Austin Blind Salamander
(*Eurycea waterlooensis*)

5-Year Review:
Summary and Evaluation

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

5-YEAR REVIEW

Species reviewed: Austin Blind Salamander (*Eurycea waterlooensis*)

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5-YEAR REVIEW
Austin Blind Salamander (*Eurycea waterlooensis*)

1.0 GENERAL INFORMATION

1.1 Reviewers

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1.2 Methodology used to complete the review

The U.S. Fish and Wildlife Service (Service) conducts status reviews of species on the List of Endangered and Threatened Wildlife and Plants (50 CFR 17.12) as required by section 4(c)(2)(A) of the Endangered Species Act (16 U.S.C. 1531 et seq.). The Service provides notice of status reviews via the Federal Register and requests new information on the status of the species (e.g., life history, habitat conditions, and threats). Data for this status review were solicited from interested parties through a Federal Register notice announcing this review on July 26, 2019 (84 FR 36113). This review was conducted by the Austin Ecological Services Field Office and considered both new and previously existing information from federal and state agencies, municipal and county governments, non-governmental organizations, academia, and the public. The primary source of information used in this analysis was the final rule listing the Austin blind salamander as endangered (78 FR 51277-51326), research published in scientific journals, and unpublished technical reports. Comments received were evaluated and incorporated as appropriate.

1.3 Background

The purpose of this 5-year review is to ensure that the Austin blind salamander has the appropriate level of protection under the Endangered Species Act. This review documents a determination by the Service as to whether the status of this species has changed since the time of its listing. This review also provides updated information on the current threats, ongoing conservation efforts, and the priority needs for future conservation actions.

The Austin blind salamander is a fully-aquatic, neotenic salamander that is entirely dependent on the Barton Springs Segment of the Edwards Aquifer, its spring openings, and surrounding habitats to meet its feeding, breeding, and sheltering requirements. This species occurs entirely within the bounds of a major metropolitan area (i.e., Austin-Round Rock Metropolitan Area) and is dependent upon a regional aquifer system. Its surface occurrences have been recorded only within Zilker Park, a city park within Austin, Travis County, Texas. This species was federally listed as endangered on August 19, 2013.

1.3.1 FR Notice citation announcing initiation of this review

A Federal Register notice (84 FR 36113) announcing this review was published on July 26, 2019. This notice solicited new information about species biology, habitat conditions, conservation measures, threats, and trends from other agencies, both Federal and State, nongovernmental organizations, academia, and the general public.

1.3.2 Listing history

Original Listing
FR notice: 78 FR 51277-51326
Date listed: September 19, 2013
Entity listed: Austin blind salamander (*Eurycea waterlooensis*)
Classification: Endangered

1.3.3 Associated rulemakings

Critical habitat for the Austin blind salamander was designated on August 20, 2013, in Travis County, Texas (78 FR 51327-51379).

1.3.4 Review History

The Austin blind salamander was included in nine Candidate Notices of Review (67 FR 40657, June 13, 2002; 69 FR 24876, May 4, 2004; 70 FR 24870, May 11, 2005; 71 FR 53756, September 12, 2006; 72 FR 69034, December 6, 2007; 73 FR 75176, December 10, 2008; 74 FR 57804, November 9, 2009; 75 FR 69222, November 10, 2010; 76 FR 66370, October 26, 2011). The Service listed the Austin blind salamander as endangered on August 19, 2013 (78 FR 51277). This is the first 5-year review for this species since its listing as endangered in 2013.

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

The Austin blind salamander has a recovery priority of 2C, which indicates a species at high risk of extinction with a high recovery potential and in some conflict with economic development.

1.3.6 Recovery Plan or Outline

Name of plan or outline: Barton Springs Salamander (*Eurycea sosorum*) Recovery Plan Amended to include Austin Blind Salamander (*Eurycea waterlooensis*)
Date issued: January 12, 2016
Dates of previous revisions, if applicable: The Barton Springs Salamander Recovery Plan was published on September 21, 2005 (70 FR 55412–55413). This

plan was amended to include the Austin blind salamander, and this addendum was approved in January 2016.

2.0 REVIEW ANALYSIS

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

2.1.1 Is the species under review a vertebrate?

__X__ Yes
_____ No

2.1.2 Is the species under review listed as a DPS?

_____ Yes
__X__ No

2.1.3 Is there relevant new information for this species regarding the application of the DPS policy?

____ Yes
__X_ No

2.2 Recovery Criteria

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

Yes. The recovery plan was originally written for the Barton Springs salamander, which co-occurs with the Austin blind salamander at Parthenia, Old Mill, Eliza, and Upper Barton Springs in Zilker Park, Austin, Texas. After the Austin blind salamander was listed as endangered, the Barton Springs salamander recovery plan was amended to formally add the Austin blind salamander (Service 2016, entire).

2.2.2 Adequacy of recovery criteria

2.2.2.1 Do the recovery criteria reflect the best available and most up-to date information on the biology of the species and its habitat?

____ Yes
__X_ No

2.2.2.2 Are all of the 5 listing factors that are relevant to the species addressed in the recovery criteria (and is there no new information to consider regarding existing or new threats)?

____ Yes
__X__ No

All of the listing factors ((A) the present or threatened destruction, modification, or curtailment of its habitat or range; (D) the inadequacy of existing regulatory mechanisms; and (E) other natural or manmade factors affecting its continued existence) were addressed in the recovery criteria. However, since the listing, new information has become available regarding existing threats.

2.2.3 List the recovery criteria as they appear in the recovery plan, and discuss how each criterion has or has not been met, citing information

Recovery actions in the Barton Springs Salamander Recovery Plan apply to the Austin blind salamander, as they apply to the Barton Springs salamander, regardless of which species is named in a given objective or criterion.

Objective 1 – Protect water quality (Listing Factors A, D, E)

Downlisting Criterion 1 – Mechanisms (such as laws, rules, regulations, and cooperative agreements) are in place to protect and, when necessary, improve water quality (including sediment quality) in the Barton Springs watershed to ensure the long-term survival of self-sustaining populations of the Barton Springs salamander in its natural environment. Additional information is required to determine the water quality needs of the Barton Springs salamander to refine this criterion. Specifically, the following actions should be conducted: (1) determine if previously documented levels of water quality constituents may be directly or indirectly detrimental to the salamander, and (2) determine which water quality constituents may negatively affect the salamander and the levels (concentrations, durations, and combinations of these) that effects may occur. Until this criterion is refined, concentrations of water quality constituents that could have a negative impact on the salamander should remain below levels that could exert direct lethal or sublethal effects (such as effects on reproduction, growth, development, or metabolic processes) on individuals or developmental life stages, or indirect effects on the salamander's habitat or prey base. Although not all of the thresholds for each of the possible water quality constituents are known, exposure to these constituents should not exceed those exposures (that is, concentrations, durations, and combinations of these) to which the salamander has been exposed in the past.

Delisting Criterion 1(a) – The mechanisms to protect water quality at Barton Springs are shown to be effective.

Delisting Criterion 1(b) – Commitments are in place to ensure the continued, long-term protection of water quality at Barton Springs at a level that provides for the long-term conservation of the Barton Springs salamander.

Table 1. Downlisting and delisting criteria for Objective 1 (Protect water quality, and current status toward completion). Criteria are from the Barton Springs Salamander Recovery Plan, amended to include Austin blind salamander (US Fish and Wildlife Service 2016, p. 2.2-1). This objective addresses listing factors A, D, and E.

Recovery Criterion	Status of Completion
Downlisting Criterion 1	Partially complete - Voluntary plans (such as the Regional Water Quality Protection Plan for the Barton Springs Segment of the Edwards Aquifer and Its Contributing Zone (Naismith Engineering, Inc. 2005, entire), the Barton Springs/Edwards Aquifer Conservation District Management Plan (BSEACD 2017, entire) and the Habitat Conservation Plan (HCP) for Managed Groundwater Withdrawals from the Barton Springs Segment of the Edwards Aquifer (BSEACD 2018, entire) exist, but adoption of the guidance within them has not occurred at every applicable jurisdiction within the watershed. There are some mechanisms (such as Austin's Municipal Code as a result of changes to the Watershed Protection Ordinance (Austin, Texas Municipal Code § 25 and § 30 [2019]) in place to protect water quality within the Barton Springs watershed, but research is needed to determine whether these regulations are likely to be adequate to protect water quality sufficiently to ensure the long-term survival of the Austin blind salamander.
Delisting Criterion 1(a)	Not complete – This criterion cannot be completed until Downlisting Criterion 1 is completed.
Delisting Criterion 1(b)	Not complete – This criterion cannot be completed until Downlisting Criterion 1 and Delisting Criterion 1 (b) are completed.

Objective 2 – Prevent or contain catastrophic spills (Listing Factors A, E)

Downlisting Criterion 2 – A comprehensive hazardous material spills plan for the Barton Springs watershed is developed and implemented with measures to avoid or completely contain catastrophic spills. The risk of harm to the Barton Springs salamander from hazardous spills should be reduced to an insignificant level. This criterion needs to be refined by developing a methodology for assessing risk to the Barton Springs salamander.

Delisting Criterion 2(a) – Evaluation of the hazardous spills plan shows it to be effective in minimizing risks to the Barton Springs salamander to an insignificant level.

Delisting Criterion 2(b) – Long-term commitments to implement the hazardous materials spills plan are in place.

Table 2. Downlisting and delisting criteria for Objective 2 (Prevent or contain catastrophic spills), and current status toward completion. Criteria are from the Barton Springs Salamander Recovery Plan, amended to include Austin blind salamander (US Fish and Wildlife Service 2016, pp. 2.2-1–2.2-2). This objective addresses listing factors A and E.

Recovery Criterion	**Status of Completion**
Downlisting Criterion 2	Partially complete – The City of Austin has developed a Barton Springs Salamander Catastrophic Spill Response Plan as required by their HCP and associated section 10(a)(1)(B) incidental take permit (City of Austin 2015a, p. 1). It contains information necessary to address spills within the contributing and recharge zones for Barton Springs that present a threat to the Barton Springs population of the Barton Springs salamander including pre-spill planning information, salamander rescue and response procedures, spill containment and response procedures, and monitoring measures. However, this criterion requires the inclusion of measures to avoid or completely contain catastrophic spills. This is beyond the purview of the City of Austin and would require cooperation from multiple government entities and municipalities to develop and implement. We are unaware of the existence of a comprehensive hazardous material spills plan, so we consider this criterion partially complete. A methodology for assessing risk to the Austin blind salamander does not currently exist. A risk assessment methodology for the Austin blind salamander would be needed to fully achieve Downlisting Criterion 2.
Delisting Criterion 2(a)	Not complete – This criterion cannot be completed until Downlisting Criterion 2 is completed.
Delisting Criterion 2(b)	Not complete – This criterion cannot be completed until Downlisting Criterion 2 and Delisting Criterion 2 (a) are completed.

Objective 3 – Protect water quantity (Listing Factors A, D, E)

Downlisting Criterion 3(a) – Develop and implement an Aquifer Management Plan that ensures natural springflows at Barton Springs outlets (Main Springs, Eliza Springs, Sunken Garden Springs, and Upper Barton Springs). Springflows are continuous at Main Springs, Eliza Springs, and Sunken Gardens Springs even in severe drought. During drought, flows do not fall below the historic low flow of 10 cfs, as measured at the USGS monitoring well that measures flow from all four sites combined.

Downlisting Criterion 3(b) – The Barton Springs Pool is managed in a way that springs remain flowing as described in the City of Austin's 1998 HCP, which means that the pool will not be lowered for cleaning should the flow fall below 54 cfs.

Delisting Criterion 3(a) – Measures to ensure natural springflows at the four spring outlets and continuous springflows at Main Springs, Eliza Springs, and Sunken Garden Springs are shown to be effective.

Delisting Criterion 3(b) – Long-term commitments are in place to maintain these measures.

Table 3. Downlisting and delisting criteria for Objective 3 (Protect water quality), and current status toward completion. Criteria are from the Barton Springs Salamander Recovery Plan, amended to include Austin blind salamander (Service 2016, p. 2.2-2). This objective addresses listing factors A, D, and E.

Recovery Criterion	Status of Completion
Downlisting Criterion 3(a)	Partially complete – BSEACD HCP was finalized in 2018 and covers incidental take of the Barton Springs and Austin blind salamanders for groundwater withdrawals from registered wells in the Barton Springs Segment of the Edwards Aquifer that are authorized and regulated under the BSEACD's permitting program (BSEACD 2018, pp. 53–73). This HCP includes measures to minimize and mitigate impacts and contribute to the recovery of the Barton Springs salamander (BSEACD 2018, pp. 142–183). These measures address a variety of aquifer management issues. However, they also include the adoption of rules that restrict the total amount of groundwater withdrawn monthly from the aquifer during extreme drought conditions to a total of no more than 5.2 cubic feet per second (cfs) curtailed on an average annual basis, which will produce a minimum springflow of not less than 6.5 cfs during a recurrence of the drought of record (BSEACD 2018, p. 63). Since this is less than the historic low flow of 10 cfs, as required by this downlisting criterion, we consider this criterion partially complete.
Downlisting Criterion 3(b)	Complete – To prevent dewatering of surface habitat of Eliza Spring, the City of Austin's amended HCP allows for drawdowns during flows below 54 cfs with the Service's concurrence (Dries et al. 2013, p. 217).
Delisting Criterion 3(a)	Partially Complete – During the period of severe drought from June 2008 to June 2009, the total discharge at Barton Springs dropped below 25 cfs, from June 2008 to October 2009. During this time, Parthenia Spring in Barton Springs Pool and Eliza Spring remained wet with detectable water flow for the entire period, although mean water flow velocity at Eliza Spring was significantly lower during the drought. Water remained in the surface habitat of the spring pool at Old Mill Spring, but there was no detectable discharge and the stream was dry (Dries et al. 2013, p. 156). Discharge at Barton Springs also dropped below 25 cfs in 2006 for 4.4 months, in 2011 for 5.6 months, and in 2013 for 6.3 months (Smith et al. 2013, p. 21). Without a comprehensive aquifer management plan in place that ensures continual, natural spring-flows at Barton Springs, we cannot be sure that flows will not drop below the historic low flow of 10 cfs. Therefore, until Downlisting Criterion 3(a) is completed, this criterion is not fully complete.
Delisting Criterion 3(b)	Not complete – Although the City of Austin's HCP was amended and extended to 2033, long-term commitments beyond the HCP and its associated section 10(a)(1)(b) permit are not in place to maintain these measures past 2033.

Objective 4 – Maintain healthy, self-sustaining salamander population levels throughout the Barton Springs ecosystem (Listing Factors A, E)

Downlisting Criterion 4(a) – Barton Springs salamanders appear to be thriving in their natural environment, as indicated by their presence and condition based on annual survey information.

Downlisting Criterion 4(b) – Population Viability Analyses (using information from mark-recapture studies) show that reproduction is adequate to sustain a stable or increasing population. Until such analyses are completed, the criteria should be that salamanders less than 1-inch (25 mm) in total length should comprise at least 50 percent of the total number of salamanders observed each year.

