Major Amendment and Extension of the Habitat Conservation Plan for the Barton Springs Salamander (*Eurycea sosorum*) and the Austin Blind Salamander (*Eurycea waterlooensis*) to allow for the Operation and Maintenance of Barton Springs and Adjacent Springs.

FINAL
July 2013

Eurycea sosorum
The Barton Springs Salamander

Eurycea waterlooensis
The Austin Blind Salamander

Prepared by the City of Austin
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Executive Summary

The City of Austin (hereafter the "City") must have an incidental take permit issued consistent with Section 10(a)(1)(B) of the federal Endangered Species Act (hereafter the "Act") by the U.S. Fish and Wildlife Service (hereafter the "Service") to allow for the continued operation of Barton Springs Pool, a popular natural swimming area. Operation and maintenance of Barton Springs Pool is an otherwise lawful activity that causes incidental harm or harassment of the endangered Barton Springs Salamander (*Eurycea sosorum*) and may harm or harass the Austin Blind Salamander (*Eurycea waterlooensis*), proposed for federal endangered species protection August 2012 (U.S. Fish and Wildlife Service 2012). This habitat conservation plan is a major amendment to the existing Habitat Conservation Plan (HCP), and describes actions to be taken to minimize and mitigate the impact of incidental take to the maximum extent practicable.

The Service issued the City's existing 10(a)(1)(B) incidental take permit and approved the associated Habitat Conservation Plan for *E. sosorum* in 1998; these expire in October 2013. Therefore, the City has developed this major amendment to that HCP to accompany an application for a renewed 10(a)(1)(B) permit, with a proposed term of 20 years, from 2013 through 2033. This plan not only covers endangered *E. sosorum*, but also *E. waterlooensis*, proposed for listing as endangered (U. S. Fish and Wildlife Service 2012). *Eurycea waterlooensis* was not formally described until 2001, after approval of the City's existing HCP. Explicit inclusion of *E. waterlooensis* in this amended habitat conservation plan and 10(a)(1)(B) permit precludes the need for a new, separate HCP if the federal status of *E. waterlooensis* changes. This will not only formalize the ongoing voluntary efforts of the City to conserve *E. waterlooensis*, but also ensure that the City can lawfully continue operations at Barton Springs uninterrupted by a change in federal status of *E. waterlooensis*. Because the plan includes measures to protect the quality and quantity of groundwater emanating from Barton Springs, they also protect water in subterranean habitat before it exits the aquifer. These measures provide benefits to both species.

The Plan Area for this amended habitat conservation plan consists of a polygon surrounding the Barton Springs complex, which provides all known habitat of the Barton Springs (*E. sosorum*) and the Austin Blind salamanders (*E. waterlooensis*). The area is a contiguous region that encompasses subterranean and surface aquatic environments and supporting riparian terrestrial habitat around Upper Barton Spring, Old Mill Spring, Eliza Spring, and Barton Springs Pool. The area is entirely owned by the City and is part of Zilker Park in Austin, Travis County, Texas. The Plan Area is almost entirely within the boundaries of proposed critical habitat for the Austin Blind Salamander. Most of the proposed critical habitat is also within Zilker Park and owned by the City of Austin.

The minimization and mitigation measures in this amended HCP include some of those in the existing plan and are associated with operation and maintenance of Barton Springs Pool, habitat restoration, management of captive refugium populations, and education about Barton Springs and the Edwards Aquifer. This plan also considers the relative impacts of potential alternative mitigation and minimization measures, including closure of Barton Springs Pool to recreation, and return to maintenance procedures in place prior to implementation of the City's existing habitat conservation plan. These measures were ultimately rejected in favor of the proposed actions.

A habitat conservation plan can include only actions that occur within the legal jurisdiction of the applicant. Therefore, only City actions on City property are covered by this habitat conservation plan. Some actions that cannot be covered by this plan include regulation of groundwater withdrawal from the Edwards Aquifer, urban development outside of the City's jurisdiction, and wastewater disposal regulated by the State of Texas. These and other actions in the watershed are regulated by state and regional entities (*e. g*., Barton Springs Edwards Aquifer Conservation District, the Texas Commission on Environmental Quality).

The issuance of a major amendment and renewal of the 10(a)(1)(B) incidental take permit by the Service to the City is a federal action and must comply with the National Environmental Policy Act. Compliance with the National Environmental Policy Act will be assessed in a separate Environmental Assessment prepared by an independent agent for the Service.

