the species;
- Ecological significance of the portion of the range affected by the Covered Area of the CCAA;
- Level of knowledge about the Covered Species and the degree of specificity of the species' conservation program under the CCAA; and,
- Whether failure to adopt additional Conservation Measures would appreciably reduce the likelihood of survival and recovery of the Covered Species.

In the unlikely situation in which an unforeseen circumstance results in likely jeopardy to a species covered by this CCAA and enhancement of survival permit, the Service could revoke this CCAA and permit as a last resort. However, the Service and its cooperators would first exercise all possible means to remedy the situation through other means (50 CFR § 17.22(d)(7)).

14.0 Covered Activities

14.1 CCAA related conservation, research, and monitoring activities

Covered Activities for this CCAA include the proposed conservation measures, applied research, long-term monitoring, and adaptive management activities described herein. These activities are designed to increase populations and improve habitat for the Covered Species by protecting critical habitats from future disturbance, ensuring appropriate flow conditions for population persistence, maintaining current data on distribution and population health, identifying populations of conservation priority, and defining key water quality and habitat stressors. The conservation activities will enable and encourage natural (and perhaps with help from TPWD or FWS sponsored reintroductions) increases in population number and extent of candidate mussels, as threats to the species, namely reduced flows during critical dry periods through management of the BRA system, are reduced through implementation of a comprehensive conservation strategy to benefit mussels in the Brazos basin. Information generated through the applied research and long-term monitoring will be used in an adaptive management framework to facilitate sound management activities, for the purposes of providing a substantial net conservation benefit over the 20-year term of the CCAA and permit. Although harm to the Covered Species is expected to be minimal and incidental to the proposed conservation, research and monitoring activities; all appropriate measures will be taken to minimize harm or incidental take that could occur during the implementation of those activities. Examples of potential incidental take could potentially include death of individual organisms during applied research studies, or disturbance of habitat during monitoring activities. However, since these conservation activities will provide a net conservation benefit over the course of the CCAA, incidental take associated with implementation of these activities, or the water supply

management and other legal activities outlined in Section 14.2, will be covered by the ESA section 10(a)(1)(A) enhancement-of-survival Permit, should either of the Covered Species become listed as threatened or endangered.

14.2 Existing BRA Water Supply and Delivery

This CCAA covers the activities conducted by BRA during their day-to-day water supply and delivery operations. Operating the BRA System involves multiple components including physical operation and maintenance of reservoirs and associated diversion, storage, and delivery of surface water, as well as compliance with water right permits and contract requirements.

Routine operation and maintenance activities generally include: water releases from the reservoir; inspections, cleaning, and repairs to intake structures and pump stations; inspecting, cleaning, replacing or repairs to dam gates and other mechanical structures on dams; dewatering concrete stilling basins below reservoirs for dam safety inspection, and when necessary, repairs to this part of the structure; and replacing or adding riprap for erosion control on the river banks immediately downstream of the dams but still within the dam's footprint. Although the known locations of Covered Species are sufficiently downstream of BRA dams to minimize the effects of these activities on the Covered Species, it is possible that these routine operation and maintenance activities could result in take of the Covered Species, should they become listed.

It should be noted that water supply operations in the Brazos River are complex and influenced by multiple users. The water rights associated with the BRA System currently equate to about 38% of the total permitted diversions within the basin. The 11 existing reservoirs authorize a total collective impoundment storage volume of 2,222,949 acre-feet, or approximately 53% of the total permitted storage within the entire basin.

The BRA operates its System in accordance with its water rights and water supply contracts to help meet water needs in the basin and to provide a resilient water supply. During times of drought, when senior water right holders' permitted water supply is not being met through natural flows, the State of Texas' Water Rights system requires that the BRA allow the passage of inflows through its reservoirs to meet the senior water right holders' needs. This water is transported via the bed and banks of the Brazos River and its tributaries. Additionally, many Brazos basin surface water users that contract with BRA for water supply are located in the lower Brazos basin. The primary method of conveyance of stored waters to these customers is also via the bed and banks of the Brazos River and its tributaries. Thus, during times of drought, downstream water deliveries from the BRA's System result in flow in the Brazos River and its tributaries.

Furthermore, the WMP associated with BRA's System Operation Permit (Water Use Permit No. 5851) requires that the State of Texas' Environmental Flow Standards for the Brazos basin must be met before water can be diverted from the Brazos River and its tributaries under Permit 5851 (BRA WMP Technical Report Section 4.0). The BRA will continue to develop new water supply projects, both surface water and groundwater, with the goal of increasing drought security and water availability for both human and aquatic species, including the Covered Species, in the BRA's System. Coincidentally, environmental flow standards must be accounted for in all new

surface water supply projects. Note that construction of new water supply and delivery infrastructure is beyond the scope of this CCAA, and new water supply and delivery infrastructure will be permitted separately should one or more of the Covered Species become listed under the Act. However, maintenance and operation of new infrastructure, like the Allen's Creek project, is expected to further the goals of this CCAA by helping to provide a net conservation benefit to the Covered Species over the 20-year term of this CCAA and permit, as described in Section 9.3.2. Thus, Covered Activities include maintenance and operation of existing as well as future water supply and delivery infrastructure developed in accordance with this CCAA but not their initial construction. New water supply projects that do not result in adverse impacts will provide benefits to freshwater mussels to the extent that BRA can use new water supply to provide for the instream flow and habitat needs of freshwater mussels, especially during droughts, through management of the BRA system of reservoirs.

15.0 Incidental Take

As part of this agreement, a variety of voluntary conservation measures will be implemented to benefit the Covered Species and population monitoring will be conducted to examine trends in population status through time. Should the Covered Species become listed, exact levels of incidental take associated with the activities in this CCAA are undeterminable at this time, but are expected to be minimal. Although minimal incidental take could occur as a result of activities in this agreement, implementation of this CCAA and subsequent conservation measures will provide conservation benefit to the Covered Species that is expected to result in net conservation benefit overall. The USFWS will issue an ESA section 10(a)(1)(A) enhancement-of-survival permit to BRA providing incidental take coverage for the Covered Activities and Conservation Measures described in this CCAA in the event one or more of the Covered Species is subsequently listed as threatened or endangered. Any take will be incidental to otherwise lawful activities described in this CCAA. Further, the BRA does not expect that the Covered Activities and Conservation Measures will result in long-term damages to habitats for the Covered Species.

Incidental Take could occur as a result of BRA's activities that involve operation and maintenance of its existing water supply and delivery infrastructure, and from implementation of its conservation, management, and monitoring program designed to benefit freshwater mussels. For example, false spike or Texas fawnsfoot may be inadvertently harmed by the downstream effects of: individual plant treatment of aquatic-approved herbicides; releases of water from stilling basins that is of high temperature, low dissolved oxygen or otherwise degraded; or through sediments transported downstream following maintenance of reservoir infrastructure including dams, rip-rap, and stilling basins. Further, false spike or Texas fawnsfoot may be inadvertently killed or injured during population surveys and other long-term monitoring activities, or habitat manipulations in the short-term. Considered altogether, incidental take associated with BRA's activities is not expected to be great enough to compromise the viability of populations of false spike or Texas fawnsfoot in the Brazos River basin.

The Covered Species are expected to naturally increase in population numbers and extent following implementation of the conservation measures and associated activities or are otherwise reintroduced. If that were to occur, there is an increased likelihood that injury or death to a false

spike or Texas fawnsfoot individual will occur as a result of BRA's ongoing water management and conservation activities. Adverse effects to the false spike or Texas fawnsfoot could occur in the forms of death, injury, and reproductive failure during the implementation of water management or conservation activities. For example, false spike or Texas fawnsfoot may be inadvertently killed or injured during population surveys and other long-term monitoring activities, or habitat manipulations in the short-term. Direct take of Covered Species, if listed and if determined to be necessary, for applied research would be provided for in individual 10(a)(1)(A) scientific permits issued directly to the researchers, and not by the CCAA. Individuals of the Covered Species may experience reproductive failure and reduced growth rates associated with being handled during surveys or relocation events, or from environmental stress associated with short-term periods of reduced flows. Sub-adult life stages including glochidia and juveniles may be especially sensitive. False spike or Texas fawnsfoot may be killed or injured due to infrastructure maintenance or upgrades associated with BRA's surface water supply and delivery operations, or catastrophic failure. Although considered unlikely, false spike or Texas fawnsfoot may also be killed or injured during routine water management activities (i.e., delivering water from BRA reservoirs to downstream customers via the bed and banks of the Brazos River).

The USFWS anticipates that incidental take of Covered Species will be difficult to detect for the following reasons: juveniles of the covered species have a small body size and finding a dead or impaired juveniles is unlikely; losses may be masked by seasonal fluctuations in population size (and detectability) or by losses associated with actions or events outside of BRA's control; losses are most likely to be sub lethal and difficult to measure. Larger individuals are easier to detect, especially because they are usually found in aggregations called mussel beds. Although this agreement does not anticipate that large scale dewatering events of entire mussel beds leading to stranding of adult mussels because of BRA's activities, it is still possible that, in combination with factors outside of BRA's control, the death of mature individuals could be visibly detectable if entire riffles or bank habitats are persistently dewatered. Sub-adult life stages are not likely to be detected. The level of monitoring identified in this agreement would detect this level of take, especially because BRA will have knowledge of flow conditions in occupied stream reaches. Larger individuals are also more likely to be encountered during monitoring activities and take associated with such encounters is relatively easy to quantify, track, and report.

BRA will notify USFWS as soon as reasonably possible in the event that BRA becomes aware of any take occurring or expected to occur resulting from covered activities or implementation of conservation measures.

The purpose of the agreement is to protect false spike and Texas fawnsfoot habitat areas, and to reduce threats so habitat areas can expand; therefore, USFWS expects that the conservation activities covered by the CCAA and permit will increase the amount and quality of suitable false spike and Texas fawnsfoot habitat. There may be minimal, short-term negative effects to some of the false spike or Texas fawnsfoot habitat features associated with some of the covered activities, but generally the effects are expected to be beneficial and result in a net conservation benefit for the Covered Species in the 20-year term of the agreement.

Level and Type of Take and Impacts

Incidental take should be expressed in terms that are measurable and enforceable in the CCAA and in the incidental take permit. The unit of take must be practicable which means it can be monitored and the results of monitoring can be applied to adaptive management decisions.