Delisting Criterion 4 – Survey data indicate the Barton Springs salamander population is stable or increasing and expected (with a probability of at least 95 percent) to be viable for 100 years. This determination should be based on threat assessments and salamander survey data. The data should cover an adequate time span and include appropriate demographic parameters to assess long-term viability.

Table 4. Downlisting and delisting criteria for Objective 4 (Maintain healthy, self-sustaining salamander population levels throughout the Barton Springs ecosystem), and current status toward completion. Criteria are from the Barton Springs Salamander Recovery Plan, amended to include Austin blind salamander (US Fish and Wildlife Service 2016, pp. 2.2-2–2.2-3). This objective addresses listing factors A and E.

Recovery Criterion	Status of Completion
Downlisting Criterion 4(a)	Not complete – At this time the health of Austin blind salamander populations are difficult to discern due to low capture rates and numbers during surveys. Because of this, we cannot determine that Downlisting Criterion 4(a) has been met.
Downlisting Criterion 4(b)	Not complete – Population viability analyses for the Austin blind salamander have not been conducted.
Delisting Criterion 4	Not complete – This criterion cannot be completed until Downlisting Criterion 4(b) is completed.

Objective 5 – Manage surface habitat to adequately reduce local threats to the Barton Springs ecosystem (Listing Factors A, D)

Downlisting Criterion 5 – Surface habitat management is met by the ongoing implementation and completion of the actions detailed within the City of Austin's HCP (see Section 1.7, Conservation Measures).

Delisting Criterion 5(a) – Long-term monitoring shows that the measures outlined in the HCP have been effective.

Delisting Criterion 5(b) – Long-term commitments are in place to maintain the measures outlined in the HCP.

Table 5. Downlisting and delisting criteria for Objective 5 (Manage surface habitat to adequately reduce local threats to the Barton Springs ecosystem), and current status toward completion. Criteria are from the Barton Springs Salamander Recovery Plan, amended to include Austin blind salamander (US Fish and Wildlife Service 2016, pp. 2.2-3). This objective addresses listing factors A and D.

Recovery Criterion	Status of Completion
Downlisting Criterion 5	Complete – Surface habitat management at Barton Springs has been met by the ongoing implementation and completion of the City of Austin's HCP. A major amendment and extension of this HCP was finalized in July 2013 (Dries et al. 2013, entire), which renewed the City of Austin's associated section 10(a)(1)(b) incidental take permit to 2033. The City of Austin has developed a Habitat Management Plan for each of the four spring sites that comprise the Barton Springs complex to "improve the quality of aquatic habitat and ecosystem health" (City of Austin 2018a, p. 1). Efforts to restore and maintain surface habitat, which is highly modified by impoundments at Barton Springs, are currently ongoing. The goals of these efforts include: (1) maximizing availability of interstitial spaces, (2) restoring shallow, flowing water near springs to provide less embedded cover, and (3) reducing anthropogenic habitat disturbance (City of Austin 2018a, pp. 2–3).
Delisting Criterion 5(a)	Not complete – Long-term monitoring of the HCP's conservation measures has not been undertaken; therefore, this criterion has not been met.
Delisting Criterion 5(b)	Not complete – Although the City of Austin's HCP was amended and extended to 2033, long-term commitments beyond the HCP and its associated section 10(a)(1)(b) permit are not in place to maintain these measures past 2033.

Objective 6 – Establish and maintain captive population(s) to ensure protection from extinction (Listing Factors A, E)

Downlisting Criterion 6(a) – A captive propagation and contingency plan (CPCP) is developed and implemented.

Downlisting Criterion 6(b) – Establish an adequate number of captive Barton Springs salamanders in secure locations. This criterion should be refined through further studies to determine the adequate size and genetic structure of captive populations. At the present, establishment of two captive populations is deemed adequate, but this may change based on future information. Number of populations, size, and structure should be outlined during the development of the CPCP.

Delisting Criterion 6(a) – Adequate captive populations have been assembled and maintained following the recommendations provided in the CPCP.

Delisting Criterion 6(b) – Captive breeding and reintroduction techniques are shown to be successful and reliable.

Delisting Criterion 6(c) – Commitments are in place to maintain adequate captive populations for any needed salamander restoration work.

Table 6. Downlisting and delisting criteria for Objective 6 (Establish and maintain captive population(s) to ensure protection from extinction), and current status toward completion. Criteria are from the Barton Springs Salamander Recovery Plan, amended to include Austin blind salamander (US Fish and Wildlife Service 2016, pp. 2.2-3). This objective addresses listing factors A and E.

Recovery Criterion	**Status of Completion**
Downlisting Criterion 6(a)	Not complete – A CPCP has not been developed for this species.
Downlisting Criterion 6(b)	Not complete – Only a few Austin blind salamanders are currently in captivity (City of Austin 2017, p. 6). The appropriate size and genetic structure of captive populations has not yet been determined. The City of Austin does not separate or breed Austin blind salamanders according to spring site of origin as this species is primarily aquifer dwelling, and the number of distinct populations is unclear (City of Austin 2017, p. 6). This criterion has not been met.
Delisting Criterion 6(a)	Not complete – Adequate captive populations have not been assembled and a CPCP has not been written; therefore, this criterion has not been met.
Delisting Criterion 6(b)	Not complete – Captive breeding and reintroduction techniques for Austin blind salamander are yet to be developed; consequently, this criterion has not been met.
Delisting Criterion 6(c)	Not complete – The City of Austin has committed to maintaining their captive breeding facility through 2033 as required in their HCP and associated section 10(a)(1)(B) incidental take permit (Dries et al. 2013, p. 12). Action 5.1 of the Barton Springs Salamander Recovery Plan specifies the development of "participation plans" for each facility participating in captive breeding of Austin blind salamanders that outlines their level of commitment. These participation plans have not been developed for either the City of Austin facility.

2.3 Updated Information and Current Species Status

2.3.1 Biology and Habitat

Due in large part to their low abundance compared to other central Texas *Eurycea* species, Austin blind salamanders (hereafter also referred to simply as "salamanders") are often not the primary focus of research in either lab or field settings. No new peer-reviewed articles focusing specifically on the salamanders have been published since the species was listed in 2013.

2.3.1.1 New information on the species' biology and life history

Research on the Barton Springs salamander, which co-occurs with the Austin blind salamander at Parthenia, Old Mill, Eliza, and Upper Barton springs in Zilker Park, is available and potentially applicable to the latter species. An evaluation of the acute toxicity of nitrogenous toxicants (specifically, un-ionized ammonium-nitrogen and total ammonium-nitrogen) on Barton Springs salamander found that current water quality standards are likely adequate to protect that species, although long-term chronic effects of low-level exposure is not understood (Crow et al. 2017, pp. 3004–3006). Another study examined temperature tolerance and optimal temperatures for Barton Springs salamander, and found an optimal range of about 15-24°Celsius (°C) [59–75°Fahrenheit (°F)], which the authors characterized as unsurprising (Crow et al. 2016, pp. 331–332).

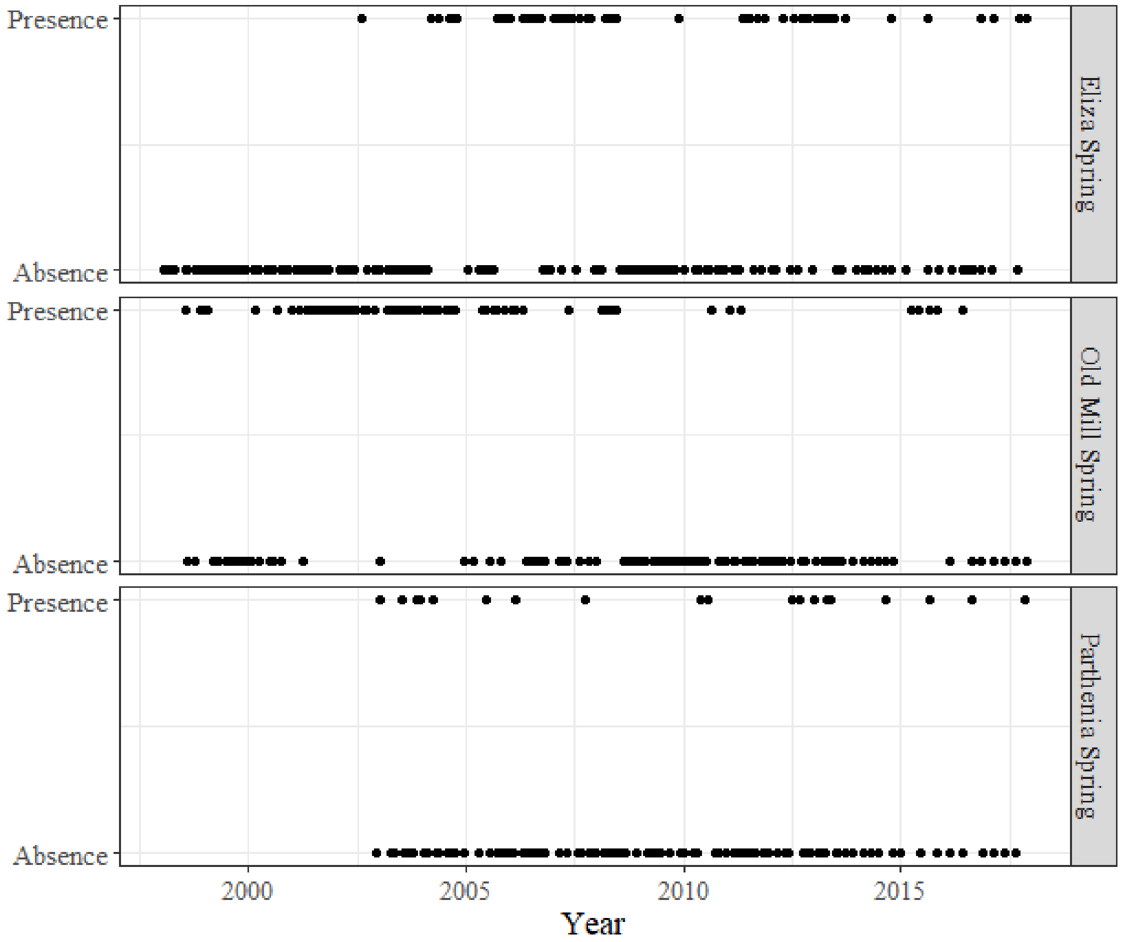
A study examining the relationship between impervious cover, the presence of contaminants in salamander habitat, and the uptake of contaminants by three central Texas *Eurycea* species confirmed positive relationships in all sampled species (Diaz et al. 2018, in press). The researchers also found that the total body burden of contaminants within the sampled salamanders was positively correlated with the time since development of the surrounding area (Diaz et al. 2018, in press). The sources of these contaminants may be highly varied, but as infrastructure ages its likelihood of failure increases, and this can result in additional pollution to the system. Thus water quality may decline both as a result of increasing impervious cover and increasing point sources such as urban leakage (e.g. leaky sewer pipes) (Bendik et al. 2014, pp. 216–217).

In general, low counts and virtually nonexistent recapture rates for Austin blind salamander continue to support the hypothesis that the species primarily occurs within the aquifer (City of Austin 2019c, p. 19). It remains unconfirmed whether surface appearance by the salamanders is intentional, perhaps to access increased food resources at the surface-subsurface boundary, or the result of accidental exit or flushing from the aquifer (Fišer et al. 2014, pp. 2–3; Robinson 2019c, personal communication).

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

The City of Austin continues to monitor both Austin blind and Barton Springs salamanders at spring sites within Zilker Park. Observations of Austin blind salamander are too low to calculate abundance estimates. Figure 1 shows Austin blind salamander presence-absence since surveys began in 1998. Although the salamander is not observed during every survey, it continues to be observed throughout the year in low numbers at three springs.

Figure 1. Monthly presence-absence values for Austin blind salamander at Zilker Park springs, 1998-2017. Based on data from the City of Austin and annual 10(a)(1)(a) reports submitted by the City of Austin as part of the permit issued for the Barton Springs Pool.



A review of the relationship between abundance and drought found that reproduction is depressed during longer drought periods (i.e., three months or more), and the authors note that this effect is observable specifically as a lagged effect on the order of months (Dries and Colucci 2018, p. 312). A related paper confirmed many of these details (Bendik and Dries 2018, pp. 5918–5920), at least for the habitat as it currently exists (i.e. impounded).

Based on annual reports from the City of Austin describing captive Austin blind salamander reproduction, it appears that mating, oviposition, and hatching can and does occur in captivity, albeit infrequently (City of Austin 2014, pp. 10–11, 2015b, pp. 8–9, 2016, pp. 7–8, 2017, pp. 7–8, 2018b, pp. 7–8).

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

Genetic analysis of Barton Springs and Austin blind salamanders found some infrequent hybridization between the two species at Zilker Park springs (City of Austin 2018b, p. 14). At this time, we do not believe this poses a risk to Austin blind salamander as a species.

2.3.1.4 Taxonomic classification or changes in nomenclature

A recent phylogenomic analysis of *Eurycea* species radiation in central Texas found that Austin blind salamander continues to be appropriately categorized as a species (Devitt et al. 2019, pp. 2627–2628).

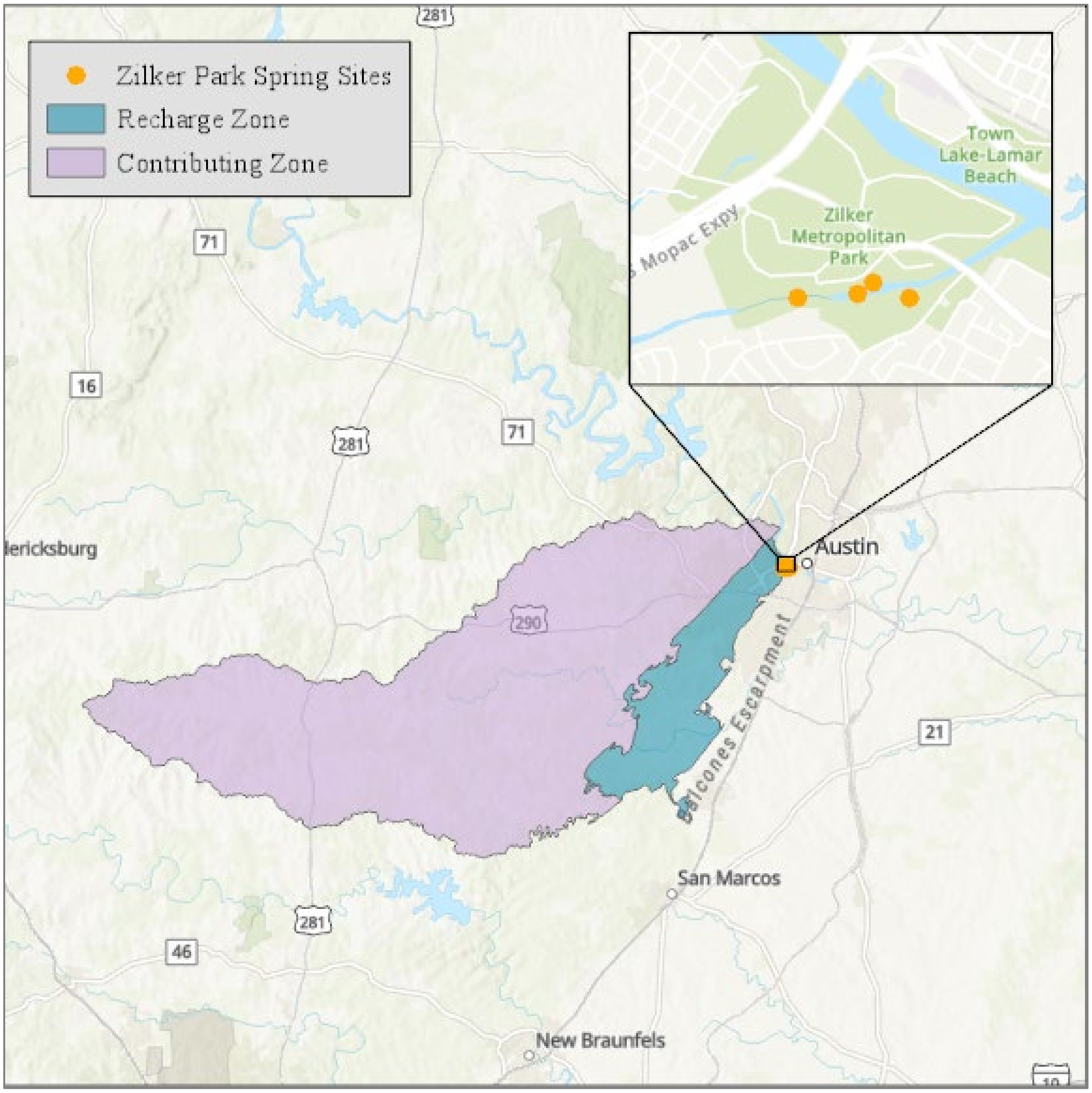
2.3.1.5 Spatial distribution, trends in spatial distribution (e.g. increasingly fragmented, increased numbers of corridors, etc.), or historic range (e.g. corrections to the historical range, change in distribution of the species' within its historic range, etc.)