This amended habitat conservation plan furthers the City's immediate goal to comply with the Endangered Species Act, and also the long-term goals of conserving and fostering the recovery of *E. sosorum* and *E. waterlooensis*. This plan also reflects the commitment of the community of Austin to preserve and improve Barton Springs (City Council of Austin Resolution No. 20061019-035) and "return the site [Barton Springs] to its rightful glory…. and respect the fragility of this unique natural and historic setting" (Limbacher and Godfrey Architects 2008). The goals of this amended habitat conservation plan are:

- Protect the evolutionary potential of wild and captive populations of *E. sosorum* and *E. waterlooensis*
- Maintain or restore natural ecosystem characteristics of *E. sosorum* and *E. waterlooensis* habitat to the maximum extent practicable
- Reduce and mitigate the impacts of detrimental anthropogenic pollutants on salamanders or their habitat
- Restore and maintain natural flow regimes in Barton Springs Pool, Eliza Spring, Old Mill Spring, and Upper Barton Spring to the maximum extent practicable
- Reduce the harassment or harm of *E. sosorum* and *E. waterlooensis* imposed by the cleaning, maintenance and operation of Barton Springs Pool
- Improve efficiency of cleaning and maintenance of Barton Springs Pool
- Continue to collect, manage, and share data on *E. sosorum* and *E. waterlooensis* populations and their habitats.

Several conservation measures included in this habitat conservation plan may be of special interest to recreational users of Barton Springs Pool (the Pool) and Zilker Park. Water level in Barton Springs Pool will be drawn down more frequently, which will improve cleaning efficiency and temporarily restore a more natural flow regime in Parthenia Spring. More frequent, small-scale removal of flood debris within Barton Springs Pool is explicitly included in this plan. Salamander habitat of Eliza Spring will be restored, including restoration of the natural outflow stream through Pool grounds to Barton Creek.

The City has made significant progress towards the goals identified in the Recovery Plan for the Barton Springs Salamander (USFWS 2005). Average population sizes of this species (*E. sosorum*) have increased significantly since the implementation of the existing habitat conservation plan in 1998. The conservation measures described in this amended habitat conservation plan will continue to support efforts to meet the goals of the Recovery Plan.

This amended habitat conservation plan will be implemented by the City. The ongoing actions are projected to cost approximately $448,000 annually and will be funded by entry fees to Barton Springs Pool and the operating budgets of the City's Watershed Protection and Parks and Recreation Departments. Habitat restoration projects will be funded from the capital improvements budget. Cost has not been estimated for all projects; however, initial cost estimates for some projects are included in the Barton Springs Pool Master Plan: Concepts for Preservation and Improvement (Limbacher and Godfrey Architects 2008).

1.0 Introduction

The City of Austin (hereafter the "City") is seeking an amendment and renewal of their permit from the U.S. Fish and Wildlife Service (hereafter the "Service") under Section 10(a)(1)(B) of the Endangered Species Act of 1973 (hereafter "the Act"). The new permit will continue coverage for City actions that impose take of endangered *Eurycea sosorum*, the Barton Springs Salamander (USFWS 1997), and *Eurycea waterlooensis*, the Austin Blind Salamander, proposed for federal protection August 2012 (U. S. Fish and Wildlife Service 2012). These actions are associated with the operation and maintenance of Barton Springs Pool as a revenue generating, spring-fed recreation facility, and management and restoration of springs within and adjacent to Barton Springs Pool. These springs are collectively known as the Barton Springs complex, which consists of four freshwater springs: Eliza Spring, Old Mill Spring (also known as Sunken Garden Spring), Parthenia Spring (located within Barton Springs Pool), and Upper Barton Spring.

1.1 Purpose and Need for Action

Operation and maintenance of Barton Springs Pool as a recreational resource imposes "take" of federally protected Barton Springs Salamander, *E. sosorum*, and Austin Blind Salamander, *E. waterlooensis*. In addition, actions conducted in areas of Barton Springs' watershed that lie within the jurisdiction of the City can degrade water quality in the Barton Springs complex and likewise affect salamander populations. The purpose of this amended habitat conservation plan is to support issuance of an Endangered Species Act Section 10(a)(1)(B) permit to comply with federal protection of natural resources under the Act. The plan describes and quantifies incidental take from otherwise lawful actions, and the measures that minimize and mitigate to the maximum extent practicable incidental take of Barton Springs and Austin Blind salamanders. A habitat conservation plan is a mandatory prerequisite to obtaining an incidental take permit under Section 10(a) of the Act. This amended habitat conservation plan describes the actions supervised or conducted by the City on City property that may adversely affect the Barton Springs Salamander (*E. sosorum*) and the Austin Blind Salamanders (*E. waterlooensis*), and the measures the City will take to minimize and mitigate these effects. The objective of this habitat conservation plan is to promote the long-term, evolutionary persistence of both species while continuing operation of Barton Springs as a recreational resource. The conservation measures in this plan focus on protection and restoration of aquatic epigean (living or growing at or near the ground surface, hereafter "surface") habitat, and preservation of aquatic subterranean habitat in the Barton Springs complex. To the extent that the plan protects inputs to the aquifer, it will protect both subterranean and epigean habitat and conservation measures beneficial to the Barton Springs Salamander (*E. sosorum*) will likewise be beneficial to the Austin Blind Salamander (*E. waterlooensis*).

1.2 Regulatory Framework

Section 9 of the federal Endangered Species Act (16 USC 1538(a)) prohibits "take" of any federally endangered wildlife. Take is defined as an action that may harm, harass, pursue, shoot, wound, hunt, kill, trap, capture or collect members of an endangered species. Section 10(a)(1)(B) of the Endangered Species Act of 1973 (16 USC 1539(a)(1)(B)) authorizes the Service to issue a permit allowing take of protected species that is incidental to otherwise lawfully conducted activities. For the issuance of an incidental take permit, the applicant must submit a conservation plan that satisfies the requirements of Section 10(a)(2)(A) of the Act.