We anticipate that incidental take of these species will be difficult to definitively quantify for the following reasons: finding a dead or impaired specimen is unlikely; and losses may be masked by seasonal fluctuations in environmental conditions and/or numbers of each species. Therefore, it is not possible to provide precise numbers of mussels that will be harassed, harmed, or killed during implementation of this CCAA. In such instances where take is otherwise difficult to detect and/or quantify, we may quantify take in terms of some aspect of the species' habitat that may be diminished or removed by the action. We are therefore using a percentage of the stream miles per zone that maybe affected as a habitat surrogate measure to identify when take has been exceeded. Negative effects to mussel habitats associated with BRA's Covered Activities are expected to be temporary in nature, and the magnitude of those effects is expected to vary from year to year. Through implementation of the CCAA, possible temporary habitat disturbance are expected to naturally recover with time.

The causal link between using stream miles of riverine habitat as a surrogate (50 CFR 402.14(i)(1)(i)) for take of individual mussels is the fact that mussels spend the majority of their life cycle relatively immobile with most of their bodies buried in sediment of the stream bed. BRA's covered activities include physical disturbance of stream beds as well as possible changes to water quality, water levels, and flow rates. Activities that disturb stream beds and alter water quality, water levels, and flow rates could injure or kill false spike and Texas fawnsfoot (adult mussels, juveniles, larval glochidia) or displace mussels or their host fish (possibly disrupting reproduction) to unsuitable habitats. Low water levels could expose mussels to desiccation, heat stress, and predation. Water quality degradation could result in excessive valve closure, which has been reported to have negative effects on mussel health and reproduction (through increased energetic costs and reduced feeding rates; Haney et al. 2019, p. 13).

These take approximations can inform possible levels of injury or death to individuals of the Covered Species due to BRA's Covered Activities, and set targets that can be monitored and reported annually. BRA can monitor and document the percentage of stream miles in each zone affected by its actions (and possibly others), through a variety of measures including remote sensing and habitat monitoring. Additionally, dead shells and recently dead individuals may be detected during routine or contemporaneous monitoring visits, and reported to the Service.

Given Zone A is 56.4 stream miles of potential false spike habitat, and that most of these stream miles are distant from BRA infrastructure that could cause take, one could assume that not more than 10% of those stream miles could be adversely affected by BRA's covered activities over the term of the CCAA, yielding 5.64 stream miles that could somehow be adversely affected in 20 years.

Given Zone B is 181.6 stream miles of potential high density Texas fawnsfoot habitat, and that most of these stream miles are distant from BRA infrastructure that could cause take, one could

assume that not more than 10% of those stream miles could be adversely affected by BRA's covered activities over the term of the CCAA, yielding 18.16 stream miles that could somehow be adversely affected in 20 years.

Given Zone C is 246.2 stream miles of potential low density Texas fawnsfoot habitat, and that most of these stream miles are distant from BRA infrastructure that could cause take, one could assume that not more than 10% of those stream miles could be adversely affected by BRA's covered activities over the term of the CCAA, yielding 24.62 stream miles that could somehow be adversely affected in 20 years.

Given Zone D is 355.1 stream miles where Texas fawnsfoot is presumed to be absent but possibly will be restored to low density over the next 20 years, and that most of these stream miles are distant from BRA infrastructure that could cause take, one could assume that not more than 10% of those stream miles could be adversely affected by BRA's covered activities over the term of the CCAA, yielding 35.51 stream miles that could be somehow be adversely affected in 20 years.

Therefore, in total, not more 83.93 stream miles are expected to be harmed by BRA's Covered Activities cumulatively over 20 years. Because incidental take of these species will be difficult to detect and monitor, BRA will notify the Service if it expects its activities will affect more than 10% of the habitat identified in any particular zone, cumulatively in 20 years.

16.0 Regulatory Assurances

If approved, The USFWS provides regulatory assurances to BRA that so long as the CCAA is implemented as agreed, the USFWS will not require additional conservation measures nor impose additional land, water, or resource-use restrictions, beyond those stated and agreed to in this CCAA. These assurances are made consistent with the USFWS Candidate Conservation Agreements with Assurances Policy (2016, 81 FR 95164) and will be authorized in an ESA Section 10(a)(1)(A) enhancement-of-survival permit that becomes effective when and if either of the Covered Species is listed as threatened or endangered in the future. The enhancement-of-survival Permit will authorize the incidental take of the species by BRA as long as their actions are consistent with the CCAA, subject to the terms and conditions described in 50 CFR 17.22(d)(1) and 50 CFR 17.32(d)(1).

17.0 Agreement Term, Responsibilities, Amendment and Termination

17.1 Agreement Term

This CCAA will have a duration of 20 years from the date of signature. It can be renewed upon application by BRA provided the USFWS determines that it still provides net conservation benefit and still complies with applicable CCAA policy.

Should any of the Covered Species become listed as threatened or endangered, the enhancement of survival permit will become effective and remain in effect through the expiration of the CCAA.

17.2 Responsibilities of Each Party

BRA shall be responsible for:

- Funding, administering, and implementing this CCAA and associated voluntary conservation measures per the designated timeline (Section 10.0)
- Reporting to USFWS as described in Section 11.0
- Notifying the USFWS in the event that any lands, waters, or other rights subject to this CCAA are transferred to another entity.

USFWS shall be responsible for:

- Evaluating the results of monitoring data and conservation measures to assess if the actions of this CCAA are providing the desired net conservation benefit
- Reviewing and approving annual reports submitted by BRA
- Issuing an enhancement-of-survival permit to BRA to allow for incidental take of the Covered Species should either of the Covered Species become listed as threatened or endangered in the future. This permit would only authorize incidental take while conducting Covered Activities within the Covered Area.

Both parties shall be responsible for:

- Alerting the other party should any conflicts with ongoing conservation programs for the Covered Species arise or become known.

17.3 Modifications and Amendments

Any party to this CCAA may propose minor amendments to the agreement by providing written notice to the other party. This written notice will include a description of the proposed amendment, the justification for the amendment, and the expected results or outcomes. Once proposed, the other party has 60 days to respond to the amendment request. Proposed amendments will become effective upon the other parties' written concurrence, and the CCAA document will be modified or added, as appropriate, unless there is a change in affects to covered species.

In the event that an amendment results in a different level of take than that associated with the original CCAA, changes in the permit conditions, addition or removal of covered species, an extreme unforeseen circumstance, or a change to the net conservation benefit such that the CCAA standard may not be met, this would be considered a major amendment. A major amendment will be subject to procedural requirements of Federal laws and regulations and a formal CCAA amendment process. This process could include additional analysis by the USFWS, public notification in the Federal Register, and NEPA analysis.

17.4 Dispute Resolution

The BRA and USFWS agree to work together in good faith to resolve any disputes using dispute resolution procedures agreed upon by all parties.

17.5 Termination of CCAA, Suspension or Revocation of Permit

The BRA may terminate the implementation of the CCAA's voluntary management actions at any time for any cause prior to the CCAA's expiration date, even if the expected benefits have not been realized. In such a case, if any of the Covered Species have been listed and an Enhancement of Survival Permit has been issued, BRA would be required to surrender the permit and thus relinquish all associated take authority and assurances.

If issued, the USFWS may suspend or revoke the Enhancement of Survival Permit for cause in accordance with the laws and regulations in force at the time. Criteria for revocation are identified in 50 CFR 17.22 (d)(1) for species that are subsequently listed as endangered and 50 CFR 17.32 (d)(1) for species that are subsequently listed as threatened.

18.0 Authorized Signatures

For the Brazos River Authority:



David Collinsworth

General Manager/CEO

Brazos River Authority

For the U.S. Fish and Wildlife Service:

Jeffery M. Fleming

Deputy Regional Director,

U.S. Fish and Wildlife Service

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Appendices

Appendix A. Other Native Freshwater Mussel Species

Although specifically targeted at the two Covered Species (False spike and Texas fawnsfoot), conservation measures identified in this CCAA will result in conservation benefit for all native freshwater mussel species in the Covered Area. Based on historic and current records and recognizing the latest taxonomic changes, there are 22 freshwater mussel species (including False spike and Texas fawnsfoot) that potentially occur in the Brazos River basin and could benefit from conservation measures in this agreement (**Table A-1**; Howells 2014; Williams et al. 2017; Johnson et al. 2018). Although sporadic records occur throughout the basin, the most recent survey data indicate that freshwater mussels are currently most diverse and abundant in the lower mainstem Brazos River, as well as several larger tributaries including the Leon River, Little River, Navasota River, and Yegua Creek (Randklev et al. 2013, 2017; Bonner et al. 2018; Khan et al. 2018). It should also be noted that some portions of the basin have yet to be comprehensively surveyed.

Table A-1. Freshwater mussels of the Brazos River basin.

Scientific Name	Common Name
<i>Arcidens confragosus</i>	Rock pocketbook
<i>Amblema plicata</i>	Threeridge
<i>Cyrtonaias tampicoensis</i>	Tampico pearlymussel
<i>Cyclonaias pustulosa</i>	Pimpleback
<i>Fusconaia mitchelli</i>	False spike
<i>Glebulia rotundata</i>	Round pearlshell
<i>Lampsilis hydiana</i>	Louisiana fatmucket
<i>Lampsilis teres</i>	Yellow sandshell
<i>Leptodea fragilis</i>	Fragile papershell
<i>Ligumia subrostrata</i>	Pondmussel
<i>Megalonaias nervosa</i>	Washboard
<i>Potamilus ohiensis</i>	Pink papershell
<i>Potamilus purpuratus</i>	Bleufer
<i>Pyganodon grandis</i>	Giant floater
<i>Quadrula apiculata</i>	Southern mapleleaf
<i>Toxolasma parvum</i>	Lilliput
<i>Toxolasma texasiense</i>	Texas lilliput
<i>Tritogonia verrucosa</i>	Pistolgrip
<i>Truncilla macrodon</i>	Texas fawnsfoot
<i>Unio merus declivis</i>	Tapered pondhorn
<i>Unio merus tetralasmus</i>	Pondhorn
<i>Utterbackia imbecillis</i>	Paper pondshell

Appendix A References

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Appendix B. Hydrologic Modeling

1.0 Introduction

The hydrologic modeling detailed below was conducted as one component of the conservation strategy outlined in the CCAA above. This hydrologic modeling, summarized in Section 8.0 of the CCAA, was used to evaluate future low-flow risk to freshwater mussels within the Covered Area during the permit period, and to thus assist in spatially and temporally prioritizing conservation measures. The analysis focused on low flow events, as these events were considered most likely to potentially influence freshwater mussel persistence. Although large flood flows may also influence freshwater mussel persistence, the BRA has limited ability to manage flood flows. The U.S. Army Corps of Engineers (USACE) is the primary owner and operator of flood control reservoirs in the basin.