The Austin blind salamander is found in four Barton Springs outlets in the City of Austin's Zilker Park, Travis County, Texas: Parthenia (Main) Spring, Eliza Spring, Sunken Garden (Old Mill or Zenobia) Spring, and Upper Barton Spring (Dries 2012, p. 4; Bendik 2018, personal communication). Zilker Park (142 hectares (ha) [350 acres (ac)]) is owned by the City of Austin. Figure 2 shows the spring sites in Zilker Park as well as the surrounding area that influences habitat in the Edwards Aquifer and these spring sites.

Although the Austin blind salamander has not been observed at Upper Barton Spring during any of the City's formal surveys (City of Austin 2014, pp. 2–7, 2015b, pp. 1–4, 2016, pp. 2–6, 2017, pp. 2–5, 2018b, pp. 2–6), a sighting based on photographic evidence was reported in November 2013 (Bendik 2018, personal communication). Thus, Upper Barton Spring, and the subsurface conduits and aquifer it is attached to, will be included as habitat for Austin blind salamanders (Mahler et al. 2006, pp. 2–3, 65). None of the surface connections among the four springs that were present before modification via dams and diversions have been restored (Dries 2012, p. 4).

Since Austin blind salamander was listed, new occurrence records for Barton Springs salamander have been published (Devitt and Nissen 2018, pp. 298–300). No Austin blind salamander have been seen at these new locations and at this time we are not inferring that Austin blind salamander may be present at these spring sites in the Barton Springs aquifer watershed.

Figure 2. Occurrences of the Austin blind salamander in Zilker Park, Austin, Travis County, Texas. Data obtained from the Barton Springs-Edwards Aquifer Conservation District and Austin Ecological Services Field Office files.



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

Habitat in Zilker Park

Dries and Colucci (2018, entire) completed a study examining the influence of surface habitat condition and flow regimes on the relative abundance of Barton Springs salamander. Their conclusions are applicable to Austin blind salamander as well. They note that prior to the construction of Barton Springs Pool, the amphitheaters at Old Mill Spring and Eliza Spring, and the diversion of Barton Creek, there were surface water connections between the three springs (Dries and Colucci 2018, p. 304). Today subsurface migration is still possible through extant hydrological connections within the Edwards Aquifer, but overland migration would occur in an inhospitable environment (Dries and Colucci 2018, pp. 304–305).

Based on their results, those authors argue that free-flowing water and low levels of sediment are predictive of higher Barton Springs salamander abundance, and note that the impounded nature of the springs at Zilker Park are probably "inhibit[ing] the ability of endangered *E. sosorum* [Barton Springs salamander] to thrive and recover by altering natural flow regimes" (Dries and Colucci 2018, p. 311). Conservation measures intended to combat some of the ill effects of altered natural habitats are described in section 2.3.1.8 below. The direct effects of flooding on salamanders and their habitat at the spring outlets is described in the listing rule; we do not have new information on the influence of flooding.

At the time of listing, the best available models predicted that under a recurrence of drought-of-record conditions and no curtailment of groundwater pumping, Barton Springs would cease to flow for at least four months (Smith and Hunt 2004, p. 24; BSEACD 2018, pp. 32–35). The models have not changed substantially, but the BSEACD now has a Management Plan and HCP that provides mechanisms for curtailing pumpage during drought and to enforce those limitations (BSEACD 2018, pp. 50–67).

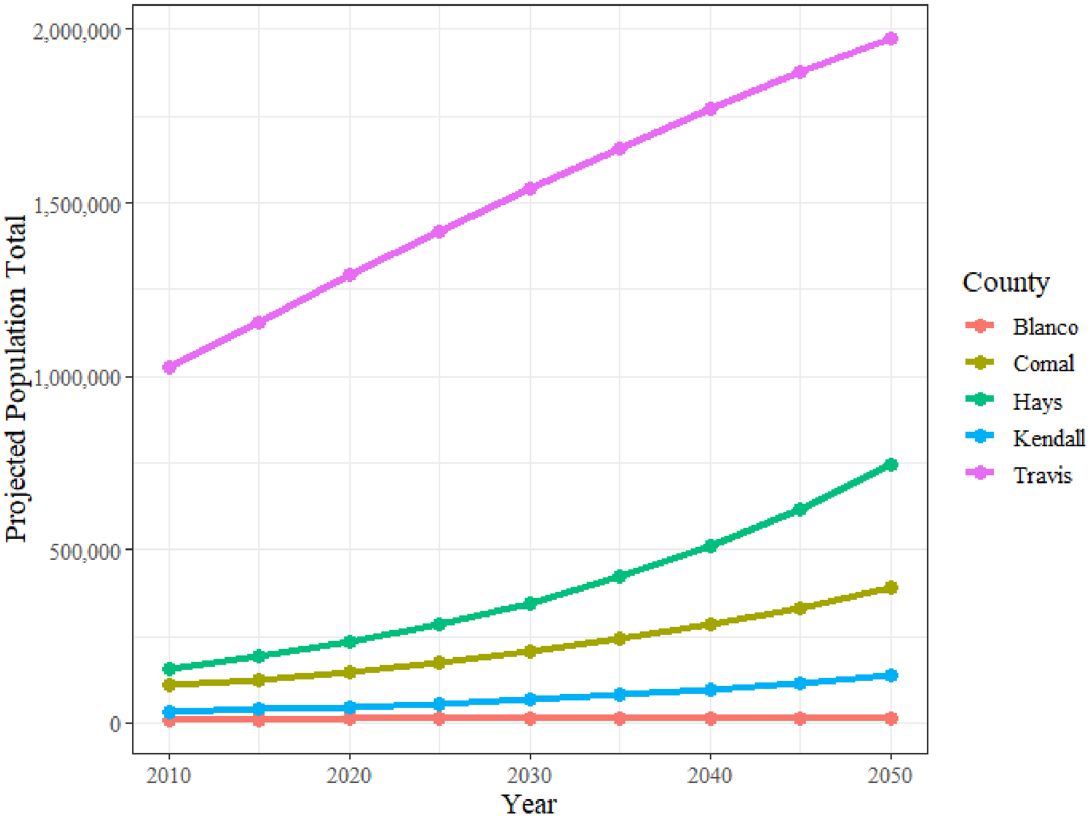
Ecosystem conditions for the Barton Springs Segment of the Edwards Aquifer

Human Population Growth

The U.S. Census Bureau counts of total population and households demonstrate positive trends over time within the recharge and contributing zones of the aquifer (Figure 3). We conducted this analysis by obtaining the block group boundaries for the area intersecting the recharge and contributing zones of the aquifer, and mapping that to the population and household tables available from the Census (U.S. Census Bureau 2000a, 2000b, 2010a, 2010b, 2017a, 2017b). The Texas Demographic Center publishes population projections refined to the county level that project these positive trends continuing into the future for the five counties that overlap the recharge and contributing zones of the aquifer (Figure 4; Texas Demographic Center 2018).

Figure 3. Total human population and number of households and total population in the contributing and recharge zones of the Barton Springs segment of the Edwards Aquifer. Data for 2000 from Census 2000, 2010 data from Census 2010, and 2013–2017 data from the American Community Survey 5-Year 2017 dataset.

Figure 4. Projected total population in the five counties that overlap the contributing and recharge zones of the Barton Springs segment of the Edwards Aquifer (Texas Demographic Center 2018).



Impervious cover and land use

Because land use change, particularly conversion to urban, suburban, and exurban development, and its associated increase in impervious cover are known stressors, we quantified these metrics to assess trends. The NAWQA Wall-to-Wall Anthropogenic Land Use Trends (NWALT) GIS dataset was used as the basis for assessing change over time (Falcone 2015). Land use is categorized at the coarse scale by a set of land use types, and at the fine scale by a set of land use classes. A crosswalk is available in Falcone (2015). We clipped the national dataset to the area intersecting the contributing and recharge zones of the Barton Springs segment of the Edwards Aquifer and summed the total area in each class.

The increase in impervious cover as a consequence of land conversion from a "low use" state (defined as not having obvious indications of anthropogenic influence) to developed and semi-developed states means that the converted lands in these zones may contribute to declining water quality (Schueler et al. 2009, pp. 310–314). This shift is depicted in Figure 5. Decreased water quality was identified in the listing rule as a stressor to the Austin blind salamander and impervious cover can be considered as indirectly affecting the species. We note further that the land still in "low use" today is vulnerable to development in the future. Conducting a simple linear regression on these land use change datasets yields quantitative values for the rate of land use conversion, as shown in Table 7. Low use lands in the areas contributing to water quality where the salamanders occur are being converted to developed and semi-developed at a steady rate.

Figure 5. Change in land use in the contributing and recharge zones of the Barton Springs segment of the Edwards Aquifer over time, by coarse scale types. Data points in this analysis are from 1974, 1982, 1992, 2002, and 2012 (Falcone 2015).

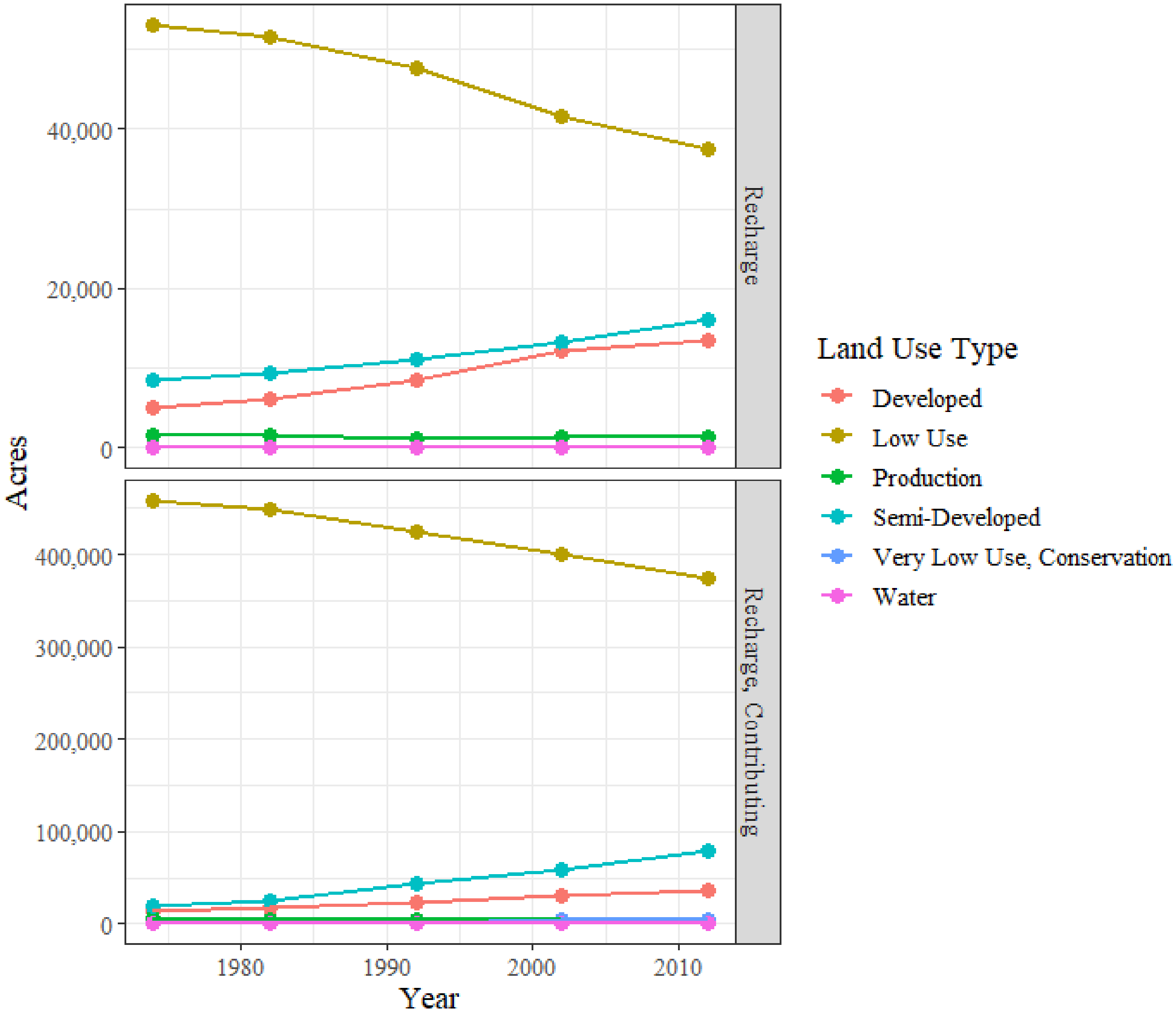
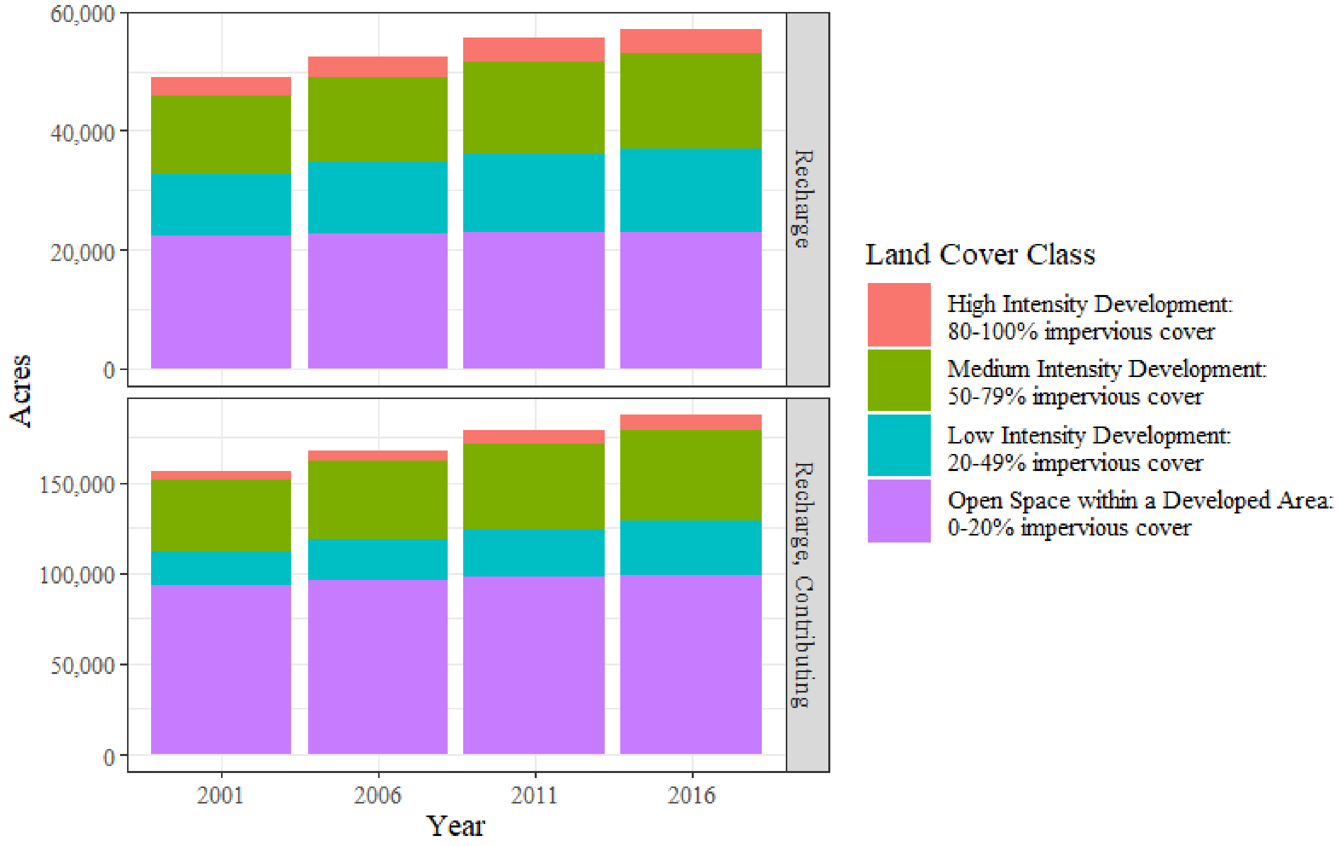