Section 10(a)(2)(B)(ii) of the Act allows non-federal entities to conduct otherwise lawful activities likely to cause take of endangered species, as long as the detrimental effects of the activities are minimized or mitigated to the maximum extent practicable. Habitat conservation plans are the vehicles by which such take can be authorized, given that it will be minimized and mitigated to the maximum extent practicable.

This amended habitat conservation plan was developed to satisfy the requirements of Section 10(a)(2)(A) of the Act by increasing the likelihood of the survival and recovery of the Barton Springs and the Austin Blind Salamander species in the wild to the maximum extent practicable. This plan describes the effects of the incidental harm or harassment of covered salamanders on fate of the salamander species, identifies the measures by which those effects will be minimized and mitigated, compares alternatives to the proposed measures, and identifies the parties responsible for implementing and funding implementation of the plan. Although this plan describes habitat conservation actions in the immediate future (20 years), persistence of the covered species is a long-term goal that inherently requires consideration of evolution in a dynamic ecosystem. Therefore, this plan explicitly states how the proposed conservation measures contribute to protecting evolutionary health of the species.

The issuance of an incidental take permit by the Service requires an analysis of the environmental impacts resulting from activities listed in a habitat conservation plan in accordance with the National Environmental Policy Act (NEPA) (42 USC 4321-4327). NEPA requires that the Service provide a formal assessment of impacts of the proposed issuance of an incidental take permit on the human environment and a review of alternatives to the proposed actions (42 USC 4332(c)). The Environmental Assessment associated with the City's proposed habitat conservation plan will be prepared for the Service by an independent consultant paid by the City.

In recognition of the effects of urban development and construction activities within the City's jurisdiction on water quality at Barton Springs, this habitat conservation plan requires monitoring and reduction of pollutant loadings in storm water. This is accomplished through the Storm Water Management Plan associated with the City's Texas Pollutant Discharge Elimination

System permit (30 TAC 305), which includes specific provisions for water quality monitoring and protection in the Contributing and Recharge zones of the Edwards Aquifer to protect the water quality of Barton Springs. Separate from this plan, the City also protects water quality by limiting impervious cover, requiring setbacks from critical environmental features, preventing erosion during construction, and requiring treatment of storm water runoff from development projects through regulations specified in Chapter 25-8 of the City of Austin Land Development Code.

Protection of water quality from effects of activities conducted outside the City's jurisdiction is provided by Texas Commission on Environmental Quality Edwards Aquifer Rules (30 TAC 213) and Enhanced Measures for the Edwards Aquifer (TCEQ 2007). State regulations also cover wastewater disposal via direct discharge or land application of effluent consistent with the federal Clean Water Act.

Although sufficient and reliable spring flow is critical to the survival of the Barton Springs and Austin Blind Salamander, the City does not have the authority to regulate groundwater withdrawal from the Barton Springs Segment of the Edwards Aquifer. Consequently, it cannot be addressed by this habitat conservation plan. Groundwater withdrawal from this area is regulated by the Barton Springs Edwards Aquifer Conservation District according to Texas state law; a separate federal 10(a)(1)(B) permit and habitat conservation plan for take of Barton Springs' *Eurycea* salamanders resulting from groundwater withdrawal is in development by this groundwater conservation district. However, the City's amended habitat conservation plan includes formal coordination with regional partners to protect water quantity and quality at Barton Springs. Finally, this habitat conservation plan does not cover actions by persons or entities other than the City. Therefore, it is not a regional habitat conservation plan as defined by Texas state law and is not subject to additional state requirements under Texas Parks and Wildlife Code Chapter 83(B).