When evaluating future hydrology scenarios, it is important to note that BRA is not the sole water management entity in the basin. Conditions are dependent on inter-related operations of hundreds of other water rights located throughout the basin, and the state of Texas has appointed a Watermaster to oversee use of state water rights permits in the Brazos River basin. This analysis accounted for all water users, not just BRA, to characterize future hydrology in the Covered Area.

Depending on local projected water use patterns, climate variables, and other factors the risk of future low flow conditions are expected to vary throughout the basin. The goal of this study was to evaluate the frequency of low flow conditions within segments of the Covered Area under multiple hydrologic scenarios. This information was then used to identify river segments currently occupied by the Covered Species which may experience increased low flow stress under future scenarios, and to identify areas of lower risk that could potentially serve as areas for restoration and enhancement opportunities. To accomplish this, hydrologic scenarios were modeled based on the Brazos River Water Availability Model (WAM; TCEQ 2018), as detailed below.

2.0 Methods

2.1 Study Area

This analysis focuses on the CCAA Covered Area, which includes the Brazos River basin downstream from Possum Kingdom Reservoir, sub-divided into 20 separate TCEQ stream segments. Each stream segment has an associated USGS gage location used to represent the hydrology in that segment (**Figure B-1**). To evaluate the spatial distribution of BRA management, four select gage locations were analyzed; Brazos River near Palo Pinto, Navasota River near Easterly, Little River near Cameron, and Brazos River near Hempstead.

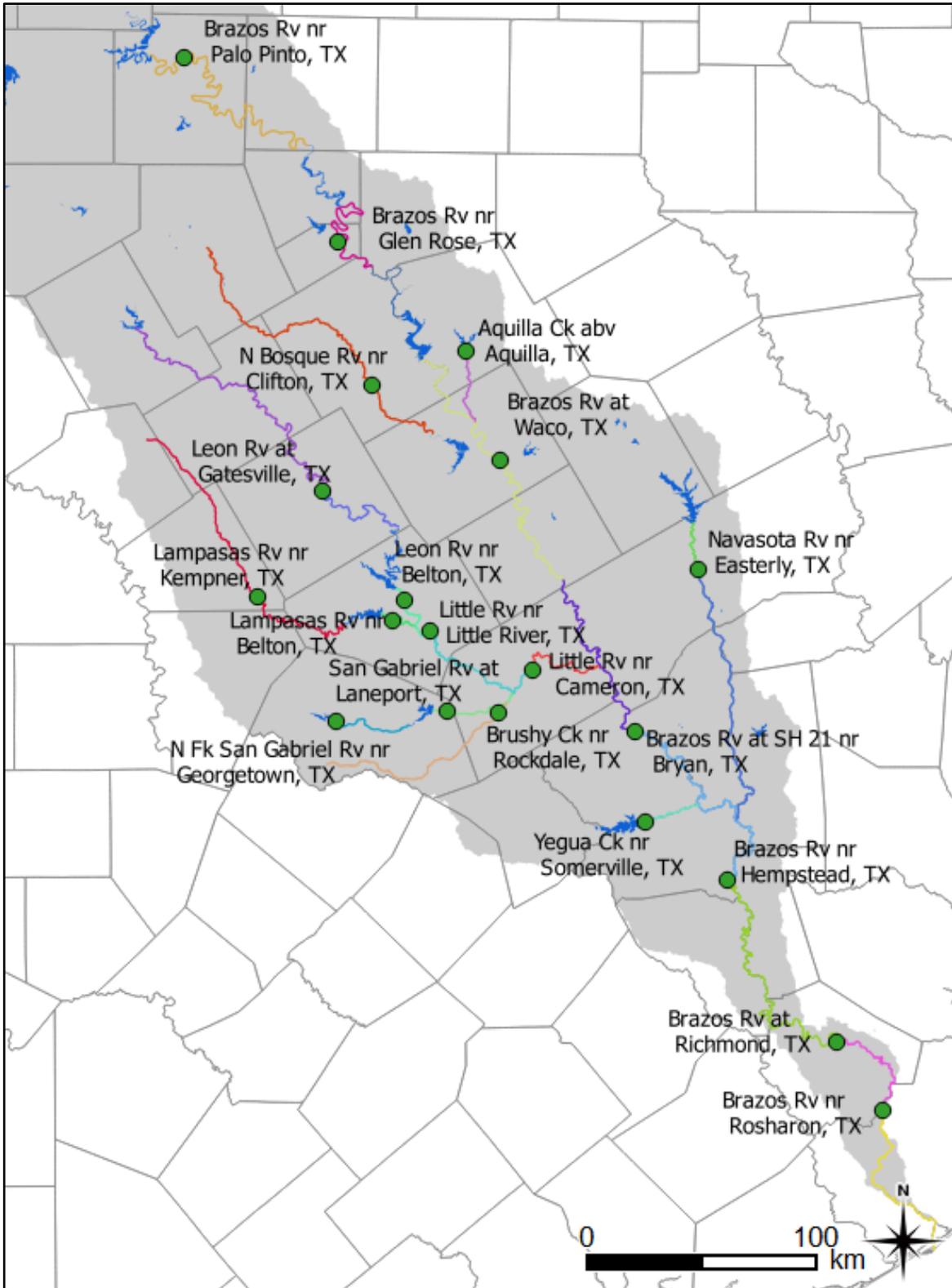


Figure B-1. Map of stream segments and associated gage locations within the Brazos River basin used in this analysis.

2.2 Water Availability Model

Future hydrology estimates were derived from the Water Availability Model (WAM) Water Rights Analysis Program (WRAP) that is relied upon by the state of Texas and maintained by the Texas Commission on Environmental Quality (TCEQ) for water rights permitting in the entire State of Texas, including the Brazos River basin. The WAM is a modeling tool used to predict the amount of water available in a river system under a specified set of conditions. It considers all water users and makes assumptions about water management, including demand schedules; diversion locations; reservoir storage and sedimentation; precipitation and evaporation; stream gains and losses; return flow discharges; and environmental flow conditions. As is typical in WAM modeling, results were simulated on a monthly-average time step. Historical observed stream flow information from USGS gage records were used as a baseline for comparison to model scenarios of projected hydrology to evaluate future changes to hydrologic patterns.

2.3 Model Scenarios

Four different time series representing different scenarios of hydrology and water management were considered for this analysis. Each time series was derived for the period 1940 through 2015 to include drought, base and high flow conditions. The scenarios analyzed included:

1. Naturalized Scenario – represents natural stream flow conditions without any influence of humans, as if no water management, reservoirs, diversions or return flows existed. This naturalized flow time series is used as the basis for the WAM modeling and was calculated based on observed records of stream flows, precipitation, evaporation, diversions, storage and return flows.
2. Historical Conditions – observed stream flow records from USGS, as available during the 1940-2015 period. Historical Conditions can be described as if history would repeat itself.
3. 2060 Scenario – hypothetical scenario where BRA water demands are set at state-projected year 2060 levels at best-anticipated locations, and where return flow discharges are added back into the streams at levels consistent with recent history, and non-BRA water rights are at full-authorization levels. In this scenario, Allen’s Creek reservoir is assumed to be constructed and in operation. Although 2060 is beyond the permit term, and thus conservative, this scenario represents the best-known projection of water management that may occur during the 20-year CCAA timeframe.
4. Full Authorization Scenario – hypothetical maximum-use future scenario. All permit holders use their maximum amount of water all of the time, and no water is returned to the river from discharges. Full Authorization can be described as a worst-case scenario for producing low flow events and provides very conservative estimates of future conditions since water demands are not expected to approach full utilization during the CCAA timeframe and a significant portion of diversions are discharged back into the river.

The Naturalized Scenario represents the projected conditions that would have occurred in the absence of any management or infrastructure and is important in understanding the naturally

dynamic nature of the system. Historical Conditions represents what has occurred over the last 75 years. Therefore, Historical Conditions are used as a baseline for comparison. Since the 2060 Scenario is the best representation of future conditions that may occur during the term of the CCAA, the majority of analysis in this document focuses on comparison of Historical Conditions to the 2060 Scenario. The Full Authorization Scenario represents a full-utilization no-return-flow condition that is important for reference, but is unlikely to occur in the timeframe of the CCAA, if ever.

2.4 Flow Conditions and Metrics Evaluated

To assess the future potential for low flow events that may influence freshwater mussel populations in each stream segment the frequency of subsistence and zero flow conditions were calculated from model results. Subsistence flows are defined as “the minimum streamflow needed during critical drought periods to maintain tolerable water quality conditions and to provide minimal aquatic habitat space for the survival of aquatic organisms” (NAS 2005). These values vary among stream segments depending upon stream size, watershed area, etc. When available, previously defined subsistence flow values for each segment were taken from the BRA Water Management Plan or from TCEQ environmental flow standards generated during the Senate Bill 3 environmental flow process (**Table B-1**; BRA 2018, TCEQ 2014). In some instances, where previously-established subsistence flow values were not available, 7Q2 values published by TPWD or TCEQ were used as subsistence values (**Table B-1**). The 7Q2 is a hydrologic statistic that represents the annual lowest mean discharge for 7 consecutive days with a 2-year recurrence interval. It should be noted that due to differences in the way they are calculated, 7Q2 values are often higher than subsistence values from environmental flow analysis. However, in the absence of identified subsistence flow values, 7Q2 values represent a comparable low flow statistic. To analyze the frequency of low flow conditions, the percent of months at or below subsistence and the percent of months at zero flow were calculated for each model scenario within each stream segment.

Table B-1. Gage locations evaluated in this analysis, subsistence flow values used, and source of subsistence values.