Table 7. Change in land use in the contributing and recharge zone of the Barton Springs segment of the Edwards Aquifer over time. Data points in this analysis are from 1974, 1982, 1992, 2002, and 2012 (Falcone 2015).

Zone	Class Type	Average Change (acres/year)	Average Change (hectares/year)
Recharge	Developed	240	97
	Low Use	-431	-174
	Production	-9	-4
	Semi-Developed	200	81
Recharge and Contributing	Developed	588	238
	Low Use	-2,256	913
	Production	-27	11
	Semi-Developed	1,604	649
	Very Low Use, Conservation	91	37

An analysis of change in developed land cover classes in the contributing and recharge zones of the aquifer over time using the National Land Cover Dataset yielded similar results (Figure 6; Yang et al. 2018). Total developed area is increasing over time, with medium and low intensity development (i.e., areas with 20–79% impervious cover) contributing a larger share of the increase in total developed area over time. Low impervious cover development characterizes around half of the combined recharge and contributing zones.

Figure 6. Developed land cover classes from the National Land Cover Dataset (2001, 2006, 2011, 2016) for the contributing and recharge zones of the Barton Springs segment of the Edwards Aquifer.



Construction

The 2013 listing rule discussed both direct (i.e., erosion from exposed ground directly into streams) and indirect (i.e., increased runoff from urbanization, and the contaminant loads associated with built environments) impacts from construction activities. In this review, the indirect effects are discussed in the specific situations about those stressors (e.g., see discussion of sedimentation below). Direct construction impacts that could significantly compromise salamander habitat are similar to a hazardous material spill: an acute disruption to the environment that occurs unpredictably and which may have significant consequences.

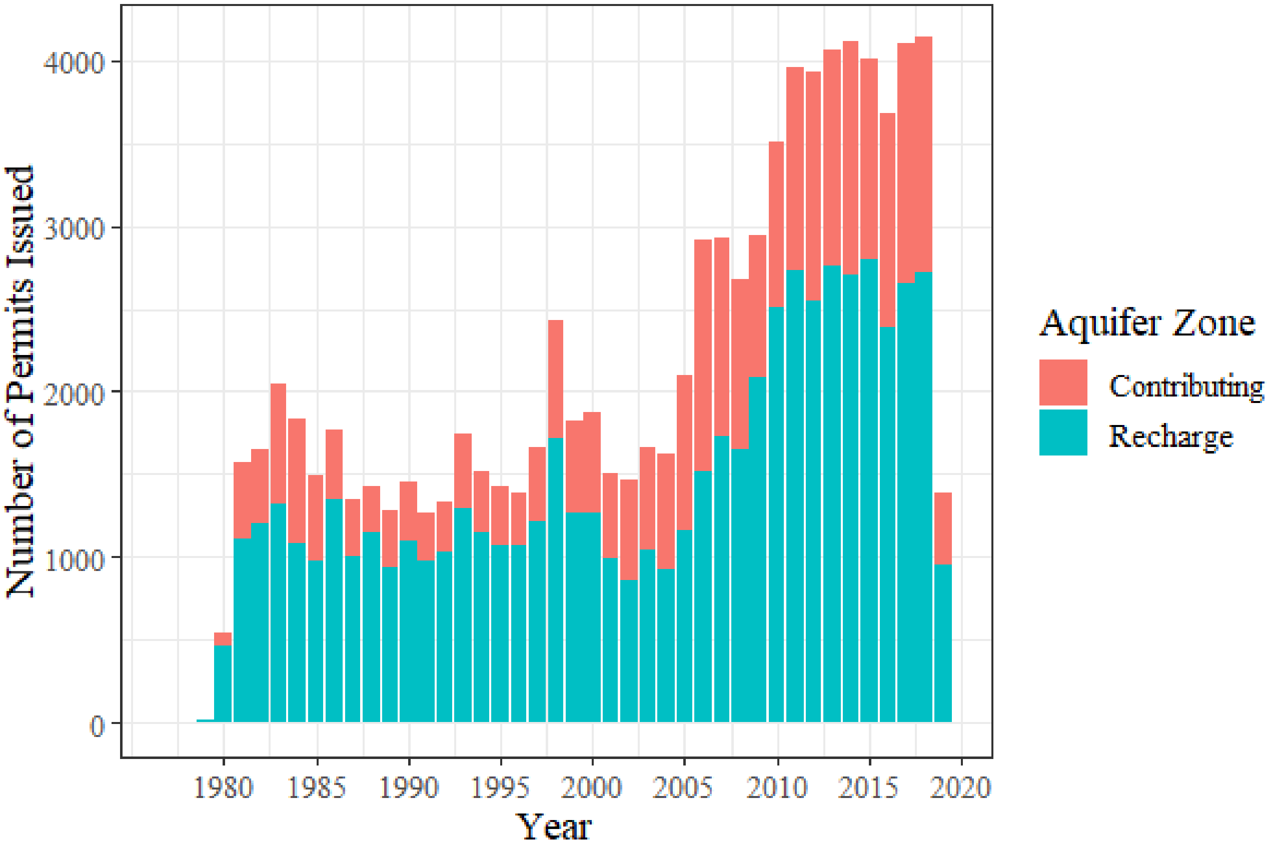
We are aware of only one “spill” of sediment that reached the Zilker Park springs since the listing rule was established that was related to construction activities in the contributing or recharge zones. In December 2018, a series of sediment plumes were observed in Barton Springs Pool, emerging from Parthenia Spring (Huber 2018). The pool was closed to the public for three days and the water tested for contaminants; calcium levels were found to be elevated, but no toxic substances were present (Huber 2018). The cause of the sediment plumes was a well being drilled around approximately 1.5 kilometers (km) [1 mile (mi)] from the springs. A stop work order was issued, the property owner cited, and the pool re-opened with no further disturbance associated with this activity (Huber 2018, 2019).

This was the first known instance of sediment from construction emerging from the springs, according to city officials interviewed by the Austin American-Statesman (Huber 2018, 2019). Because this closure was followed by heavy rains and flooding that led to the closure of the pool for safety reasons from December 27, 2018, to January 1, 2019, and again from January 2 to January 9, 2019, an assessment of any potential harm to the salamander from the construction pollution did not occur (City of Austin 2018c, 2018d, 2019a, 2019b). As a result of this event, the City of Austin's Watershed Protection Department is revising protocols so that future drillers will be unlikely to stir up sediment that would impact the springs, and provide closer on-the-ground oversight when this type of drilling takes place (Flores 2019).

Issued construction permits for the City of Austin show increases in permits issued in 2006 and 2010, and have held steady since then (Figure 7). We note that these are permits only for the City of Austin, and thus exclude much of the area of the contributing and recharge zones of the aquifer spatially, and do not account for construction activities outside city limits.

Development of the Permian Highway Pipeline is proposed as of the writing of this review, with construction scheduled to begin in the fall of 2019 (City of Austin 2019f, p. 1). Impacts to the aquifer from construction of this pipeline may occur during installation or following post-construction restoration (City of Austin 2019f, p. 3). For example, because the 107 cm (42 in) diameter pipeline will be placed below ground in a trench, excavation of an area much larger will be completed in an area of karstic geology, where it is likely that the area being excavated will intersect with fissures and voids (City of Austin 2019f, p. 3). Ground-disturbing activities in these areas could alter flow pathways of water within the Edwards and overlying Trinity aquifers, changing not only how water recharges the aquifers, but also how contaminants move around below ground (City of Austin 2019f, p. 3). Over the long-term, the area under easement for pipeline construction will experience increased soil erosion, decreased rainfall infiltration, and decreased stormwater runoff infiltration until complete restoration to pre-construction conditions is completed for currently vegetated areas (City of Austin 2019f, pp. 3–4).

Figure 7. Construction permits issued by the City of Austin from 1978 to 2019 for the contributing and recharge zones of the Barton Spring segment of the Edwards Aquifer. Data from the City of Austin's Issued Construction Permits dataset.



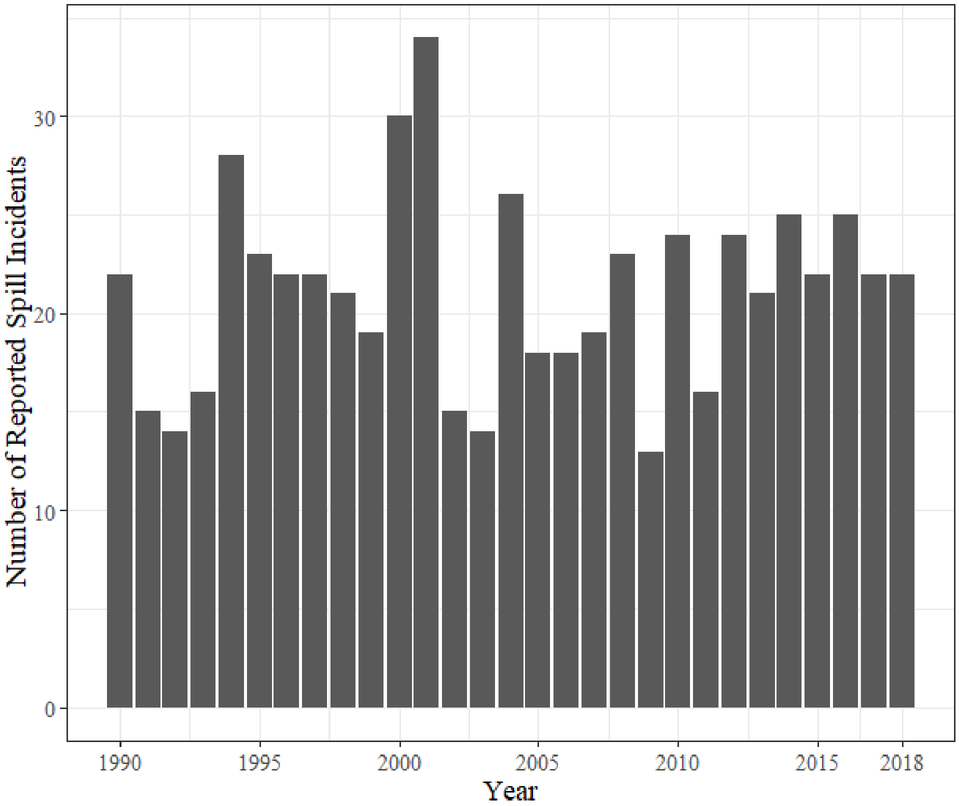
Road construction and maintenance

The Capital Area Metropolitan Planning Organization's (CAMPO) 2040 Regional Transportation Plan predicts increases in population density along the Austin-San Marcos corridor, particularly along Interstate 35, as would be expected if the land use trends shows in Figures 5 and 6 continue (CAMPO 2015, pp. 28–31). Concomitant with an increase in total population and population density is increased pressure on transit systems (CAMPO 2015, pp. 64–68). Although CAMPO includes in its planning goals strategies to reduce demand on road systems specifically, accommodating population growth is certain to result in the need to repair, improve, and expand existing roads, as well as construct new ones (CAMPO 2015, pp. 64–75). According to the Texas Department of Transportation (TxDOT) roadways datasets, in 2019 there were 2,478 km (1,540 miles mi) of roads in the aquifer contributing and recharge zones combined; 737 km (458 mi) occur in just the recharge zone (TxDOT 2019). This is an increase from 2011, when the two zones contained 1,730 km (1,075 mi) of roads, of which 371 km (231 mi) were in the recharge zone (TxDOT 2011).

Hazardous materials storage and transportation

A large amount of freight traffic, including that carrying hazardous materials, passes through the CAMPO area daily (CAMPO 2015, p. 131). Most of the truck traffic uses Interstate 35, while the train system uses rail lines (CAMPO 2015, p. 133). The rail line cuts through the City of Austin, and while moving this line to the east to avoid the urban area (and thus the salamanders) is under discussion, it is not part of the 2040 plan and thus not considered as a mitigating measure in this document (CAMPO 2015, p. 133). The listing rule reported some data on reported hazardous material spill frequency in Hays and Travis counties. We have updated the analysis from the time of the listing rule using the same primary data source (U.S. Coast Guard 2019) to 2018, and plotted the results in Figure 8. There was no significant trend based on a simple linear regression analysis, but if only the past several years are examined, there is some evidence of a slight increase over time. This spill database should include any spills that were associated with rail or truck freight traffic.