1.3 Species Covered

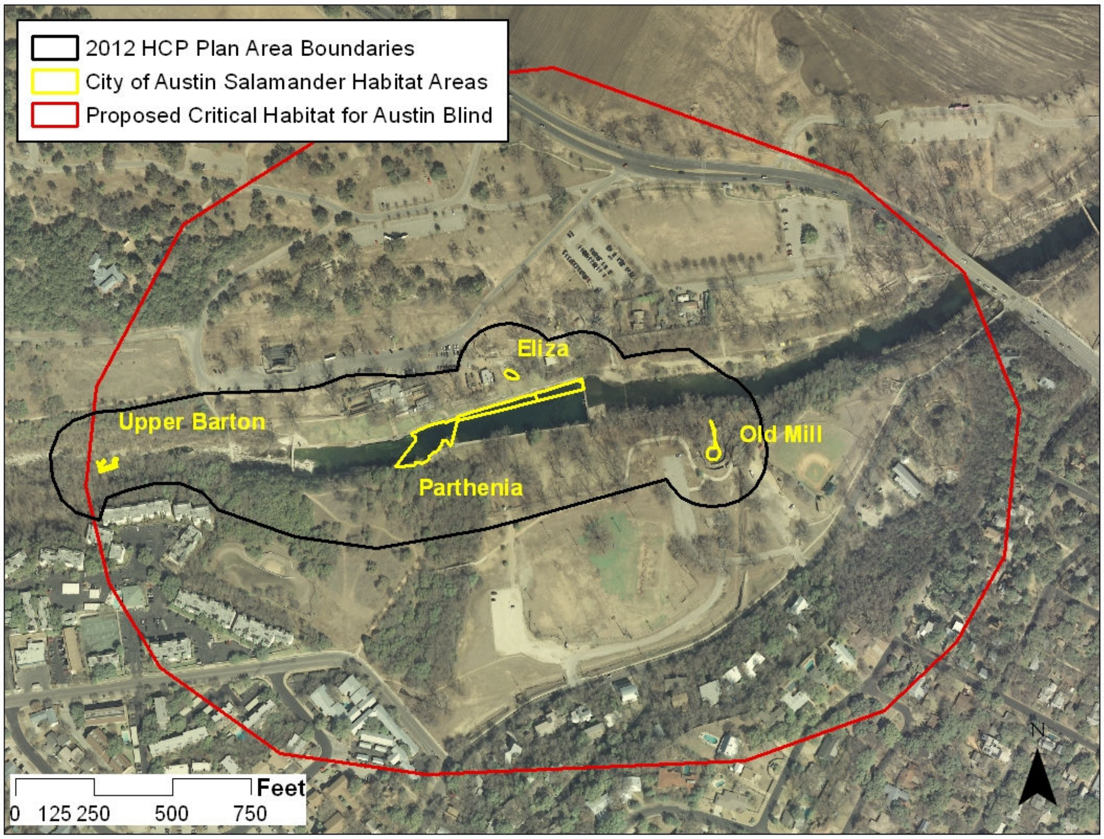
The species covered in this habitat conservation plan are the Barton Springs Salamander (*Eurycea sosorum*), and the Austin Blind Salamander (*Eurycea waterlooensis*). *Eurycea sosorum* is a federally protected endangered species (USFWS 1997); *E. waterlooensis* is proposed for listing as endangered (USFWS 2012). The Barton Springs complex is the only known habitat for both species. *Eurycea sosorum* is primarily an epigean species (living or growing at or near the ground surface, hereafter "surface") residing in all four springs; the extent and frequency of use of subterranean habitat is unknown (Chippindale et al. 1993, Hillis et al. 2001). *Eurycea waterlooensis* is a primarily subterranean species (underground); the extent of its range is unknown. It is seen in surface habitat of the three perennial springs, Parthenia, Eliza, and Old Mill, but has never been found in surface habitat of intermittent Upper Barton Spring. The biology of both species is similar; they are perennibranchiate ("always gilled"), solely aquatic (never metamorphose), long-lived, and invertebrate predators. Their ranges are sympatric (same geographical area) and syntopic (habitat areas in close proximity), and both may use the subterranean habitat connecting the four springs as migration routes. Primary scientific literature on both species is lacking (but see Chippindale *et al*. 1993, Hillis *et al*. 2001, Gillespie 2011). Much that is known is contained in white papers (USFWS 2005, City of Austin 2005, City of Austin 2006, City of Austin 2007, City of Austin 2008, City of Austin 2009, City of

Austin 2010, City of Austin 2011), and more is known of natural history of the Barton Springs Salamander, *E. sosorum* than the Austin Blind Salamander, *E. waterlooensis*.

1.4 Plan Area

The Plan Area is located within Zilker Park in Austin, Travis County, Texas, and surrounds a cluster of four hydrologically connected springs (Figure 1). The area encompasses all of the known surface habitats of the Barton Springs Salamander (*E. sosorum*) and the Austin Blind Salamander (*E. waterlooensis*) and a protective buffer of approximately 150 feet surrounding the entire cluster of springs. The boundary of the Plan Area is confined to property owned by the City and the buffer is consistent with City criteria for protection of critical environmental features. The Plan Area is intended to include areas of historical surface links and inferred subterranean pathways among all four springs (Figure 1 of Dries 2012, Appendix A). While the Plan Area for this amended HCP is consistent with the existing HCP, the footprint of delineated salamander habitat in Barton Springs Pool differs (see Section 3.2). The Plan Area is almost entirely within the boundaries of proposed critical habitat for the Austin Blind Salamander (Figure 1). Eighty-six percent of critical habitat is within Zilker Park and owned by the City of Austin, while the remainder (14 %) is on private property within the City of Austin's legal jurisdiction.

Figure 1. Map of the Plan Area and all known surface habitat of *Eurycea sosorum* and *E. waterlooensis* within Zilker Park, Austin, Travis County, Texas. Plan area perimeter is outlined in black, surface habitats outlined in yellow. The perimeter of proposed critical habitat of *Eurycea waterlooensis* is indicated by the red circle. *Eurycea waterlooensis* has not been observed in surface habitat of Upper Barton.