USGS Gage	USGS Gage No.	Subsistence Flow (cfs)	Subsistence Source
Brazos River near Palo Pinto	08089000	17	BRA WMP ¹
Brazos River near Glen Rose	08091000	16	BRA WMP ¹
Aquilla Creek above Aquilla	08093360	0.1	7Q2 TPWD ³
North Bosque River near Clifton	08095000	1	SB3 TCEQ ²
Brazos River near Waco	08096500	56	BRA WMP ¹
Leon River near Gatesville	08100500	1	BRA WMP ¹
Leon River near Belton	08102500	4.7	7Q2 TPWD ³
Lampasas River near Kempner	08103800	10	SB3 TCEQ ²
Lampasas River near Belton	08104100	4.8	7Q2 TPWD ³
Little River near Little River	08104500	55	BRA WMP ¹
North Fork San Gabriel River near Georgetown	08104700	1.1	7Q2 TPWD ³
San Gabriel River at Laneport	08105700	3.6	7Q2 TPWD ³
Brushy Creek near Rockdale	08106300	3.4	7Q2 TCEQ ⁴
Little River near Cameron	08106500	32	BRA WMP ¹
Brazos River at SH21 near Bryan	08108700	300	BRA WMP ¹
Yegua Creek near Somerville	08110000	0.1	7Q2 TPWD ³
Navasota River near Easterly	08110500	1	BRA WMP ¹
Brazos River near Hempstead	08111500	510	BRA WMP ¹
Brazos River near Richmond	08114000	550	BRA WMP ¹
Brazos River near Rosharon	08116650	430	BRA WMP ¹

¹ Subsistence flow values for locations included in the BRA System Operation Permit Water Management Plan (BRA WMP) that are the same as SB3 TCEQ locations.

² Subsistence flow values derived from adopted Texas Commission on Environmental Quality (TCEQ) rules for the Brazos River basin, 30TAC 298 G, effective March 6, 2014. These locations are not included in the BRA WMP.

³ Published 7Q2 subsistence flow values at locations that are part of an environmental flow agreement between BRA and Texas Parks and Wildlife Department (TPWD and BRA 2015).

⁴ Published 7Q2 flow values from TCEQ for areas outside of the BRA WMP.

3.0 Results

3.1 Spatial Distribution of BRA Management

Model results were extracted to understand how naturalized flow available for water use at specific locations was allocated to the 1,000+ water right records according to their priority and amount of water demands. These allocated amounts of available flow were divided into two categories: BRA Water Rights and All Other Water Rights. In addition, because BRA stores much of its water when it is first available and then returns that water to the river at a later time by making reservoir releases, BRA releases to downstream customers were also extracted to compare the relative magnitude. This combination of storage and subsequent release is indicative of amounts of water managed by BRA, relative to other water rights users. Excess flood water stored and released by USACE for flood control purposes are generally considered in the

modeling and these flood flows represent a significant volume. However, for this discussion about managed water use to satisfy water demands in the basin, only the portion of flood flows that were claimed or allocated by water users were extracted.

Modeled use of BRA's management of water rights comprised less than 50% of total combined surface water use in the basin, although the degree of BRA's water management varied spatially across the basin and also varied according to hydrologic condition. In the upper basin near Palo Pinto, available flow allotted to and managed by BRA is greater than 50% (**Figure B-2a**). Conversely, the available flow allotted to BRA decreased substantially in the lower Brazos River at Hempstead (**Figure B-2b**), due to multiple other large senior water rights in the lower Brazos River basin. Within the major tributaries, BRA is allotted differing portions of the available water. Due to operating Lake Limestone, BRA also contributed downstream water supply reservoir releases into the Navasota River (**Figure B-2c**). Future BRA management in the Little River, as modeled in the WAM, is primarily based on meeting local customer demands rather than water delivery releases to customers (**Figure B-2d**). However, downstream releases in this reach still occur as a result of USACE flood flow releases.

Although this analysis was based on all flow levels, BRA influence generally increases under low flow conditions and decreases under high flow conditions. During high flow periods, BRA has limited ability to manage water in the basin because BRA does not control flood storage in any reservoirs. During low flow periods under the Full Authorization Scenario, BRA releases of stored water generally account for between 20-85% of water in covered stream reaches, with less management and influence in the lower basin.

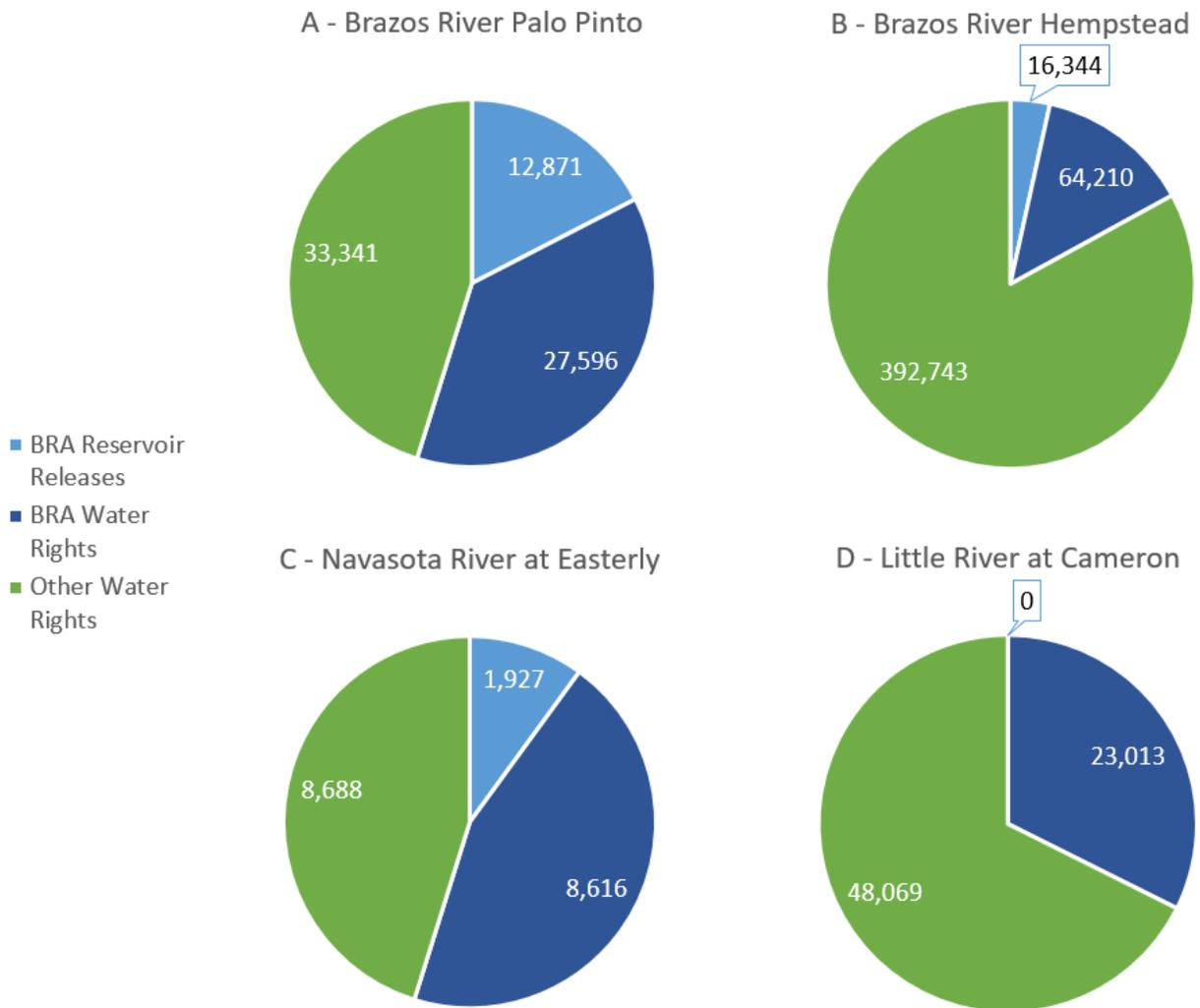


Figure B-2. Spatial distribution of BRA management based on average available flows and reservoir releases (acre-feet/month) at 4 USGS stream gages (Brazos River at Palo Pinto [A] and Hempstead [B], Navasota River at Easterly [C], and Little River at Cameron [D]) under the Full Authorization Scenario, averaged across the simulation period 1940-2015.

3.2 Subsistence Flows

Subsistence flows are naturally occurring infrequent periods of low flow during drought situations. Therefore, it is not surprising that all stream segments evaluated have experienced subsistence flow conditions under the Naturalized Scenario (**Figure B-3**). The natural frequency of subsistence conditions within each stream segment is projected to have ranged from 2.2% at the Brazos River near Rosharon to 23.5% at Aquilla Creek above Aquilla (**Table B-2**).

Subsistence flows generally occurred in higher frequency within tributaries than in the mainstem, as smaller watersheds of tributaries are more strongly influenced by localized drought conditions than larger catchments.

Historically, the percent of time at or below subsistence flows ranged from 0.4% at the Brazos River near Palo Pinto to 13.8% in the North Fork San Gabriel River near Georgetown (**Table B-2, Figure B-4**). The percent of time at or below subsistence was generally greater in segments

where subsistence values were based on 7Q2 values than in segments where subsistence values were determined based on environmental flow analysis. When compared to the Naturalized Scenario, 15 of 20 locations exhibit reduced frequency of subsistence flows under Historical Conditions. The five locations in which frequency of subsistence flows has increased include Leon River near Gatesville, Lampasas River near Belton, North Fork San Gabriel River near Georgetown, San Gabriel River at Laneport, and Brazos River near Rosharon.

When the 2060 Scenario is compared to Historical, the percentage of time at or below subsistence flows increased in some segments and decreased in others (**Table B-2, Figure B-5**). The percent of time at or below subsistence decreased to 0% in the Navasota River at Easterly, Aquilla Creek above Aquilla, Yegua Creek near Somerville, Brushy Creek near Rockdale, and the Leon River near Belton. Frequency of subsistence flows also decreased considerably in the North Bosque River near Clifton, Leon River near Gatesville, Little River near Cameron, and the Brazos River near Richmond. In contrast, the percentage of time at or below subsistence flows increased considerably in the San Gabriel system (North Fork near Georgetown and mainstem near Laneport), the Lampasas River near Belton, and the lower Brazos River near Rosharon.