Figure 8. Number of reported spill incidents in Hays and Travis counties, by year, from 1990 to 2018. Data from the United States Coast Guard National Response Center tables (U.S. Coast Guard 2019).



The Texas Commission on Environmental Quality (TCEQ) maintains data about the presence of hazardous waste storage and contaminated sites. These data were not presented in the 2013 listing rule. Table 8 tallies the number of entities that present a potential hazard to waters that flow to Barton Springs (i.e. are located in the contributing or recharge zones of the Barton Springs Segment of the Edwards Aquifer).

The leaking petroleum storage tank (LPST) dataset tracks tanks that were reported to TCEQ for exceeding standards for either soil or water contamination from the early 1980s to the present (TCEQ 2019a; Dunahoo 2019, personal communication). Figure 9 shows the 62 LPSTs located within the contributing and recharge zones by date entered into the TCEQ database, date the leaking tank permit was closed out, and the priority status of the leak (see Table 9 for priority status definitions). The data in this figure has been jittered to facilitate viewing of multiple points (that is, a small amount of random noise has been added to the data so that points with the same X and Y values do not fall exactly on top of one another). The figure illustrates the number of years between discovery of a leak to closure of the remediation permit by the year the leak was discovered. The black line has a slope of 1 such that points that fall on the line generally indicate leaks that were addressed the same year they were reported. Points farther from this line have a larger period between the entered and closure dates. In recent years, the period between the "entered" date and the "closed" date has been shorter than in the past, particularly the 1990s. Five spills, which occurred between 1990 and 1996, were determined to have impacted the Edwards Aquifer (priority status 1.6). As of this writing, all had been remediated to the TCEQ's satisfaction. One LPST, in the City of Blanco (within the contributing zone), has an active permit and is currently classified as priority status 3.1 (groundwater affected, see Table 9) (TCEQ 2019g).

Table 8. Number and type of hazardous waste sites within the contributing and recharge zones of the Barton Springs segment of the Edwards Aquifer. Data from TCEQ publically available GIS datasets (TCEQ 2019a, 2019b, 2019c, 2019d, 2019e, 2019f, 2019g).

Hazardous Waste Type	Aquifer Zone	Number
Brownfields	Recharge	1
Industrial And Hazardous Waste Corrective Action Sites	Recharge	1
	Contributing	5
Municipal Solid Waste Sites / Landfill	Recharge	2
	Contributing	7
Industrial & Municipal Wastewater Outfalls	Contributing	6
Petroleum Storage Tanks	Recharge	28
	Contributing	47
Leaking Petroleum Storage Tank	Recharge	24
	Contributing	40

Figure 9. Leaking petroleum storage tank information from the Texas Commission on Environmental Quality (TCEQ 2019a).

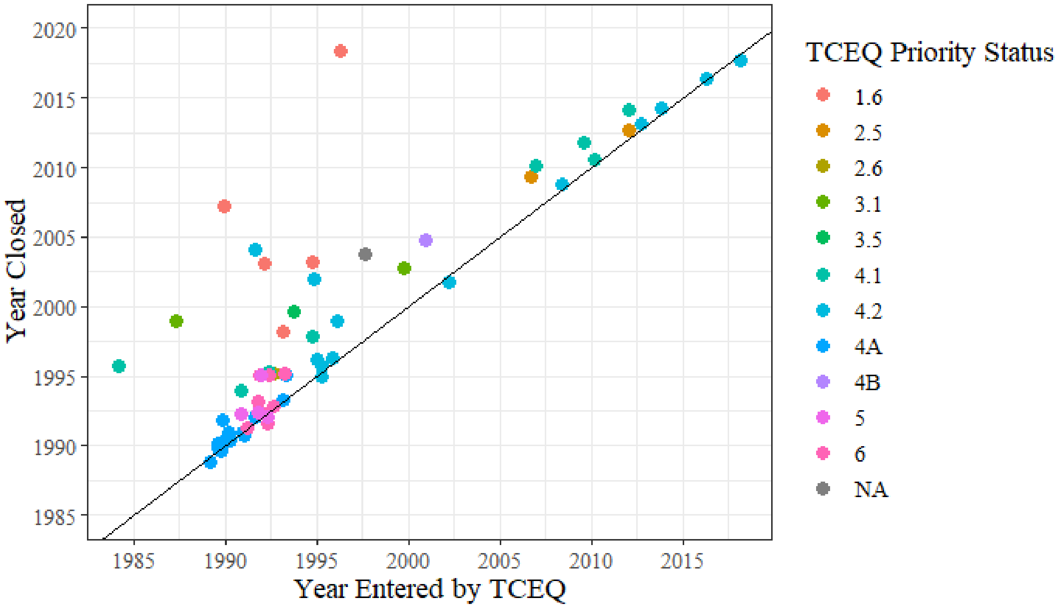


Table 9. Definitions of Texas Council on Environmental Quality Priority Status values for leaking petroleum storage tanks. Values 4A, 4B, 5, and 6 are historical statuses that are not in use today, having been phased out about 20 years ago (Dunahoo 2019, personal communication).

Priority Status Numeric Value and Definitions
1.6 – The Edwards aquifer, recharge zone or transition zone is affected.
2.5 – Groundwater is affected and a public or domestic water supply well is located within 0.25 miles of the UST/AST system or source area.
2.6 – Groundwater or storm water runoff is affected and discharges within 500 feet of the known extent of contamination to a surface water body used for human drinking water, contact recreation, habitat to a protected or listed endangered plant and animal species.
3.1 – Groundwater is affected and a public or domestic water supply well is located between 0.25 and 0.5 miles from the UST/AST system or source area.
3.5 – A designated major or minor groundwater aquifer is affected or immediately threatened.
4.2 – The vertical extent of contamination has been defined and the assessment results document that groundwater is not affected.
4.1 – Groundwater is affected.
4.0 – Assessment incomplete; project closed out as a 4.0
4A (Historical Priority) – Soil contamination only; full site assessment and remedial action plan required
4B (Historical Priority) – Minor surface water impact
5 (Historical Priority) – Minor soil contamination; remedial action plan not required
6 (Historical Priority) – Minor soil contamination; no remedial action required

Oil and gas transmission pipelines are another potential source of hazardous material spills on the contributing and recharge zones of the aquifer. We obtained a summary of active and proposed pipeline mileage for this area (IHS 2019) and calculated that there are 264 km (164 mi) of pipeline in the contributing and recharge zones. These pipelines transport crude oil, natural gas, and natural gas liquids (Table 10). The proposed pipeline totals include those for the proposed Permian Highway Pipeline, expected to be developed across the contributing and recharge zones of the aquifer beginning in fall 2019 (IHS 2019; City of Austin 2019f, pp. 1–2). The size of each pipeline varies, with the proposed Permian Highway Pipeline being much larger in diameter than the other active and proposed pipelines crossing the contributing and recharge zones of the aquifer (City of Austin 2019f, p. 2). Gas transmission pipelines specifically can contain liquid contaminants, which could be accidentally released into the surrounding karst environment by accident (City of Austin 2019f, pp. 4–6). The City of Austin's Watershed Protection Department attempted to quantify the specific risks from the proposed Permian Highway Pipeline to the Austin blind salamander as a result of a leak or spill, but could not due to a lack of information about several aspects of the pipeline and its operations (City of Austin 2019f, pp. 4–5).

All "development and production of oil, gas, or a geothermal resource within the jurisdiction of the Texas Railroad Commission" are not considered regulated "activities

> having the potential for polluting the Edwards Aquifer and hydrologically connected surface water in order to protect existing and potential uses of groundwater and maintain Texas Surface Water Quality Standards" (Texas Natural Resource Conservation Commission 1996, p. 1). Consequently, the construction and maintenance of these pipelines is not subject to guidance mitigating impacts to karst features such as voids, and development of these pipelines is not subject to the Edwards Aquifer rules (Texas Natural Resource Conservation Commission 1996, entire; City of Austin 2019f, pp. 1–2).

Table 10. Active and proposed pipeline linear distance by product for the contributing and recharge zones of the Barton Springs segment of the Edwards Aquifer. Data from IHS Energy's Enerdeq Browser (IHS 2019).

Pipeline Type	Crude Oil	Natural Gas	Natural Gas Liquids	Total
Active	31 km (19 mi)	66 km (41 mi)	31 km (19 mi)	127 km (79 mi)
Proposed	11 km (7 mi)	68 km (42 mi)	58 km (36 mi)	137 km (85 mi)
Total	42 km (26 mi)	134 km (83 mi)	88 km (55 mi)	264 km (164 mi)

> Municipal water and sewer lines were also identified in the listing rule as a potential source of exposure to hazardous or degraded water in the event of a leak or rupture in the pipes containing these waters. While uncommon, such breaks can and do occur, even in lines that are only a few decades old, as in the case of a rupture in the West Travis County Public Utility Agency water line in 2015 (aci consulting 2018, p. iv). We worked with the City of Austin to identify water lines, wastewater lines, and septic tanks present within the contributing and recharge zones of the aquifer (Cooke 2019a, 2019b, 2019c, 2019d, 2019e); this information is displayed in Table 11. These totals are likely an underestimate of the true values since there are other water and wastewater lines within the boundary of interest for which we did not gain access to data, and because not all septic tanks have been inventoried and mapped by the City of Austin (Cooke 2019e). The number of miles and number of septic tanks within the contributing and recharge zones has increased every year since the salamander was listed. These values are expected to continue increasing in the future as currently proposed additions come on line and as new additions are proposed and eventually brought into service (Cooke 2019a, 2019b, 2019c).

Table 11. Linear distances of wastewater and regular water pipes, and number of septic tanks within the contributing and recharge zones of the Barton Springs segment of the Edwards Aquifer. Data from the City of Austin (Cooke 2019a, 2019b, 2019c). Only lines and tanks currently in service are included in these calculations.

Structure Type	Recharge Zone	Contributing Zone	Total
Wastewater Line	521 km (324 mi)	201 km (125 mi)	723 km (449 mi)
Water Line	761 km (473 mi)	529 km (329 mi)	1,291 km (802 mi)
Septic Tank (number)	136	221	357

Water quantity

Urbanization in this region are associated with significant water use. Within the BSEACD, municipal public water supply accounts for 77% of the authorized use for permitted wells in the district (BSEACD 2018, p. 6). Water supply and needs projects calculated for the BSEACD show a shift from a water supply surplus of approximately 172,687,200 meters^3 (m^3) [140,000 acre-feet (af)] in 2020 to a deficit of nearly 135,682,800 m^3 (110,000 af) in 2070 (BSEACD 2018, p. 40). These needs are due primarily to urban development from Austin to San Marcos, and represent future significant pressure on water supplies to the aquifer, given that surface waters in the Barton Springs segment of the aquifer are the source of aquifer recharge. Hence, merely drawing from surface water does not automatically alleviate pressure on the aquifer itself) (BSEACD 2018, p. 40). Increased water demand associated with increasing human populations may strain water supplies under a drought-recurrence scenario similar to the past several decades (Runkle et al. 2017, p. 1). Projections of future climate change indicate water supplies are likely to be compromised by more evaporation, exacerbating the water scarcity issue further (Runkle et al. 2017, p. 1).

The Texas Water Plan, revised in 2017, predicts a moderate increase in demand for water over the next 50 years (Texas Water Development Board 2017, pp. 53–59). The BSEACD finalized a revised management plan in 2017, followed by a Habitat Management Plan in 2018. Pumpage history from the BSEACD shows a leveling off of actual pumpage, even as permitted pumpage has steadily increased (BSEACD 2017, p. 31, 2018, p. 51).

Water quality

An analysis of water quality trends at the Zilker Park springs covering the period 1995–2015 found that a positive trend exists for several indicators of lowered water quality, as summarized in Table 3 (Porras 2016, pp. 7–11). There is no statistical trend in levels of dissolved oxygen (DO), strontium, total Kjeldahl nitrogen (TKN), temperature, and probably silica. Increasing trends are found for several other water quality indicators across the four Zilker Park springs where the salamander occurs. No new information on sedimentation was found.

The DO result may be the most surprising, as in the past City of Austin Water Quality Protection Department reports had indicated that DO levels have been declining over time, which would be a stressor likely to inhibit recovery of the salamander (Turner 2005, pp. 8–9, 2009, pp. 5–15; Herrington and Hiers 2010, pp. 17–19; Service 2013, p. 51308). A 2016 analysis better accounts for the confounding factor of flow by removing it from the regression equation, allowing separate tests for trends in DO over time during low flow, medium flow, and high flow periods (Porras 2016, pp. 2–10). That analysis found that DO has actually held steady over time, and City of Austin staff suggest that the previous result may have been additionally influenced by the high number of low flow periods during the years included in the analysis (Porras 2016, p. 7, 2019a, personal communication).

Rising conductivity was flagged as a potential future stressor on the salamander in the listing rule, a stressor for which trend data was lacking (Service 2013, pp. 53107–53108). The most recent analyses of water quality in the four Zilker Park springs found a trend of increasing conductivity at Parthenia Spring under both recharge and no recharge flow conditions, and at Upper Barton Spring and Old Mill Spring under recharge flow conditions. High conductivity is associated with increasing levels of development (Herrington et al. 2007, pp. 13–14). We infer that the increasing development in the contributing and recharge zones of the aquifer is the source for the observed change. Increasing development has likely led to increased surface flow contributions to the aquifer water, raising its conductivity (Garcia-Fresca 2004, p. 88; Garner and Mahler 2007, p. 5). At very low flows at Barton Springs (e.g., 5 cfs), saline water encroachment could cause conductivity levels to spike above 1,100 uS/cm, which may be a lethal concentration for *Eurycea* salamanders (City of Austin 2001, pp. 237–243; Woods and Poteet 2006, p. 42; Johns 2006, pp. 9–10). The BSEACD HCP set 6.5 cfs as its regulated minimum, a level which has not occurred in recorded history (BSEACD 2018, p. 30). Thus a flow of 5 cfs can be predicted and theoretically avoided under extreme drought conditions (BSEACD 2018, pp. 28–32). In addition, a report that reviewed previous studies on the freshwater/saline water interface found that the boundary is generally stable, and that encroachment would probably only occur under extreme drought (Hunt et al. 2014, entire). No new experiments have been conducted on conductivity/salinity tolerance on salamanders.

Available water quality information on nutrients presents mixed results. The concern about nutrient levels for tributaries of Barton Creek reported by TCEQ in 2012 is not present in the 2016 analysis, with none of the tributaries, or other streams crossing the recharge zone of the aquifer, reported as having levels of nutrients or nitrate that reached a level of concern (TCEQ 2012, p. 344, 2016, pp. 214–267). At the same time, the City of Austin's updated analysis of water quality at the Zilker Park springs found an increasing trend in levels of nitrate/nitrite at Parthenia, Eliza, and Old Mill Springs under recharge flow conditions (Table 12, Porras 2016, pp. 7–8). The analysis did not project when nitrate/nitrite levels might reach a level considered by TCEQ to be an exceedance.