1.5 Permit Duration

The term proposed for this amended habitat conservation plan and associated incidental take permit is 20 years. The 20-year term was selected based on the ability of the City to reliably forecast potential projects that may affect the salamanders at least 20 years into the future. The City is able to fully commit the financial resources necessary to implement the conservation measures specified in this plan for the proposed 20-year term. The Austin City Council has authorized City staff by resolution 20111103-034 on November 3, 2011, to prepare and submit this plan to the Service in support of an incidental take permit for the covered species.

2.0 Environmental Setting

2.1 Climate

The Plan Area is located within the subtropical humid climate region of Texas (Nickels *et al.* 2010). Latitude, elevation, and proximity to the Gulf of Mexico influence the climate of the region. Surface water in arid climates is influenced by wide variation in key climatic characteristics, such as precipitation and temperature. This variation plays an integral role in the natural resilience and ecological health of creeks, rivers, and streams (Resh *et al*. 1988, Poff and Ward 1989, Spellman and Drinan 2001), and their resident flora and fauna. Conserving Barton Springs' *Eurycea* requires some inference of the natural environmental variation under which the species evolved.

2.1.1 Temperature/Evaporation

The Edwards Plateau region of central Texas is generally arid with hot summers and mild winters (Larkin and Bomar 1983). Based on the United States National Weather Service data from 1854 to 2011, air temperature in Austin can range from -5°F during the winter to 112°F in the summer. Daytime temperatures in summer are hot, with highs over 90°F about 80 percent or more of the time. The hottest temperatures typically occur in August and lowest temperatures, in January. The average daily temperature in spring (February – April) is 61°F, in summer (May – July) is 80°F, in fall (August – October) is 78°F, and in winter (November – January) is 54°F, with daily variation of approximately 20°F in all seasons (National Climate Data Center 2012). Daytime temperatures of 32°F or less have occurred from December through February; they are typically few (1 – 12) and short-lived (< 18 consecutive days) (National Climate Data Center 2012). The 30-year normal annual average high and low temperatures have increased in the past decade, from 79°F (1971 – 2000) to 80°F (1981- 2010), and 49°F to 51°F.

Elevated air temperature coupled with low humidity increases loss of surface water to the atmosphere through evaporation. The average monthly gross lake-surface evaporation in this region ranges from approximately 2.5 inches in January to about 9 inches in August (Larkin and Bomar 1983). Annual lake evaporation rate in Austin, Texas, is often twice the precipitation rate. Long-term average annual evaporation is 52.89 inches per year, roughly 1.6 times the annual average precipitation rate of 32.97 inches per year (National Climate Data Center 2012).

2.1.2 Precipitation

The Edwards Plateau is characterized by episodes of drought and flood (Baker 1977) driven by variation in precipitation. Average annual precipitation in the Edwards Plateau is approximately 32 inches with multi-decade extremes that vary from 11.5 inches in 1954 to 64.7 inches in 1919 (National Climate Data Center 2010). Precipitation in the Edwards Plateau does not occur according to annual cycles. There are episodes of little or no precipitation, interspersed with periods of rainfall, sometimes heavy, leading to the alternation between floods and droughts. Although historically precipitation is highest during May and September, heavy rainfall can occur any time of year.

Global moisture patterns related to ocean temperature fluctuations in the equatorial Pacific Ocean produce tropical storms and hurricanes according to long-term climatic cycles of El Niño-La Niña. These cycles influence weather in Central Texas; La Niña conditions usually produce drier-than normal conditions for Central Texas, with El Niño producing wet conditions (National Climate Data Center 2010). Tropical storms and hurricanes in the Gulf of Mexico reach the coast of Texas on average 0.67 times per year (Brown *et al*. 1974), typically during summer and fall. Some of these storms move inland and meet the Balcones Escarpment where the moisture-laden air rises, resulting in heavy rainfall over the Edwards Plateau.

Although climate predictions often indicate hot and dry summers, tropical storms can be the dominant influence on Central Texas weather. These storm systems can account for nearly half of annual rainfall, resulting in the flash flooding common throughout the Edwards Plateau (Woodruff and Wilding 2008), as well as rises in creek flow and groundwater levels. However, wet periods may be of short duration and separated by periods of low rainfall and hot temperatures. For example, August 2010 was one of the hottest and driest months on record, yet tropical storms in June and September 2010 resulted in record rainfall (6 and 10 inches, respectively). Immediately preceding and following 2010 were years of little rainfall and severe drought. Without the influences of the hurricanes and tropical storms, the Barton Springs segment of the Edwards Aquifer would likely experience more frequent and severe droughts.

2.1.3 Drought Frequency, Intensity, and Duration

A consequence of periods of no precipitation is depletion of the quantity of water in the aquifer. Droughts can vary in duration, frequency, and intensity within and among years, decades, and centuries as a result of natural climatic variation.