When compared to Historical Conditions, the Full Authorization Scenario leads to increased frequency of subsistence in 14 of 20 stream segments, with frequency of subsistence exceeding 15% at multiple sites (**Table B-2, Figure B-6**). A general increase in frequency of low flows under this scenario is expected since it includes full utilization of all water rights and no return flows. However, six locations experienced decreases in frequency of subsistence flows under this scenario, including: Aquilla Creek above Aquilla, Leon River near Gatesville, Leon River near Belton, Navasota River near Easterly, Brazos River near Hempstead, and Brazos River near Richmond.

Table B-2. Percent of time at or below subsistence flows for each gage location under each scenario. The last column represents the best representation of the difference between projected future conditions within the term of the CCAA (2060) and past conditions (Historical). Positive values in the last column represent an increase in the percent of time at or below subsistence flows, whereas negative values represent a decrease.

USGS Gage	USGS Gage No.	Percent of Time at or Below Subsistence				Difference (2060 - Historical)
		Naturalized Scenario	Historical Conditions	2060 Scenario	Full Authorization Scenario	
Brazos River near Palo Pinto	08089000	7.5	0.4	0.3	3.8	-0.1
Brazos River near Glen Rose	08091000	4.3	1.2	3.2	13.3	2.0
Aquilla Creek above Aquilla	08093360	23.5	12.3	0.0	0.0	-12.3
North Bosque River near Clifton	08095000	8.5	6.2	0.1	8.6	-6.1
Brazos River near Waco	08096500	2.7	1.3	3.1	1.7	1.8
Leon River near Gatesville	08100500	4.1	4.6	1.9	4.5	-2.7
Leon River near Belton	08102500	6.2	5.2	0.0	0.0	-5.2
Lampasas River near Kempner	08103800	7.6	3.8	7.3	11.3	3.5
Lampasas River near Belton	08104100	6.3	12.3	48.8	16.2	36.5
Little River near Little River	08104500	10.0	1.4	1.8	30.0	0.4
North Fork San Gabriel River near Georgetown	08104700	10.5	13.8	60.7	50.6	46.9
San Gabriel River at Laneport	08105700	6.5	7.5	24.0	32.2	16.5
Brushy Creek near Rockdale	08106300	19.0	5.3	0.0	19.2	-5.3
Little River near Cameron	08106500	4.0	2.9	0.4	15.7	-2.5
Brazos River at SH21 near Bryan	08108700	6.2	2.0	1.6	2.4	-0.4
Yegua Creek near Somerville	08110000	9.3	8.7	0.0	14.4	-8.7
Navasota River near Easterly	08110500	8.6	2.1	0.0	0.8	-2.1
Brazos River near Hempstead	08111500	6.5	2.4	2.3	0.1	-0.1
Brazos River near Richmond	08114000	4.9	2.7	0.1	0.0	-2.6
Brazos River near Rosharon	08116650	2.2	3.7	9.5	16.3	5.8

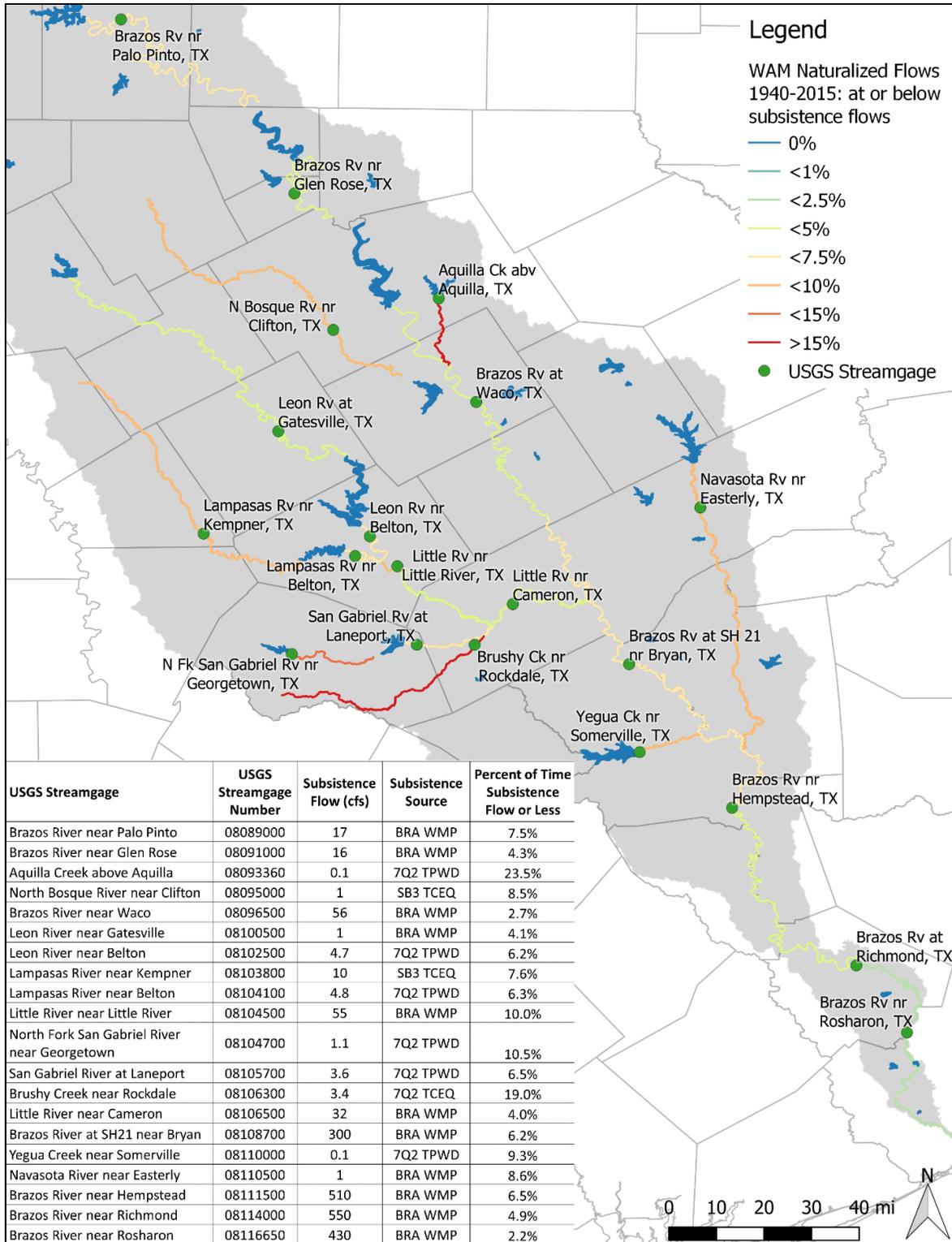


Figure B-3. Percent of time at or below subsistence flow based on the Naturalized Scenario.

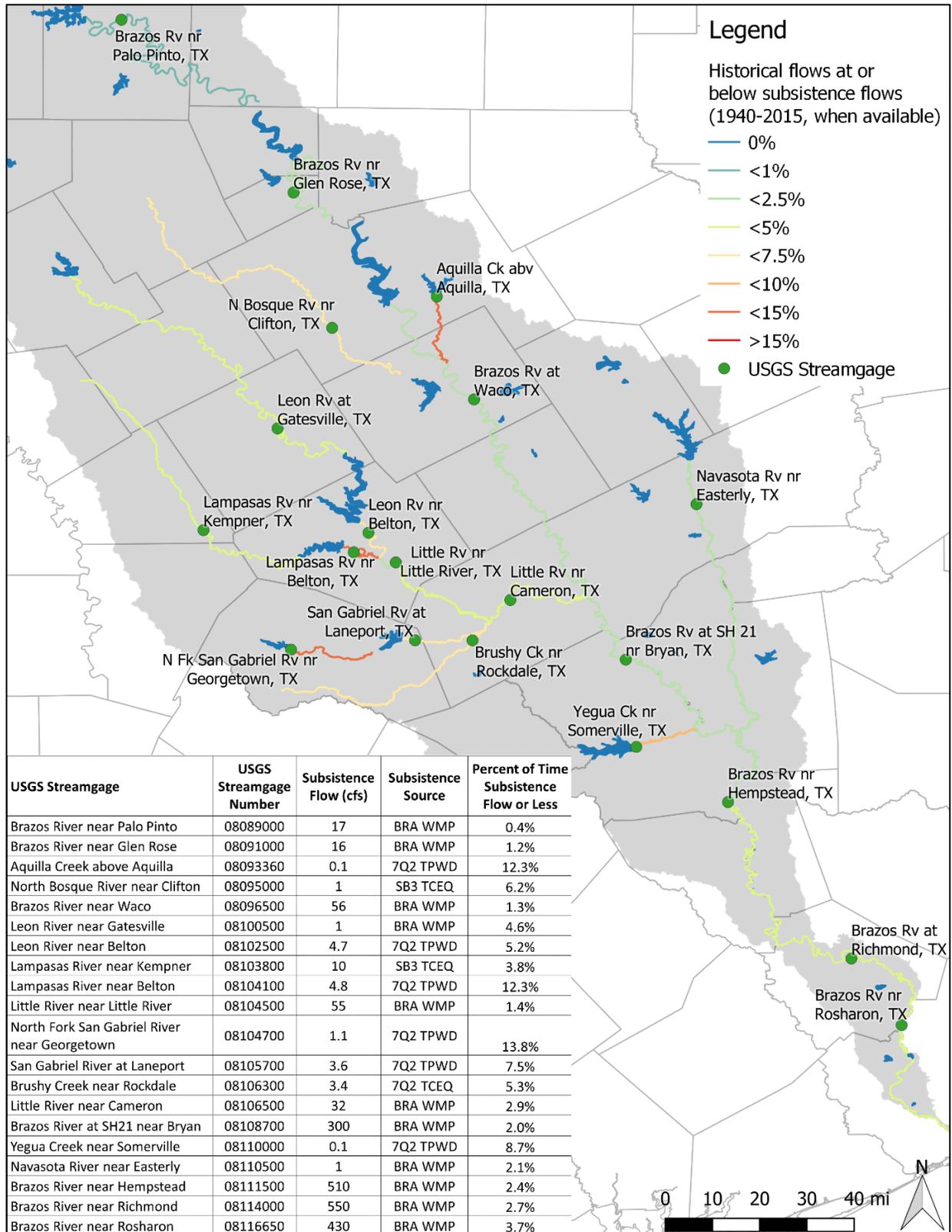


Figure B-4. Percent of time at or below subsistence flow based on Historical Conditions.