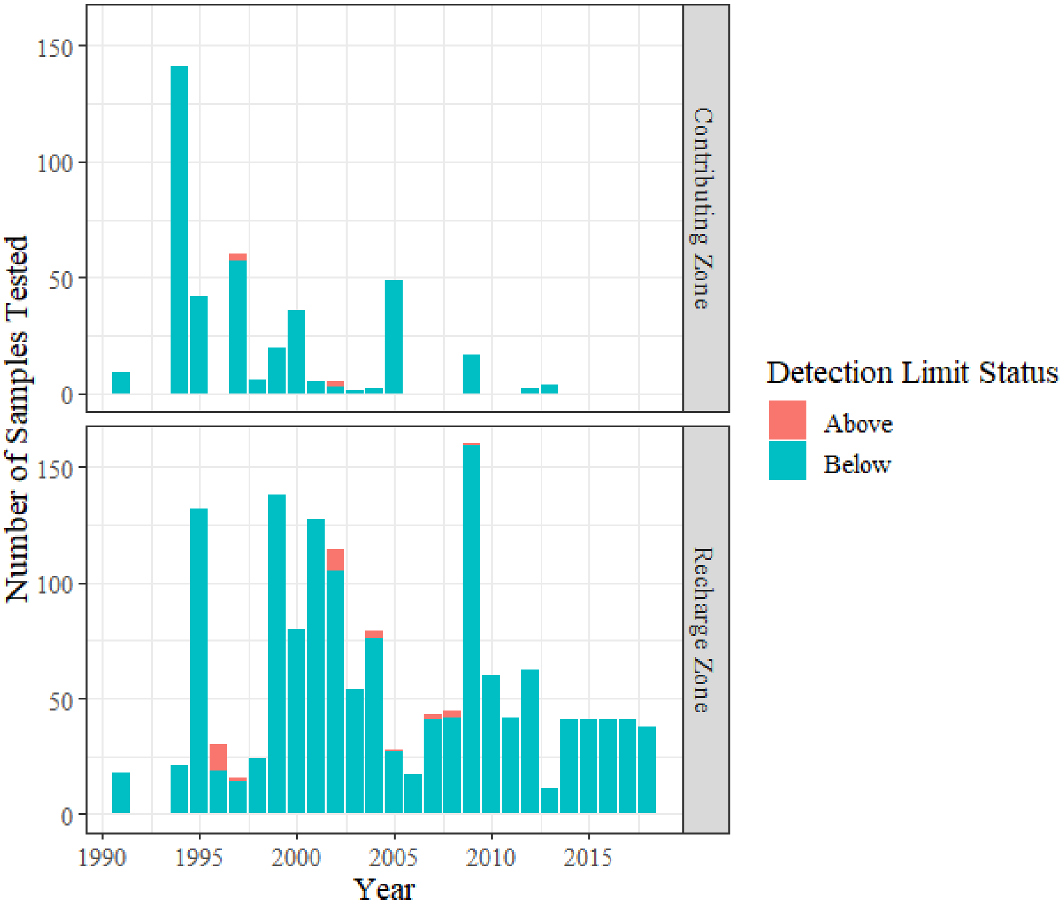
The City of Austin conducts regular monitoring for PAHs at many locations, including the four Zilker Park springs where the salamander has been observed (City of Austin 2019d). In a comprehensive assessment of PAHs at the Zilker Park springs across 2013–2014, it was uncommon to detect any PAH at Upper Barton Spring, Eliza Spring, or Sunken Garden Spring, and concentrations never surpassed the threshold effect concentration, or TEC ("the concentration under which adverse effects are not expected to occur") (Richter 2015, pp. 3, 13–33). However, this is not the case at Parthenia Spring. Although in general levels of PAHs are lower now than in the past, especially before the ban on coal tar sealants took effect in the City of Austin in 2006, many samples from Parthenia Spring contained concentrations of some PAHs that were above the TEC, with frequencies of such detections on the rise (Richter 2015, pp. 22–33). At Parthenia Spring, concentrations above the probable effect concentration ("the concentration above which adverse impacts are expected") were rare and there is not a trend of an increasing frequency of these detections (Richter 2015, pp. 3, 33).

Table 12. Water quality parameter trends for Zilker Park springs for the period 1995–2015. Adapted from Porras (2016).

Water Quality Parameter	Flow Condition	Parthenia Spring	Eliza Springs	Old Mill Springs	Upper Barton
Dissolved Oxygen	Recharge	None	None	None	None
	No Recharge	None	None	None	None
Calcium	Recharge	Increase	Increase	Increase	Increase
	No Recharge	None	Increase	Increase	Increase
Chloride	Recharge	Increase	Increase	Increase	Increase
	No Recharge	None	Increase	None	None
Conductivity	Recharge	Increase	None	Increase	Increase
	No Recharge	Increase	None	None	None
Fluoride	Recharge	None	None	None	None
	No Recharge	Increase	None	None	None
Magnesium	Recharge	Increase	None	None	None
	No Recharge	None	Increase	None	Increase
Nitrate/nitrite	Recharge	Increase	Increase	Increase	None
	No Recharge	None	None	None	None
pH	Recharge	Decrease	None	None	None
	No Recharge	None	None	Increase	None
Silica	Recharge	None	None	None	insufficient data
	No Recharge	None	None	None	insufficient data
Sodium	Recharge	Increase	None	Increase	Increase
	No Recharge	Decrease	None	None	Increase
Strontium	Recharge	None	None	None	None
	No Recharge	None	None	None	None
Sulfate	Recharge	Increase	Increase	Increase	None
	No Recharge	None	None	None	Increase
Temperature	Recharge	None	None	None	None
	No Recharge	None	None	None	None
Total Kjeldahl Nitrogen	Recharge	None	None	None	None
	No Recharge	None	None	None	None

Other pesticides described in the listing rule as a significant threat to the salamander include but are not limited to atrazine, carbaryl, diazinon, simazine, malathion, and prometone. In comparison to other water quality indicators such as those described above, testing for these has not been as intensive. Testing for these was not described in the 2016 TCEQ water quality assessment. The City of Austin tests for a variety of contaminants, including organophosphates, triazines, and carbamates, the chemical classes that include the above chemicals as well as others not specifically listed. We reviewed the results from these sampling efforts for locations within the recharge and contributing zones of the aquifer, and show a summary in Figure 10.

Figure 10. Water quality testing results for organophosphates, triazines, and carbamates at sampling sites within the contributing and recharge zones of the Barton Springs segment of the Edwards Aquifer (City of Austin 2019d).



Climate Change

Since the publication of the listing rule, new information on climate change has been published. Effects of climate change on temperature and precipitation are the most commonly reported and discussed impacts. A National Oceanic and Atmospheric Administration (NOAA) report assessing the effect of climate change on Texas highlights the fact that even under lower emissions scenarios (e.g., RCP 4.5), by the end of the century, the coldest years will feel like the warmest years today, and the warmest years will be about 3.3°C (6°F) warmer than the hottest year from the historical record (Runkle et al. 2017, p. 1). Warming under a higher emissions scenario (RCP 8.5) would lead to higher temperatures (Runkle et al. 2017, p. 1). As the temperature of groundwater and average air temperature are related, it is reasonable to predict that increases in aquifer and spring water temperatures will follow increases in air temperatures (Mahler and Bourgeais 2013, p. 295). However, the length of the lag time for this correlation under climate change scenarios, as well as the detailed mechanistic relationship between climate change and groundwater quality, is not understood (Mahler and Bourgeais 2013, p. 295; Kløve et al. 2014, pp. 262–263).

The Fourth National Climate Assessment, published in 2018 by the U.S. Global Change Research Program, predicts that between now and 2100, the frequency and intensity of heavy precipitation events in the southern Great Plains region is likely to increase (Kloesel et al. 2018, p. 996). This region is already prone to drought, but the length and severity of drought are also predicted to increase steadily (are already increasing) (Kloesel et al. 2018, pp. 992, 1008).

These predictions also appear in a report specifically targeted at the City of Austin, which downscales climate models to this subregion (Hayhoe 2014, entire). An increase in temperatures, measured several different ways (for example, as the overall average, days with lows below 0°C (32°F), days with lows above 26.7°C (80°F), as days above 37.8°C (100°F), etc.) is projected with high certainty (Hayhoe 2014, pp. 4, 9). There is moderate certainty about projections that future extreme precipitation events will become slightly more common in the coming decades, regardless of emissions scenario (Hayhoe 2014, pp. 6, 9). There is less certainty about the precipitation projections (Hayhoe 2014, p. 9). The downscaling results predict little to no change in annual average precipitation and length of longest dry period, and a slight increase in the number of dry days annually, again regardless of emissions scenario (Hayhoe 2014, p. 6).

Lower soil moisture levels are also predicted as a consequence of this change in precipitation patterns (Kloesel et al. 2018, p. 996). Changes in soil moisture may increase the likelihood of issues with other infrastructure. During the 2011 central Texas drought, water main breaks were common. In the event of future droughts, water main breaks, and potentially other subsurface pipe ruptures, will again be at greater risk of occurrence (Kloesel et al. 2018, p. 1004).

Conservation Measures

Barton Springs-Edwards Aquifer Conservation District

The BSEACD adopted a HCP covering Austin blind salamander in 2018 (BSEACD 2018, entire). This plan complements the BSCEAD Management Plan (BSEACD 2017, entire). The plans include numerous measures intended to conserve this species. For example, the Extreme Drought Withdrawal Limitation, in place since 2007, caps withdrawals during extreme drought (BSEACD 2017, pp. 13–14). In addition, an Ecological Flow Reserve was created to hold now-retired permitted production and thereby dedicate some water to ecological purposes specifically (BSEACD 2018, p. 14). The plans include a Desired Future Condition (i.e. goal) to preserve a minimum flow at Barton Springs of 6.5 cfs during a recurrence of Drought-of-Record conditions in order to ensure that the salamander habitat does not disappear in the event of another severe drought (BSEACD 2018, pp. 16–17). As of 2018 the District's models calculate that in the event of another extreme drought, they would fail to meet the 6.5 cfs desired future condition by 0.3 cfs; efforts to ameliorate this are ongoing (BSEACD 2018, p. 17).

City of Austin

The City of Austin has undertaken restoration and habitat conservation measures at the four springs in Zilker Park in order to improve the quality of the habitat in the springs and decrease the impacts of human disturbance to the salamanders and their habitat (Robinson 2019a, p. 2). Management of Barton Springs Pool usually directly affects Parthenia Spring, which is located within the pool. Chemical cleaning (e.g. with chlorine) has been prohibited since 1998, and areas of the pool that are habitat for the salamander may not be cleaned with high pressure (Robinson 2019a, p. 4). Drawdowns are limited in frequency and scope, and salamander biologists must be present during the drawdowns to watch for and rescue any stranded salamanders (Robinson 2019a, p. 4). Sediment is removed from habitat in the pool during quarterly surveys at minimum, freeing up interstitial space for salamander sheltering and feeding (City of Austin 2018a, pp. 3–4; Robinson 2019a, p. 4). To avoid pollutants entering the pool, improved best management practices for hazardous materials near the pool (e.g. better management of gasoline-powered equipment in the vicinity), a berm to direct parking lot runoff away from the pool is in place, and better vegetation management reduces soil erosion (Robinson 2019a, p. 6).

Eliza Spring has undergone the most changes recently, and is currently the locality with the most robust Barton Springs salamander counts (Dries 2012, p. 17; Robinson 2019a, p. 9). Sediment is removed from habitat in the pool during quarterly surveys, freeing up interstitial space for salamander sheltering and feeding (City of Austin 2018a, pp. 3–4; Robinson 2019a, p. 9). In addition, non-native plants and animals are regularly removed from the site, native vegetation added, and a rock barrier added to the walls to prevent runoff into the spring (Robinson 2019a, p. 9). More substantially, a restoration project replaced a degraded outflow pipe with a natural surface stream, restoring approximately 23 meters^2 (m2) [250 square feet (ft^2)] of potential stream habitat, and improving habitat within the amphitheater by enabling better management of water depth (Robinson 2019a, pp. 9–12). The City of Austin is monitoring the effects of the daylighting restoration and results will be available in 2020 (Robinson 2019a, p. 12, 2019b, personal communication). Eliza Spring has been closed to the public since the mid-1990s (Robinson 2019a, p. 9).

Old Mill Spring has undergone a variety of management and restoration efforts over the years. It was closed to the public in 1998 (Robinson 2019a, pp. 15–16). The outflow stream has been modified to increase stream flow and prevent colonization by fish that prey on salamanders (Robinson 2019a, p. 15). From 2005–2012 efforts to reduce water levels, remove trash and restore debris-inhibited flows, but salamander numbers did not respond, and efforts today are reduced (Robinson 2019a, p. 15).

Austin blind salamander has been observed once at Upper Barton Spring, a site that goes intermittently dry and experiences human disturbance (Bendik 2018, personal communication; Robinson 2019a, p. 17). Signage is in place to educate visitors, intending to reduce disturbance, but the habitat here has not been modified substantially in the past so virtually no habitat restoration has taken place (Robinson 2019a, p. 17).

Protected Areas

Conservation organizations, private individuals, and government entities have collaborated to protect lands in the contributing and recharge zones with the ultimate goal of protecting and enhancing water quality in the aquifer and the Zilker Park springs. Bonds passed in 1998 provided funding for the City of Austin to begin acquiring "water quality protection lands" (City of Austin 2019e), and a new bond passed in 2018 that will supply additional monies to purchase such lands (Largey 2018). The funding goes toward purchasing both fee simple and easements, although easements make up the bulk of the holdings. The 2013 listing rule did not enumerate the total area under conservation easement or ownership at that time. We reviewed the Protected Areas Database, versions 1.4 (U.S. Geological Survey 2016) and 2.0 (U.S. Geological Survey 2018), and calculated the acres in the contributing and recharge zones. This total was similar across the two datasets, so we only include the results from PAD 2.0 in Table 13.

Table 13. Total area in protected status (either fee simple or easement) within the contributing and recharge zones of the Barton Springs segment of the Edwards Aquifer. Data from the USGS Protected Areas Database, version 2.0 (U.S. Geological Survey 2018).

Zone	Protected Hectares (Acres)	Total Hectares (Acres)	Percent of Total
Recharge	7,251 (17,918)	27,739 (68,544)	26%
Contributing	7,140 (18,310)	173,866 (429,632)	4%
Both (total)	14,391 (35,561)	201,605 (498,177)	7%

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

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

Population growth and impervious cover

Increasing human population and increasing impervious cover within the contributing and recharge zones of the aquifer are correlated with a suite of potential effects on water quality and quantity (Schueler 1994, entire; Paul and Meyer 2001, entire; City of Austin 2006, entire; Schueler et al. 2009, entire). These water quality and quantity impacts affect the ability of the Austin blind salamander to persist in the wild. Data from several sources indicates that previous predictions of increasing population and impervious cover/development over time were correct, and that positive trends are expected to continue in the future (U.S. Census Bureau 2000a, 2010a, 2017a; Texas Demographic Center 2018). Similarly, past predictions that impervious cover in the contributing and recharge zones was increasing were accurate, and overall trends continue to be positive (Falcone 2015; Yang et al. 2018). We ran linear regressions on the change in land use types from Falcone (2015) and obtained good fits for the Developed, Semi-Developed, and Low Use types. We then used the parameters from these regressions to predict the total area in these types in 2030 and 2050 (**Table 14**). The results of this analysis indicate that if development for the next few decades proceeds at the same rate and pattern of land use change, total developed and semi-developed area in the recharge and contributing zones could exceed 60% by 2050. If this level of development were to occur, it would likely have significant negative impacts on the water quality of the streams in the recharge and contributing zones, and eventually on the aquifer waters in which the Austin blind salamander lives (Schueler 1994, pp. 107–108; Schueler et al. 2009, pp. 313–314)

Table 14. Estimated (1974–2012) and projected (2030–2050) area in Developed, Semi-Developed, and Low Use types (after Falcone (2015). The area of interest is the combined recharge and contributing zones of the Barton Springs segment of the Edwards Aquifer. Values are in hectares, with proportion of the total area in the recharge and contributing zones in parentheses. Percentages do not sum to 100 because there are other land use types in the original dataset that not shown here.