The Palmer Drought Severity Index (PDSI) (Palmer 1965) uses temperature and precipitation data to measure cumulative meteorological drought standardized to local climatic conditions. Negative PDSI values reflect drier than normal conditions with extreme droughts defined by PDSI as values less than -4. Several studies have used the correlation of tree-ring data with the Palmer Drought Severity Index to infer occurrence and duration of droughts in the aquifer region as far back as the 1600s (Robinson 1976, Cook 2000, Mauldin 2003). Mauldin (2003) inferred that from 1700 to 1979, droughts occurred in 40 of those years, with average duration of 1.8 years. Droughts lasting three or more years occurred three times in the 1700s (Therrell 2000).

Since 1900, serious droughts have been recorded in parts of Texas in every decade (Riggio *et al*. 1987). Between 1931 and 1985, the number of three-month droughts in the Edwards Plateau region varied from 62 to 70, depending on location. During the same period, the number of six-month droughts varied between 32 and 40, and there were less than five 12-month droughts (Riggio *et al*. 1987). The longest period of sustained drought in the Edwards Aquifer region in the past 347 years occurred from 1951 through 1956 (Therrell 2000). Consequently, the period from 1947 to 1957 has been designated as the drought-of-record (Texas Administrative Code 357.1-357.15) for the Plan Area (Texas Region K). During the extreme drought of the 1950s, Barton Springs' discharge declined to 9.6 ft^3/s from an average of historical flow of 53 ft^3/s (Hunt and Smith 2004).

Although droughts are the result of natural climatic variation, the negative impacts of drought on aquifer water levels can be magnified by anthropogenic withdrawal of groundwater from the aquifer. Groundwater withdrawal from the Barton Springs segment of the Edwards Aquifer is regulated by the Barton Springs Edwards Aquifer Conservation District, which is developing a separate habitat conservation plan to address the impacts of groundwater withdrawal on the covered species.

Conservation measures in this amended habitat conservation plan (Section 6) focus on mitigating negative effects of the covered actions based on short-term patterns of rainfall (days and months) rather than longer terms (years) because effects of rainfall variation on the Barton Springs' discharge and the resident endemic biota occur over these shorter time scales. However, this habitat conservation plan does include a conservation measure specifying that the City and the Barton Springs Edwards Aquifer Conservation District will work cooperatively to ensure sufficient water quantity for the covered species (section 6.0). The potential for global climate change to affect the frequency or duration of droughts is addressed in the changed circumstances section of this plan (section 8). The cumulative impacts of drought and the City's covered actions on Barton Springs' salamander species are also addressed in this habitat conservation plan (section 5).

2.2 Topography

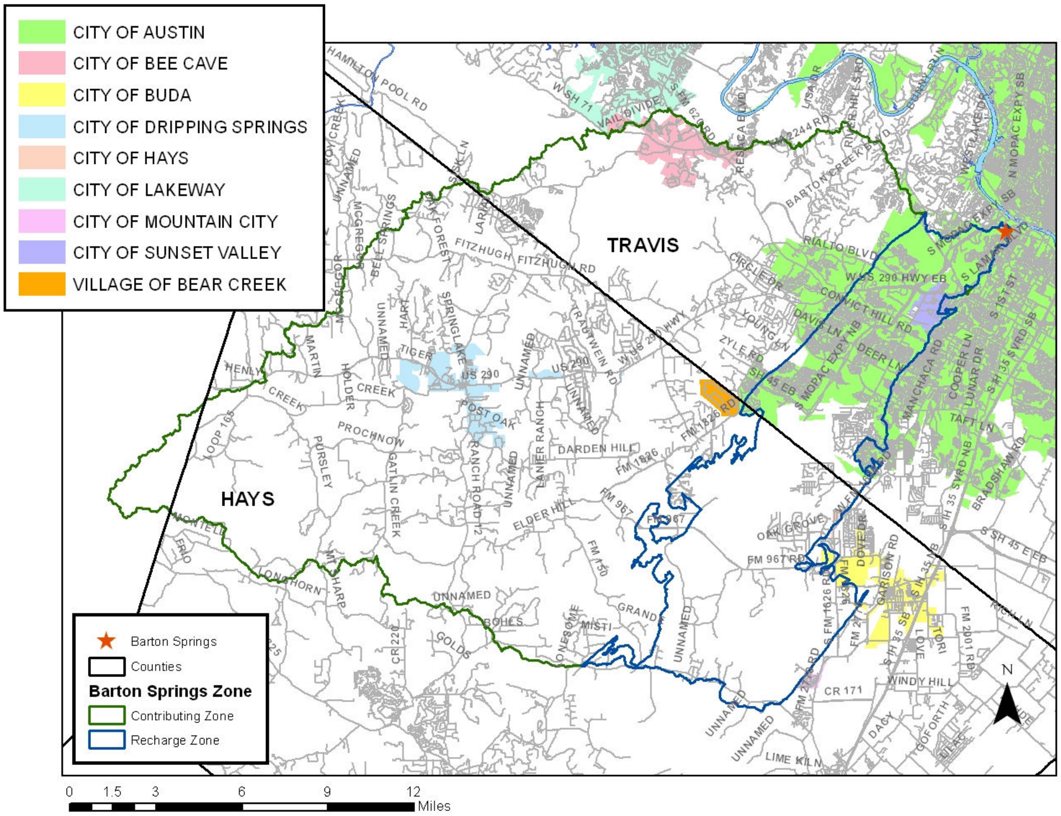
The Edwards Plateau is a southern extension of the Great North American Plains (Hunt 1974). Barton Springs is located in the Balcones Fault Zone at the southeastern edge of the Balcones Escarpment region of the Edwards Plateau (Griffith *et al*. 2004). This region is highly dissected and consists of steep, mesic canyons with high-gradient drainages and exposed limestone karstic features including sinkholes, caves, losing streams and springs (Riskind and Diamond 1986). The elevations range from maximum land surface heights in the west of approximately 1,650 feet above mean sea level to approximately 428 feet above mean sea level at the confluence of Barton Creek and Lady Bird Lake. Barton Springs Pool is located at approximately 436 feet above mean sea level. The area is often referred to as the "Hill Country" (Abbott 1986) and contains the contributing and recharge zones of the Barton Springs Segment of the Edwards Aquifer. Hence, the area has a "relative abundance of running waters" compared with other regions of central Texas (Griffith *et al*. 2004).