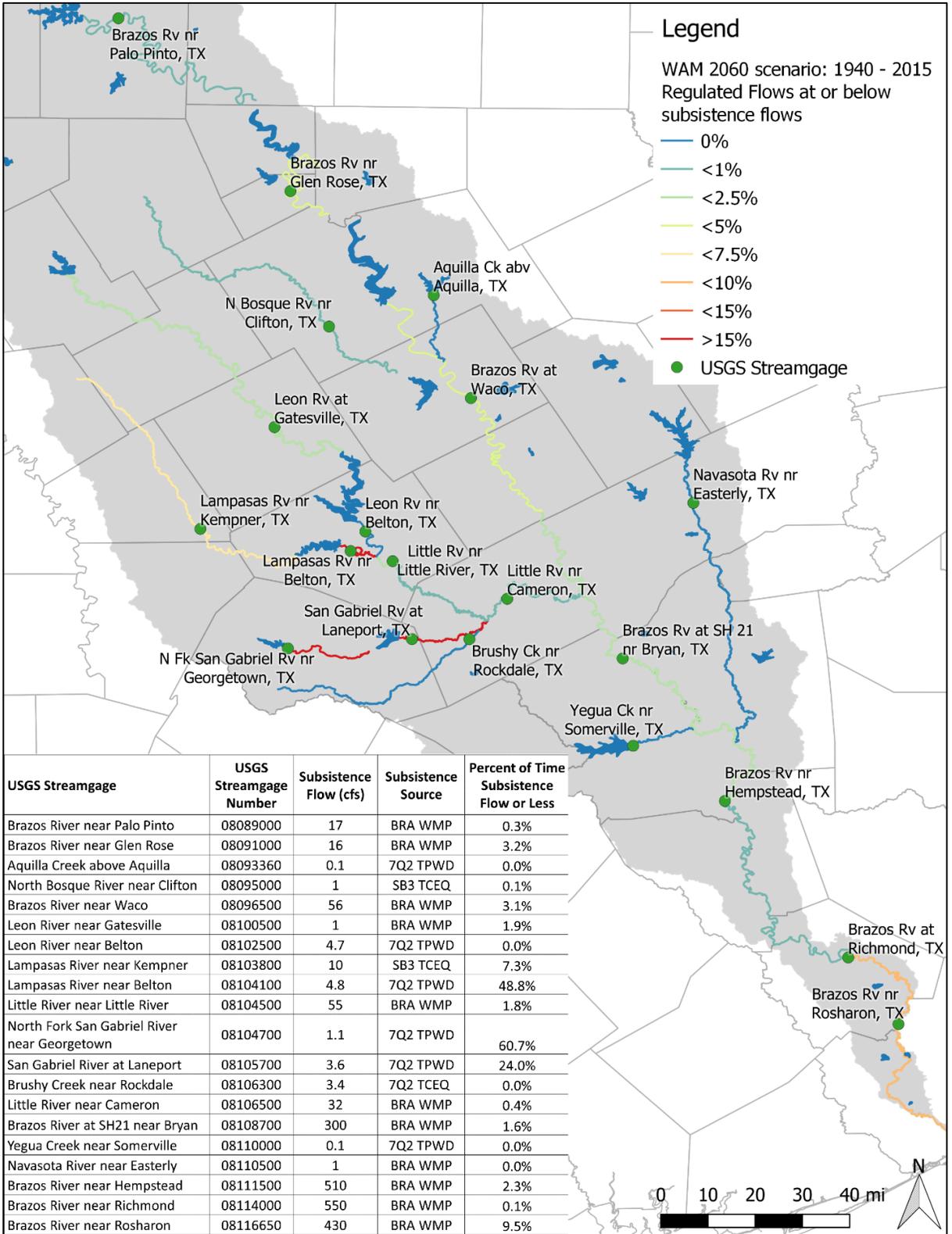


Figure B-5. Percent of time at or below subsistence flow under the 2060 Scenario.

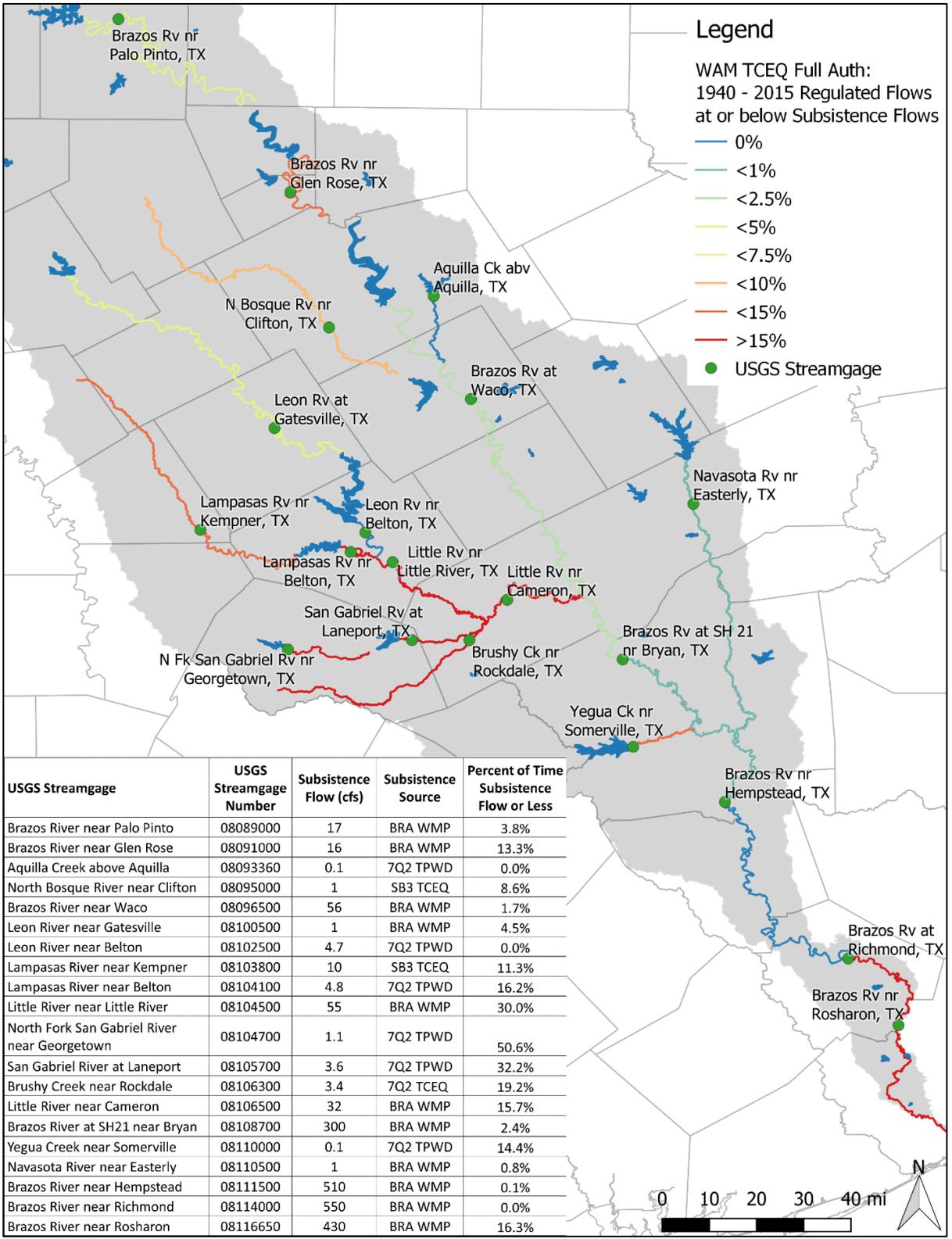


Figure B-6. Percent of time at or below subsistence flow under the Full Authorization Scenario.

3.3 Zero Flows

Zero flow conditions are projected to have naturally occurred in most of the stream segments evaluated under drought conditions. Only the Lampasas River near Kempner and the Brazos River near Hempstead show no zero flow months during the Naturalized Scenario (**Figure B-7**). Aquilla Creek above Aquilla and Brushy Creek near Rockdale exhibited the most zero flow months, with 212 and 106, respectively (**Table B-3**).

Historically, the number of zero flow months ranges from 0 in most stream reaches to 28 in Yegua Creek near Somerville (**Table B-3**). Other segments with zero flow months in the historical record include Aquilla Creek above Aquilla, North Bosque River near Clifton, Leon River near Gatesville, Leon River near Belton, and San Gabriel River near Laneport (**Figure B-8**). All locations which experienced zero flow months under the Naturalized Scenario show reductions in the number of zero flow months under Historical Conditions.

When comparing the 2060 Scenario to Historical Conditions, Aquilla Creek above Aquilla, Yegua Creek near Somerville, and Leon River near Belton are projected to experience no zero-flow months despite having them in the historical record (**Table B-3, Figure B-9**). The North Bosque River near Clifton is also projected to see a reduction in the number of zero flow months. Opposingly, several sites are projected to experience more frequent zero-flow months. The most extreme examples include the Lampasas River near Belton and the North Fork San Gabriel River near Georgetown, which are projected to have 117 and 69 zero flow months, respectively. These are the only two sites which exhibit a higher number of zero flow months in the 2060 Scenario than the Naturalized Scenario.

When comparing the Full Authorization Scenario to Historical Conditions, the occurrence and frequency of zero flow months generally increases due to lack of return flows (**Table B-3, Figure B-10**). When comparing Full Authorization to 2060, the same is generally true, although the number of zero flow months actually decreases at Lampasas River near Belton, North Fork San Gabriel River near Georgetown, and the San Gabriel River at Laneport. Given lack of return flows under Full Authorization, more water must be transported downstream through these locations to meet downstream water rights. Under the Full Authorization Scenario, 16 of 20 locations experience fewer zero flow months than under the Naturalized Scenario. Sites with more zero flow months under Full Authorization compared to Naturalized include North Bosque River near Clifton, Leon River near Gatesville, Lampasas River near Belton, and North Fork San Gabriel River near Georgetown.