Year	Developed	Semi-Developed	Low Use
1974	5,824 (3%)	7,548 (4%)	185,202 (92%)
1982	7,428 (4%)	10,034 (5%)	181,536 (90%)
1992	9,336 (5%)	17,902 (9%)	172,088 (85%)
2002	12,511 (6%)	23,708 (12%)	161,660 (80%)
2012	14,674 (7%)	31,742 (16%)	151,519 (75%)
2030	23,654 (12%)	55,581 (28%)	117,816 (58%)
2050	35,545 (18%)	88,040 (44%)	72,170 (36%)

Road construction and maintenance also increases the amount of impervious cover present on the landscape, and the amount and size of roads crossing the recharge and contributing zones of the aquifer is steadily increasing, and projected to increase in the future (TxDOT 2011, 2019; CAMPO 2015, pp. 28–31; 64–75).

Acute water quality degradation

The listing rule identified several stressors that, under the right circumstances, could lead to the extirpation of the Austin blind salamander from the wild. All impact water quality, and have the potential to be catastrophic to the species as the potentially short travel time of a contaminant through the aquifer could preclude attempts to address a spill before the aquatic habitat of the salamanders is contaminated (Turner and O'Donnell 2004, entire). Spills from hazardous waste storage sites, transit containers (rail or truck freight systems), underground storage tanks, water or sewage lines, and energy pipelines are the concern. A positive correlation with urbanization was suspected at the time of listing.

In Section 2.3.1.6, we reviewed available data on spills from these sources. We found that no trend over the period 1990–2018 in reported hazardous material spills in Hays and Travis counties (U.S. Coast Guard 2019). We also found that incidences of leaking underground storage tanks has declined over time, and that no leaking underground storage tanks have impacted the Edwards Aquifer since 1996 (TCEQ 2019a; Dunahoo 2019, personal communication). We suspect that a combination of new technologies associated with the storage and transport of hazardous materials and petroleum and improved regulations and regulatory compliance explain this decline in potential exposure events, which has occurred during a time period when the human population is growing and development is ongoing. We have locations for water and sewer lines and septic tanks that occur within Austin's jurisdiction. Older lines and septic tanks are more likely to leak and leak larger amounts, and so we continue to expect that the potential for leaks from these structures will increase over time due to both the addition of new infrastructure and the deterioration of infrastructure over time (Christian et al. 2011, p. 94).

We do not have analogous data on the leaks or spills associated with the energy pipelines, but regulation and technology are likely to result in newer pipelines being generally less likely to spill initially, with the probability of a spill or leak increasing with the age of the infrastructure (Groeger 2012). Although accidents do occur (Hiller 2017), we do not know of any that have contaminated the Barton Springs segment of the aquifer. That said, regulation of impacts to the aquifer or contributing streams from the construction, maintenance, and operation of underground energy pipelines are regulated by the Texas Railroad Commission and not subject to the Edwards Rules protecting karst features in the area, the aquifer, or its water quality, despite the likelihood of some impact being a virtual certainty at least during the construction phase of large underground pipelines (Texas Natural Resource Conservation Commission 1996, pp. 1–2; City of Austin 2019f, pp. 1–2).

Based on available data, the risk of a spill or leak from hazardous materials storage or transit, underground storage tanks, and water or sewer lines, and septic tanks appears low. The risk to aquifer health from the construction of new underground energy pipelines is much higher due to the fact that there are not requirements to mitigate impacts from such activities. The consequences of such a spill range from severe (in the case of a highly toxic spill in waters that quickly recharge to Barton Springs) to mild (in the case of a less toxic spill at a great distance from recharge features that never impacts water). Given the increase in total potential sources of spills and the ever-increasing age of infrastructure in the region, we conclude that the risk of water quality pollution from hazardous material spills has increased since the Austin blind salamander was listed, and will continue to increase in the future.

Large inputs of sediment from road, home, or well construction were identified as a potential stressor to the Austin blind salamander during the listing process. There is now a recorded instance of a well drilling operation causing sediment plumes to enter Barton Springs and degrade water quality (Huber 2018, 2019). Within the City of Austin's jurisdiction, the number of construction permits in the last 15 years is about double that of the previous 15 years (see Section 2.3.1.6 and Figure 7). Like hazardous material spills, the risk to Austin blind salamanders from construction sediment entering the aquifer is a function of the amount of material spilled, and the distance to the aquifer.

Chronic water quality degradation

Chronic water quality impairment affecting the aquatic habitat of the Austin blind salamander was also identified in the listing rule as reducing the viability of the species (U.S. Fish and Wildlife Service 2013, pp. 51297–51301). The specific sources of water quality contamination are often positively correlated with impervious cover (Schueler et al. 2009, pp. 309–313), but several are measured directly by water quality monitoring programs; we address them directly here. These stressors include the presence of PAHs, pesticides, increased levels of nutrients, conductivity, and salinity, and decreased levels of DO, and all were expected (as stated in the listing rule) to increase in the future with increases in human population and impervious cover (U.S. Fish and Wildlife Service 2013, pp. 51305–51308).

We reviewed all new water quality monitoring data and reports available from Austin's watershed protection department, and discuss those results above in the section on updated information on ecosystem conditions. We also note that water quantity issues, discussed below, can lead to water quality degradation over both the short- and long-term. Stormwater runoff may provide an influx of contaminants, impoundments may promote the accumulation of contaminants, and declines in water quantity over both the short- and long-term may cause the concentration of contaminants in the remaining water to increase (Schueler 1987, pp. 1.5-1.9; Walsh et al. 2005, pp. 713–714; Robinson 2019a, pp. 4–19).

PAHs continue to be detected in Austin blind salamander habitat, so exposure to them is certain to occur. The timeframe of the exposure continues to be ongoing and likely to occur in the future. The source of increased PAHs in Zilker Park springs has not been identified, and the frequency of concentrations above the TEC is increasing (Richter 2015, pp. 3, 13–33).

Sedimentation is a stressor to the species as it can inhibit their breathing, movement, and ability to avoid predators or locate food (Schueler 1987, p. 1.5). It can also cause habitat loss when it fills interstitial spaces otherwise available to salamanders for movement or sheltering (Welsh, Jr. and Ollivier 1998, p. 1128). This stressor was categorized as high severity and ongoing for the Austin blind salamander at the time of listing. We have no new information on trends, but due to the correlation between increased impervious cover and age of infrastructure with sedimentation, we infer that that the risk to salamanders is either unchanged or increased since the species was listed in 2013 (Geismar 2005, pp. 10–13; Porras 2019b, personal communication). Therefore, our overall conclusion is that sedimentation is certain to continue occurring, is a chronic source of water quality degradation, and is a high severity stressor currently mitigated primarily by careful management of sediment and substrate of Zilker Park springs (City of Austin 2018a, pp. 2–6). The stressor may increase in severity in the future if projected increases in the frequency of extreme precipitation events occur (Kloesel et al. 2018, p. 996).

It is well established that low DO inhibits many functions vital to life for salamanders and many other aquatic species (Mahler and Bourgeais 2013, p. 291). As detailed in the listing rule, decreased DO is often found alongside decreased water quantity, increased nutrients, increased urban development, and as a result of sewer or septic leaks (Service 2013, pp. 51302–51316). At the time of the listing rule, it was thought that anthropogenically-decreased DO levels were a high severity stressor on the Austin blind salamander that was ongoing and increasing over time.

A 2016 study that more fully accounts for the variable flow patterns found at the Zilker Park springs found that, in contrast to previous work, DO has actually held steady over time (Porras 2016, pp. 7–11). That is, there is no increasing trend in DO. However, the risk of low DO events remains (Kloesel et al. 2018, p. 1003). The consequences of such an event from severe (i.e., a very fast-occurring event, or a long duration event) to mild (i.e., a brief dip that falls within the natural range of variability for this measure). However, given the increase in total potential sources of triggering events and the water quantity stressors associated with population growth and climate change, we conclude that the risk of low DO events has increased since the Austin blind salamander was listed, and will continue to increase in the future.

The listing rule discussed potential direct impacts on the Austin blind salamander behavior and development from excess nutrients, as well as leading to indirect effects such as changes in physical habitat and decreased DO levels. Excess nutrient levels were described as moderate severity and as ongoing. Recent research on the Barton Springs salamander suggests that TCEQ limits on nutrient levels are adequate to protect that species (Crow et al. 2017, pp. 3004–3006), and TCEQ water quality reports indicate that the surface waters feeding the Zilker Park springs are not exceeding those limits (TCEQ 2012, p. 344, 2016, pp. 214–267). A trend analysis of water quality at the springs themselves found an increasing trend in nitrate/nitrite at Parthenia, Eliza, and Old Mill springs in the recharge flow condition, but this trend is small in magnitude and does not indicate that nitrate/nitrite will increase to a level where it could cause mortality in the near future (Porras 2016, pp. 7–8). Projections further into the future were not conducted.

Saline water encroachments from changes in source water to Barton Springs during periods when discharge from Barton Springs is very low is described in the listing rule as a high severity stressor, that is ongoing for the Austin blind salamander. The recently-approved BSEACD HCP asserts that saline water encroachments do not happen on their own; rather, they are a consequence of decreased water quantity (BSEACD 2018, p. 21). That is, they occur when flows through the aquifer to Barton Springs decline to such a degree that water flows into Barton Springs from an area with more saline water, which is normally confined and does not comprise a significant portion of Barton Springs' flow (Hunt et al. 2014, entire; BSEACD 2018, p. 21). Therefore, it is very difficult to isolate the effects from saline water encroachments from the other impacts to water quality associated with very low water quantity. Moreover, the discharge levels at which saline encroachments threaten the species are extremely low – below the minimum discharge set in the HCP.

Conductivity was described in the listing rule as a stressor that was expected to become significant in the future. Although water quality analyses at Zilker Park springs show some increasing trends, we do not have any new information on the effects of these increases on the Austin blind salamander. The absolute values of the measurements are still well below any effects thresholds in studies involving other salamanders (City of Austin 2001, pp. 237–243; Woods and Poteet 2006, p. 42; Porras 2016, pp. 7–11). The concern that remains is that baseline conductivity levels may increase to the point where only a small amount of saline water encroachment event would increase conductivity high enough to cause harm or mortality to the species. However, additional research is needed to predict the conditions under which this would occur.

Chronic water quantity issues

Parthenia, Eliza, and Old Mill springs originally consisted of spring runs and flowing streams, but were all impounded between the 1870s and 1920s (Robinson 2019a, pp. 6–17). As a result, the areas around the springs are pond-like, support fish that predate on salamanders, and are subject to sedimentation that must be removed manually (Robinson 2019a, pp. 4–15). Although the City of Austin has undertaken measures to restore the impoundments to a more natural state, the impoundments do and will remain. Consequently, the Austin blind salamander experiences an ongoing stressor of low to moderate severity across the springs.

Use of water from the aquifer is a potential driver of chronic water shortages. The BSCEAD regulates the use of groundwater from this segment. Because there is anthropogenic removal of water from the aquifer, we know that the natural flow of water to and out of the Zilker Park springs is altered (BSEACD 2017, p. 27). Alterations to the natural flow can then lead to chronic water quality degradation impacts on the species.

Acute water quantity issues

Drought, and its associated increased demand for water and decreased availability of water, are another stressor for the Austin blind salamander because of potential loss of habitat within the aquifer and potential impacts to water quality within the aquifer and the Zilker Park springs. The direct effect is primarily a decrease in rainwater-driven recharge of the Barton Spring segment of the Edwards Aquifer and of flow into the springs, owing to lack of precipitation (Bendik and Dries 2018, p. 15). Indirect effects include both any increases in groundwater pumping to compensate for decreased precipitation, which decreases groundwater extent and flow to the four Zilker Park springs, and decreases in water quality occurring because the relative concentration of contaminants in the water increases.

The BSEACD Management Plan and associated HCP have structures and rules in place to curtail pumping under a sequence of increasingly severe drought scenarios (BSEACD 2017, entire, 2018, entire). The drought status declared by the BSEACD reached the "Critical" level 4 times in the period from 2006–2013 (Smith et al. 2013, p. 21). During these times, single-day measurements of Barton Springs mean flow reached 19 cfs in September 2006, 13 cfs in September 2009, and 16 cfs in November 2011 (Smith et al. 2013, p. 21). During these periods drought management and curtailments of permitted pumpage were in effect, resulting in higher levels of flow than would have existed without those restrictions in place (Smith et al. 2013, pp. 21–26; BSEACD 2018, p. 61).

In addition, this stressor can lead to acute water quality degradation impacts on the Austin blind salamander. Reduced water quantity due to drought can result in water quality degradation as the concentration of contaminants is increased (Kloesel et al. 2018, pp. 1012–1013). Barton Springs and Austin blind salamander abundance is known to decrease during droughts and times of water stress (Dries 2012, pp. 15–17). Reproduction appears to decrease under these conditions as well for Barton Springs salamander (Dries 2012, pp. 15–17), and we suspect the same is true for Austin blind salamander. This stressor is likely to recur in the future, and its impact will range from moderate to high severity depending on the intensity and duration of the drought, and the concurrent demand for groundwater and any surface water that would otherwise recharge the aquifer.

Flooding events can also harm salamanders both directly and indirectly. In the listing rule it was hypothesized that strong floods may flush individuals from their habitat. As impervious cover increases in the contributing and recharge zones, and as stormwater management infrastructure ages, flooding may recur more frequently (Walsh et al. 2005, pp. 707–708; Bendik et al. 2014, p. 216). Runoff from flooding in areas with impervious cover can also provide influxes of contaminants, degrading water quality (as discussed above) (Schueler 1987, pp. 1.5-1.9; Walsh et al. 2005, pp. 713–714).

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

We have no evidence that people are collecting Austin blind salamander outside of permitted activities authorized by the Austin Ecological Services Field Office, so this factor is not relevant.

2.3.2.3 Disease or predation

The final listing rule for the Austin blind salamander concluded that neither disease nor predation were threatening the persistence of the species. We have no evidence that this has changed, so this factor is not relevant.

2.3.2.4 Inadequacy of existing regulatory mechanisms

The primary threats to the Austin blind salamander are habitat degradation related to a reduction of water quality and quantity and disturbance at spring sites (Service 2013, pp. 51297–51311). Therefore, regulatory mechanisms that protect water from the Edwards Aquifer are crucial to the future survival of this species. Federal, State, and local laws and regulations have been insufficient to prevent past and ongoing impacts to the Austin blind salamander and its habitat from water quality degradation, reduction in water quantity, and surface disturbance of spring sites, and are unlikely to prevent further impacts to the species in the future.