2.3 Groundwater Hydrogeology

The Edwards Aquifer is a limestone karst aquifer. A karst aquifer develops within relatively soluble rock with appreciable groundwater flow (Maksimovich 1963, Aley 2000, Field 2002). Dissolution by recharging waters progressively enlarges openings in the limestone and dolomite host rock creating an integrated network of conduits. The groundwater hydrology of these aquifers typically includes both rapid flow through larger conduits, and slower flow through a matrix of smaller, more diffuse pathways.

The Barton Springs complex is the largest natural discharge point for the Barton Springs segment of the Edwards Aquifer. This segment of the aquifer is located from the south bank of the Colorado River in Austin, Texas, and east to Interstate Highway 35, west to Farm-to-Market Highway 1826, and south to the cities of Buda and Kyle (Figure 2). The Recharge Zone of the Barton Springs segment is approximately 98 miles^2 that includes parts of Travis and Hays Counties (Smith and Hunt 2002). The Contributing Zone is approximately 254 miles^2 and includes Travis, Hays, and Blanco Counties (Slade *et al*. 1986). The combined areas of the Recharge Zone and the Contributing Zone are known as the Barton Springs Zone of Edwards Aquifer (Figure 2). A description of the groundwater hydrology in the Barton Springs Zone of the Edwards Aquifer is provided below and includes development of karst formations, geographic extent of contributing and recharge zones, recharge sources, subterranean water flow patterns, and travel times.

Figure 2. The Barton Springs Zone consisting of the Recharge Zone and the Contributing Zone of the Barton Springs Segment of the Edwards Aquifer. The map displays municipal limits, county limits, and the location of Barton Springs.



2.3.1 Aquifer and Springs Geologic Development

The base of the Edwards Aquifer was formed from calcium-rich shells, the remnants of ancient marine invertebrates that disappeared during the Cretaceous period of Earth's history, approximately 200 million years ago (mya). From the Paleozoic through the Cretaceous there were shallow inland seas on the continental shelves, which were home to a large variety of ancient invertebrates, many of which lived within protective shells. During the Devonian period (approximately 408 mya), continental uplift eliminated inland seas and their resident fauna, leaving behind the building blocks for formation of freshwater, karst aquifers.

In general, the Edwards Aquifer is a permeable layer of limestone confined between two less permeable layers. Below it lies the limestone of the Glen Rose Formation; above it lies the clay and rock of the Del Rio Formation. The Balcones Fault system of the Edwards aquifer uplifted 15 - 23 mya (Abbot 1986), shifting the relative elevations of these layers and creating numerous springs. In the late Miocene (approximately 6 mya), as the Colorado River began cutting down into the Edwards Aquifer, conduits of groundwater flow became exposed to the surface and ancient Barton Springs began flowing (Veni 1992, Hauwert 2009). Continued incision by the Colorado River likely led to shifts in active springs from higher to lower elevation locations

(Veni 1992, Hauwert 2009), resulting in the present-day elevation and location of Barton Springs.