Table B-3. Number of zero flow months for each gage location under each scenario. The last column represents the best representation of the difference between projected future conditions within the term of the CCAA (2060) and past conditions (Historical). Positive values in the last column represent an increase in the number of zero flow months, whereas negative values represent a decrease.

USGS Gage	USGS Gage No.	Number of Zero Flow Months				Difference (2060 - Historical)
		Naturalized Scenario	Historical Conditions	2060 Scenario	Full Authorization Scenario	
Brazos River near Palo Pinto	08089000	31	0	0	4	0
Brazos River near Glen Rose	08091000	26	0	2	12	2
Aquilla Creek above Aquilla	08093360	212	11	0	0	-11
North Bosque River near Clifton	08095000	54	10	1	56	-9
Brazos River near Waco	08096500	8	0	1	1	1
Leon River near Gatesville	08100500	28	3	9	31	6
Leon River near Belton	08102500	37	9	0	0	-9
Lampasas River near Kempner	08103800	0	0	0	0	0
Lampasas River near Belton	08104100	35	0	117	48	117
Little River near Little River	08104500	2	0	0	2	0
North Fork San Gabriel River near Georgetown	08104700	56	0	69	61	69
San Gabriel River at Lanepport	08105700	36	1	12	10	11
Brushy Creek near Rockdale	08106300	106	0	0	99	0
Little River near Cameron	08106500	8	0	0	6	0
Brazos River at SH21 near Bryan	08108700	1	0	0	0	0
Yegua Creek near Somerville	08110000	84	28	0	58	-28
Navasota River near Easterly	08110500	69	0	1	8	1
Brazos River near Hempstead	08111500	0	0	0	0	0
Brazos River near Richmond	08114000	3	0	0	0	0
Brazos River near Rosharon	08116650	2	0	0	0	0

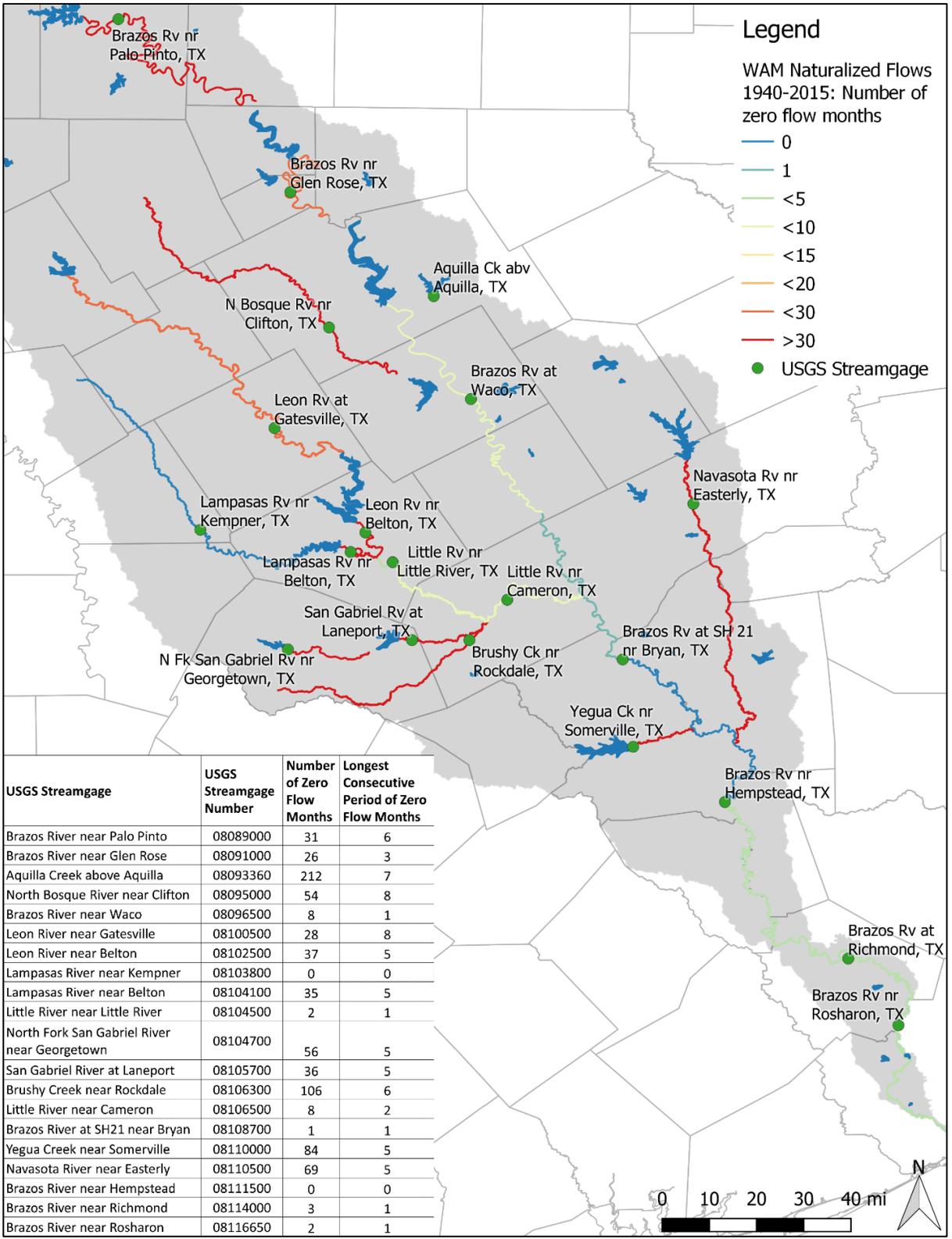


Figure B-7. Number of zero flow months under the Naturalized Scenario.

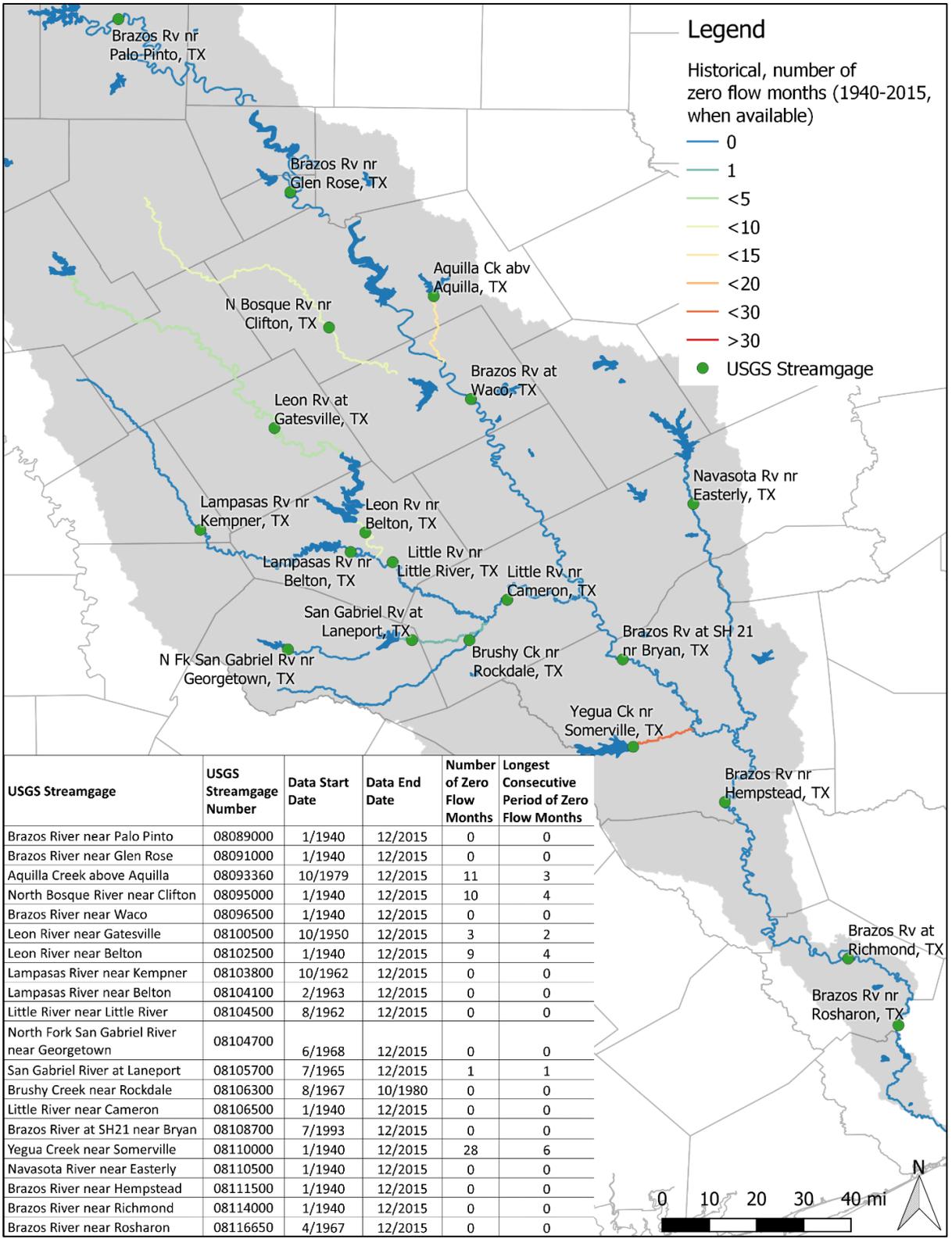


Figure B-8. Number of months of zero flow based on Historical Conditions.