State and Federal Regulations

State laws and regulations pertaining to endangered or threated animal species in the State of Texas are contained in Chapters 67 and 68 of the Texas Parks and Wildlife Department (TPWD) Code and Sections 65.171-65.176 of Title 31 of the Texas Administrative Code (T.A.C). State regulations prohibit the taking, transportation, or sale of any of the animal species designated by State law as endangered or threatened without the issuance of a permit. Although the Austin blind salamander is listed as a state endangered species, that status confers no protective provisions for the species' habitat.

Under the authority of the T.A.C. (Title 30, Chapter 213), the TCEQ regulates activities having the potential for polluting the Edwards Aquifer and hydrologically connected surface streams through the Edwards Aquifer Protection Program or "Edwards Rules." The Edwards Rules require a number of water-quality protection measures for new development occurring in the recharge, transition, and contributing zones of the Edwards Aquifer.

The Edwards Rules were enacted to protect existing and potential uses of groundwater and maintain Texas Surface Water Quality Standards. Specifically, a water pollution abatement plan (WPAP) must be in order to conduct any construction related or post-construction activities on the recharge zone. The WPAP must include a description of the site and location maps, a geologic assessment conducted by a geologist, and a technical report describing, among other things, temporary and permanent best management practices (BMPs).

Permanent BMPs and measures identified in the WPAP are designed, constructed, operated, and maintained to remove 80% of the incremental increase in annual mass loading of the total suspended solids from the site. This results in some level of water quality degradation since up to 20% of total suspended solids are ultimately discharged from the site into receiving waterways. Separate Edwards Aquifer protection plans are required for organized sewage collection systems, underground storage tank facilities, and aboveground storage tank facilities. Regulated activities exempt from the requirements of the Edwards Rules are the installation of natural gas lines; telephone lines; water lines; and other utility lines that are not designed to carry and will not carry pollutants, storm water runoff, sewage effluent, or treated effluent from a wastewater treatment facility.

Temporary erosion and sedimentation controls are required to be installed and maintained for any exempted activities located on the recharge zone. Individual landowners who seek to construct single-family residences on sites are exempt from the Edwards Aquifer protection plan application requirements provided they do not exceed 20% impervious cover. Similarly, the Executive Director of the TCEQ may waive the requirements for permanent BMPs for multi-family residential subdivisions, schools, or small businesses when 20% or less impervious cover is used at the site.

The best available science indicates that measurable degradation of stream habitat and loss of biotic integrity occurs at levels of impervious cover within a watershed much less than this (Coles et al. 2012, p. 65). The TCEQ regulations do not address land use, impervious cover limitations, some nonpoint source pollution, or application of fertilizers and pesticides over the recharge zone (30 TAC 213.3). In addition, these regulations were not intended or designed specifically to be protective of the salamanders. We are unaware of any water quality ordinances more restrictive than the TCEQ's Edwards Rules in Hays or Travis counties.

Texas has an extensive program for the management and protection of water that operates under State statutes and the Federal Clean Water Act (CWA). It includes regulatory programs such as the following: Texas Pollutant Discharge Elimination System, Texas Surface Water Quality Standards, and Total Maximum Daily Load Program (under Section 303(d) of the CWA).

In 1998, the State of Texas assumed authority from the Environmental Protection Agency (EPA) to administer the National Pollutant Discharge Elimination System. As a result, the TCEQ's Texas Pollutant Discharge Elimination System (TPDES) program has regulatory authority over discharges of pollutants to Texas surface water, with the exception of discharges associated with oil, gas, and geothermal exploration and development activities, which are regulated by the Railroad Commission of Texas. In addition, stormwater discharges from agricultural activities are not subject to TPDES permitting requirements.

The TCEQ issues two general permits that authorize the discharge of stormwater and non-stormwater to surface waters in Texas associated with: (1) small municipal separate storm sewer systems (MS4) (TPDES General Permit #TXR040000) and (2) construction sites (TPDES General Permit #TXR150000). The MS4 permit covers small municipal separate storm sewer systems that were fully or partially located within an urbanized area, as determined by the 2000 Decennial Census by the U.S. Census Bureau, and the construction general permit covers discharges of storm water runoff from small and large construction activities impacting greater than one acre of land. In addition, both of these permits require new discharges to meet the requirements of the Edwards Rules.

To receive coverage under the MS4 general permit, a municipality must submit a Notice of Intent (NOI) and a copy of their Storm Water Management Program (SWMP) to TCEQ. The SWMP must include a description of how that municipality is implementing the seven minimum control measures. These measures include (1) public education and outreach; (2) public involvement and participation; (3) detection and elimination of illicit discharges; (4) construction site storm water runoff control (when greater than 0.4 ha (1 ac) is disturbed); (5) post-construction storm water management; (6) pollution prevention and good housekeeping for municipal operations; and (7) authorization for municipal construction activities (optional).

For coverage under a construction general permit, an applicant must prepare a stormwater pollution and prevention plan (SWP3) that describes the implementation of practices that will be used to minimize, to the extent practicable, the discharge of pollutants in storm water associated with construction activity and non-storm water discharges. For activities that disturb greater than 2 ha (5 acres), the applicant must submit a NOI to TCEQ as part of the approval process.

As stated above, the two general permits issued by the TCEQ do not address discharge of pollutants to surface waters from oil, gas, and geothermal exploration and geothermal development activities, stormwater discharges associated with agricultural activities, and from activities disturbing less than 2 ha (5 ac) of land. Despite the significant value the TPDES program has in regulating point source pollution discharged to surface waters in Texas, it does not adequately address all sources of water quality degradation, including non-point source pollution and the exceptions mentioned above, that have the potential to negatively impact the Barton Springs salamander.

To discharge effluent onto the land, the TCEQ requires wastewater treatment systems within the Barton Springs Segment of the Edwards Aquifer recharge and contributing zones to obtain Texas Land Application Permits (TLAP) (Ross 2011, p. 7). Although these permits are designed to protect the surface waters and underground aquifer, studies have demonstrated reduced water quality downstream of TLAP sites (Mahler et al. 2011, pp. 34–35; Ross 2011, pp. 11–18). Ross (2011, pp. 18–21) attributes this to the TCEQ's failure to conduct regular soil monitoring for nutrient accumulation on TLAP sites and the failure to conduct in-depth reviews of TLAP applications. A study by the U. S. Geological Survey concluded that nitrate levels in the Barton Springs Segment of the Edwards Aquifer had shifted upward between 2001 and 2010 and was at least partially the result of an increase in the land application of treated wastewater (Mahler et al. 2011, pp. 34–35).

Local Ordinances and Regulations

The City of Austin's water quality ordinances (City of Austin Code, Title 25, Chapter 8) provide some water quality regulatory protection to the Austin blind salamander's habitat within Travis County. Protections include buffers around critical environmental features and waterways (up to 122 m (400 ft), permanent water quality control structures (sedimentation and filtration ponds), wastewater system restrictions, and impervious cover limitations (City of Austin Code, title 25, Chapter 8; Turner 2007, pp. 1–2). The ordinances range from relatively strict controls in its Drinking Water Protection Zones to lesser controls in its Desired Development Zones. For example, a 15% impervious cover limit is in place for new developments within portions of the Barton Springs Zone, one of the Drinking Water Protection Zones, while up to 90% impervious cover is permitted within the Suburban City Limits Zone, one of the Desired Development Zones.

Some studies have demonstrated that these ordinances play a role in protecting Austin-area surface waters from urbanization-related contaminants. In the period after the City of Austin passed water quality ordinances in 1986 and 1991, sedimentation and nutrients decreased in the five major Austin-area creeks (Turner 2007, p. 7). Peak storm flows were also lower after the enactment of the ordinances, which may explain the decrease in sedimentation (Turner 2007, p. 10). Likewise, a separate study on the water quality of Walnut Creek from 1996 to 2008 found that water quality has either remained the same or improved (Scoggins 2010, p. 15).

These trends in water quality occurred despite a drastic increase in construction and impervious cover during the same time period (Turner 2007, pp. 7–8; Scoggins 2010, p. 4), indicating that the ordinances are effective at mitigating some of the impacts of development on water quality. Another study in the Austin area compared 18 sites with stormwater controls (i.e., retention ponds) in their watersheds to 20 sites without stormwater controls (Maxted and Scoggins 2004, p. 8). In sites with more than 40% impervious cover, more contaminant-sensitive macroinvertebrate species were found at sites with stormwater controls than at sites without controls (Maxted and Scoggins 2004, p. 11).

Title 7, Chapter 245 of the Texas Local Government Code permits "grandfathering" of certain local regulations. Grandfathering allows developments to be exempted from new requirements for water quality controls and impervious cover limits if the developments were planned prior to the implementation of such regulations. However, these developments are still obligated to comply with regulations that were applicable at the time when project applications for development were first

filed (Title 7, Chapter 245 of the Texas Local Government Code, p. 1).
On January 1, 2006, the City of Austin banned the use of coal tar sealant (Scoggins et al. 2009, p. 4909), which is the main source of PAHs in Austin-area streams (Mahler et al. 2005, p. 5565). However, historically applied coal tar sealant lasts for several years and can remain a source of PAHs to aquatic systems (DeMott et al. 2010, p. 372). A study that examined PAH concentrations in Austin streams before the ban and two years after the ban found no difference, indicating that either more time is needed to see the impact of the coal tar ban, or that other sources (e.g., airborne and automotive) are contributing more to PAH loadings (DeMott et al. 2010, pp. 375–377).

Groundwater Conservation Districts

The Barton Springs/Edwards Aquifer Conservation District permits and regulates most wells on the Barton Springs segment of the Edwards Aquifer, subject to the limits of the State of Texas law. They have established two desired future conditions for the Freshwater Edwards Aquifer within the Northern Subdivision of Groundwater Management Area 10. They are as follows: (1) an extreme drought desired future condition of 6.5 cfs measured at Barton Springs and (2) an "all-conditions" desired future condition of 49.7 cfs measured at Barton Springs. These desired future conditions are meant to assure an adequate supply of freshwater for well users and adequate flow for endangered species.

Without a singular or cooperative management effort of surface and subsurface water resources, depletion of groundwater is likely to result in diminished spring flow and water table declines. This is expected to have considerable, negative impacts on the biodiversity and ecosystem functioning of the Edwards Aquifer upon which the Austin blind salamander depends for its breeding, feeding, and sheltering needs.

2.3.2.5 Other natural or manmade factors affecting its continued existence

The stressors listed under this factor in the original listing rule were small population size, ultraviolet radiation, and the nature of the aquifer-focused habitat for Austin blind salamander. We do not have new information that alters the analysis or conclusions from the original rule on these topics. There appears to be some risk to the salamanders of trampling by humans using Barton Springs Pool (City of Austin 2019c, p. 3). The City of Austin has signage in place to educate visitors and reduce this form of disturbance (Robinson 2019a, p. 17). We consider trampling by Barton Springs Pool visitors to be an ongoing stressor of very low severity that is unlikely to increase in the future.

Trends in temperature and precipitation

Changes in the frequency and intensity of temperature and precipitation due to anthropogenic climate change are already occurring in central Texas (Hayhoe et al.

2018, pp. 76–91; Kloesel et al. 2018, pp. 992–994). These trends, in conjunction with other factors, have the potential to impact the Austin blind salamander. For example, increased temperatures means that soil moisture will be decreased, and that the region will meet the standards for drought more frequently and for longer durations (Wehner et al. 2017, pp. 232–236; Kloesel et al. 2018, pp. 996–1008). The water quantity impacts on salamanders associated with drought, and the water quality impacts they may lead to (as discussed in detail in section 2.3.2.1) are therefore more likely to occur now than several decades ago, and will be more likely to occur in future decades than they are right now. If drought leads to very low flows at the Zilker Park springs, other water quality parameters, such as salinity and dissolved oxygen, are altered in ways that negatively affect the salamander (Kloesel et al. 2018, pp. 1012–1013). An increasing frequency and intensity of heavy precipitation events means that the frequency and intensity of flash flooding associated with heavy precipitation is also likely to increase (Kloesel et al. 2018, p. 996). This is especially important because ongoing increases in impervious cover as land in the region is developed are likely to exacerbate flash flooding and runoff on their own, as discussed in section 2.3.2.1.

2.4 Synthesis

The Austin blind salamander continues to be at high risk of extinction due to the rapid rate of urbanization in the contributing and recharge zones of the Barton Springs segment of the Edwards Aquifer, and to ongoing threats of decreasing water quality and quantity in the aquifer on which it depends. Rapid human population growth, increased water demands, and a warming climate with more frequent drought conditions continue to place increased stress on the limited water resources required by the Austin blind salamander to meet its breeding, feeding, and sheltering needs. Although minimum groundwater flows should be maintained to conserve this species, state law in Texas considers groundwater private property whereby there is no enforceable legal mandate at the state or local level to maintain minimum aquifer levels, spring-flow, or stream base-flow. Therefore, we recommend the Austin blind salamander remain listed as endangered.

3.0 RESULTS

3.1 Recommended Classification

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

3.2 New Recovery Priority Number

No change recommended; remain as 2C

Brief Rationale: A listed species with a recovery priority number of 2C is one that has a high degree of threats, a high potential for recovery, and a relatively high degree of conflict with development projects. Austin blind salamanders continue to be threatened by acute and chronic water quality and water quantity stressors as a result of urban development over the contributing and recharge zones of the Barton Springs segment of the Edwards Aquifer. The species' restricted range makes it vulnerable to both acute and chronic groundwater contamination. The salamander is also vulnerable to catastrophic hazardous materials spills, water withdrawals from the Edwards Aquifer that reduce flows, and impacts to the surface habitat that compromise water quality and quantity.

3.3 Listing and Reclassification Priority Number

Not applicable

4.0 RECOMMENDATIONS FOR FUTURE ACTIONS

1. Develop water quality protection levels for aquatic contaminants adequate to promote the viability of the Austin blind salamander [Recovery Objective 1].
2. Implement a comprehensive hazardous material spills plan for the Barton Springs watershed (not only the City of Austin jurisdiction area) [Downlisting Criterion 2].
3. Develop and implement a survey methodology that would allow for a better understanding of subsurface distribution of the Austin blind salamander and improved estimates of the population [Recovery Objective 4].
4. Continue coordination with biologists from the City of Austin to monitor Austin blind salamander populations and water quality indicators at the spring outlets in Zilker Park.
5. Continue captive breeding efforts at the San Marcos Aquatic Resource Center.

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U.S. FISH AND WILDLIFE SERVICE
5-YEAR REVIEW of the Austin Blind Salamander (*Eurycea waterlooensis*)

Current Classification: Endangered

Recommendation resulting from the 5-Year Review:

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

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

Review Conducted By: Maritza Mallek, Paige Najvar, and Michael Warriner, Austin Ecological Services Field Office

FIELD OFFICE APPROVAL:

Adam Zerrenner, Lead Field Supervisor, U.S. Fish and Wildlife Service, Austin Ecological Services Field Office

Approve ________________________ Date 9/12/19