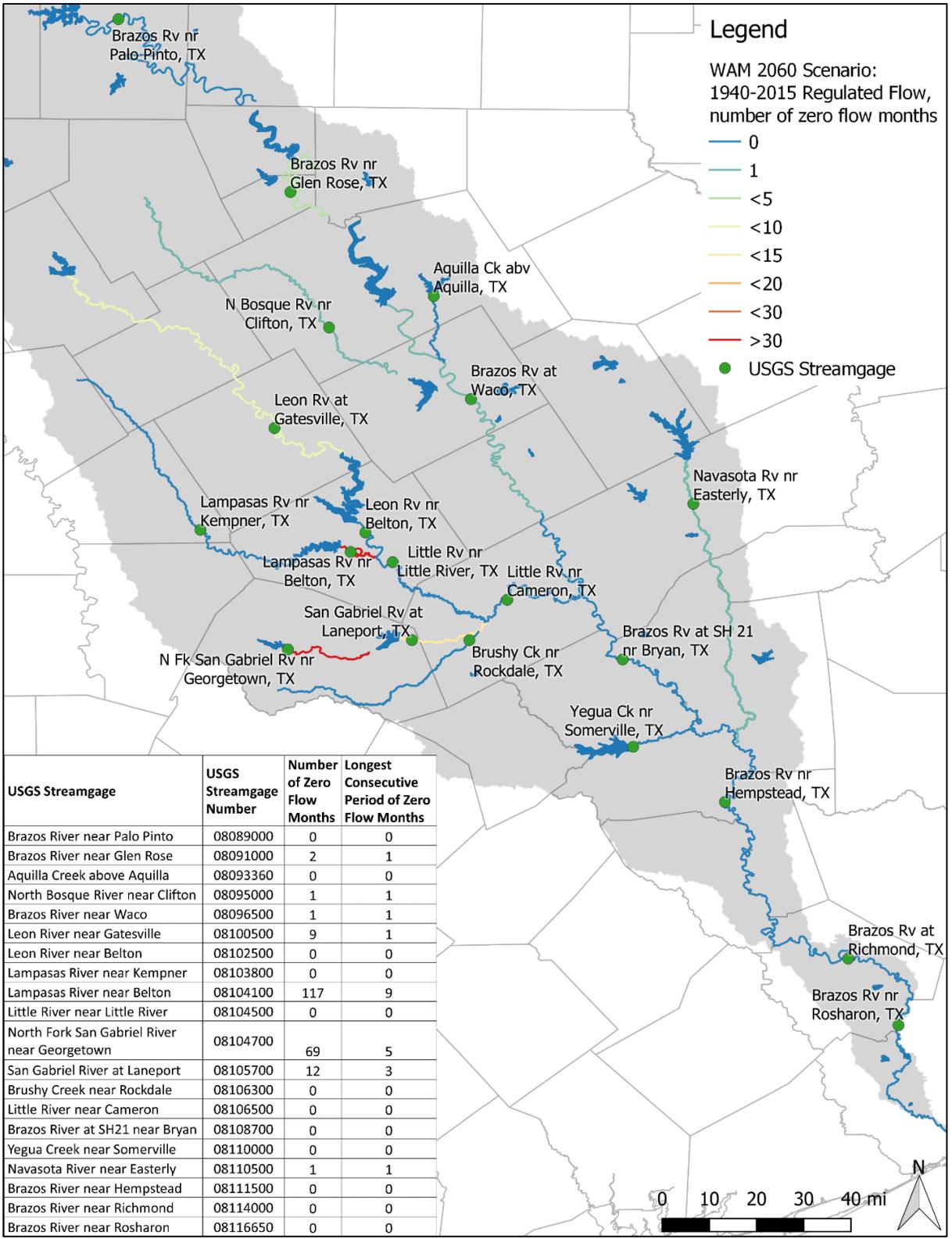


Figure B-9. Number of zero flow months under the 2060 Scenario.

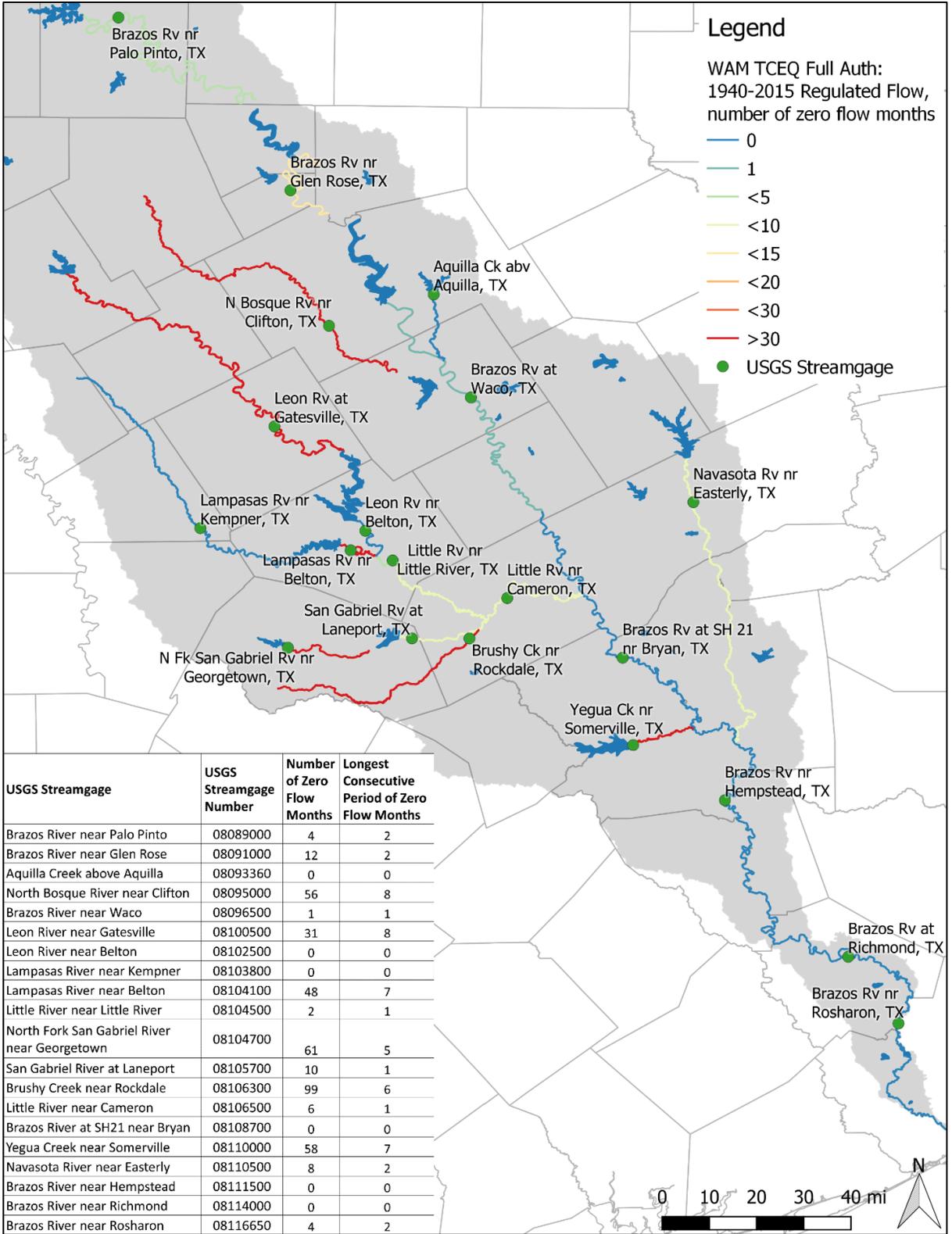


Figure B-10. Number of zero flow months under the Full Authorization Scenario.

4.0 Discussion

The results of this analysis estimate projected combined use by all surface water users within segments of the Brazos River basin under multiple hydrologic scenarios. It is apparent that the specific influence of BRA's management activities on surface water flows within the Brazos River basin varies spatially, being highest in the upper portions of the Covered Area, lowest in the lower Brazos River, and intermediate in the major tributaries analyzed. Because BRA does not control flood storage, BRA's management influence is limited under high flow conditions, and increases under low flow conditions.

Under a projected natural scenario (Naturalized Scenario), subsistence conditions occurred from 2-24% of the time and zero flow months occurred in all but two stream segments. Over the last 75 years (Historical Conditions), the frequency of such low flow conditions has generally declined due to existing water management and infrastructure. With exceptions in a few stream segments, activities such as releases from reservoirs and return flows from discharges during drought periods have resulted in reductions in the frequency of low flow events. Changes to hydrologic patterns will continue into the future as demands increase and new water management strategies are implemented. To account for potential changes to the frequency of low flow events over the course of the CCAA, the 2060 Scenario was evaluated. Lastly, the Full Authorization Scenario was evaluated to represent a worst-case scenario with full utilization of all water rights and no return flows.

Although 2060 is well beyond the 20-year CCAA permit term, and thus inherently conservative, it is the best-available projection of water management that may occur during the timeframe of this CCAA. Therefore, comparing the 2060 Scenario with Historical Conditions provides the best representation of the difference between future conditions and past conditions. Changes in the number and frequency of low flow events are evident from this analysis, although the direction and magnitude of these changes vary spatially depending on future projections in local water use and other factors.

Although this modeling is complex and based on a variety of inputs, available data, and assumptions outlined above, some general mechanisms for these projections are apparent. In general, stream segments which show increased frequency of subsistence and zero flows are in areas with predicted increases in local use. A good example of this is the North Fork San Gabriel River near Georgetown and the San Gabriel River at Laneport, both of which are projected to see increased frequency of subsistence and zero flow months during the term of the CCAA. Projected population growth within the Williamson County area will result in increased local demand and increased withdrawals from Lake Georgetown and Lake Granger. This is projected to decrease reservoir releases into the North Fork San Gabriel River and San Gabriel River.

Decreased frequency of low flow events is typically associated with increased reservoir releases to meet demands of downstream water rights or increased return flows. A good example of this is Yegua Creek near Somerville. Although this location experienced 28 zero flow days in the historical record, it is projected to see no zero flow days under the 2060 Scenario. Additionally,

the percentage of time that this location experiences subsistence flow levels is projected to decrease. Reductions in low flow events are likely due to increased reservoir releases from Lake Somerville to transport water to senior water rights lower in the basin.

Understanding such future water use scenarios is critical as a conservation strategy to inform implementation and evaluation of conservation measures in each segment. Based on this analysis, stream segments with documented Covered Species populations exhibiting increased frequencies of low flow events under future conditions (i.e., San Gabriel River) were prioritized with respect to the proposed conservation measures. In contrast, stream segments with decreased frequency of low flows under future conditions (e.g., Yegua Creek) represent potential areas for restoration and enhancement opportunities as low flow stresses are expected to be minimal in these areas.

5.0 Appendix B References

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