2.3.2 Subterranean Hydrology

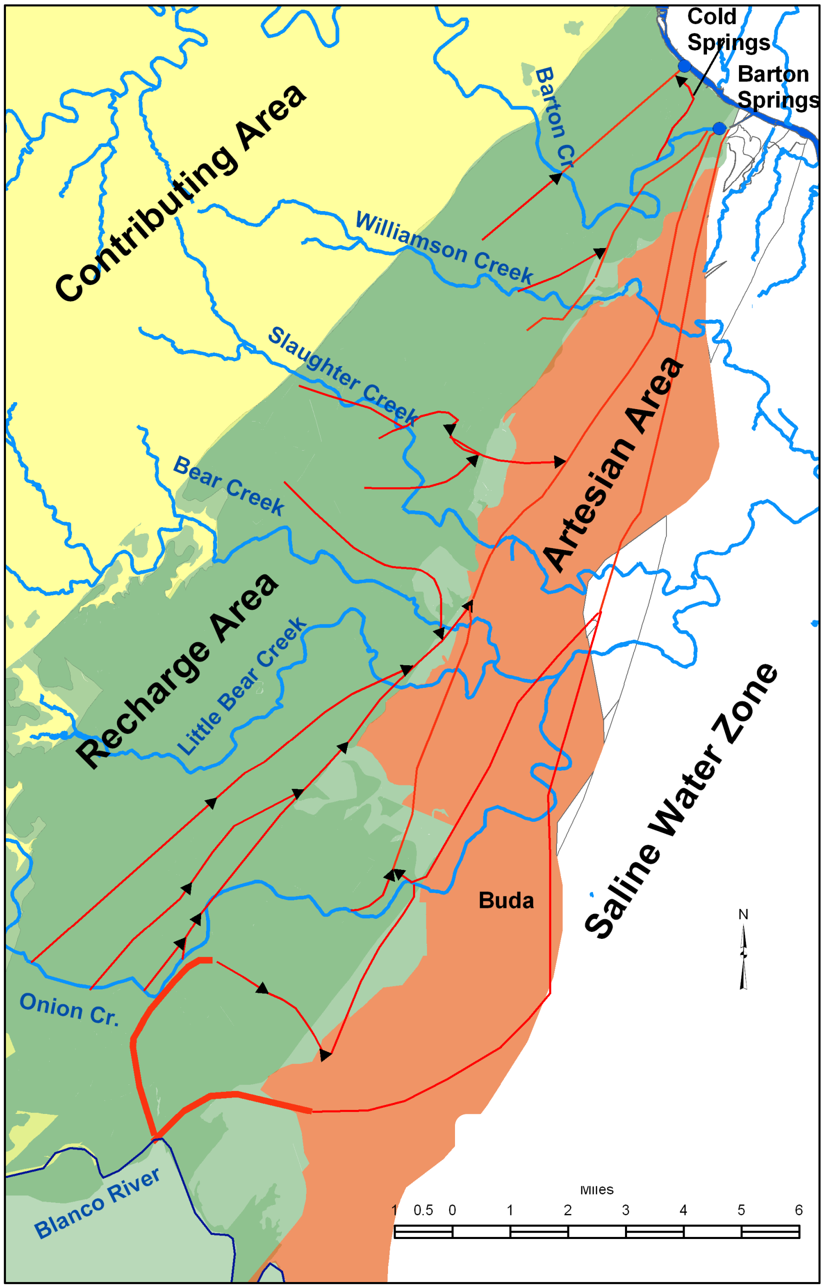
The majority of the water that recharges the Barton Springs Segment of the Edwards Aquifer originates as rainfall runoff in the Contributing Zone west of the outcrop of the Edwards Aquifer (Figure 2; Slade *et al*. 1985, Barrett and Charbeneau 1996). This water originates as rain that either runs off directly into creeks or infiltrates through upland soil.

Recharge waters enter the Barton Springs Zone of the Edwards Aquifer through caves, sinkholes, or solution-enlarged fractures in the surface channels of six creeks, Barton, Williamson, Slaughter, Bear, Little Bear, and Onion Creek (Figure 3; Slade *et al*. 1986). Additional sources of natural recharge are direct infiltration through upland soils and bedrock surfaces and leakage from adjacent aquifers (Hauwert *et al*. 2011). Leaking urban infrastructure also may contribute small amounts of recharge (Hauwert 2009).

Estimates of relative contributions of each creek to recharge feeding Barton Springs vary among studies. However, all agree that Onion Creek contributes the largest proportion (Slade *et al*. 1985, Barrett and Charbeneau 1996, Hauwert 2009), with Barton Creek the next largest contributor. However, in contrast with past research a recent study suggests that much of the recharge from Barton Creek does not feed Barton Springs, instead feeding Cold Spring (Hauwert *et al*. 2011). While upland recharge was historically reported to be approximately 15% (Slade *et al*. 1986), Hauwert et al. (2011) suggest that more recharge is occurring in the uplands than previously known (30-40%). Finally, data collected during the recent periods of severe drought in 2008 suggest the Blanco River contributes recharge to Barton Springs during drought conditions but not during wet conditions (Hauwert *et al*. 2011). Recharge from the Blanco River may play a significant role in sustaining Barton Springs flow during drought.

Recharging waters flow along various subterranean paths on their way to Barton Springs (Figure 3). The conduits in the Edwards Aquifer are sufficiently large and numerous that water can travel rapidly underground. Subterranean flow paths are constantly changing as water flow dissolves the limestone around it. Most of the subterranean flow within the Barton Springs Segment occurs along preferential flow routes, which are strongly influenced by faulting. There are three groundwater basins in this segment (Cold, Sunset Valley, Manchaca), each with a distinct network of flow routes (Hauwert *et al*. 2004). Flow paths from the Sunset Valley groundwater basin generally lead to Upper Barton and Parthenia springs, but not Eliza or Old Mill springs (Hauwert *et al*. 2004). The Manchaca groundwater basin leads to Parthenia, Eliza, and Old Mill springs but not Upper Barton Spring (Hauwert *et al*. 2004).

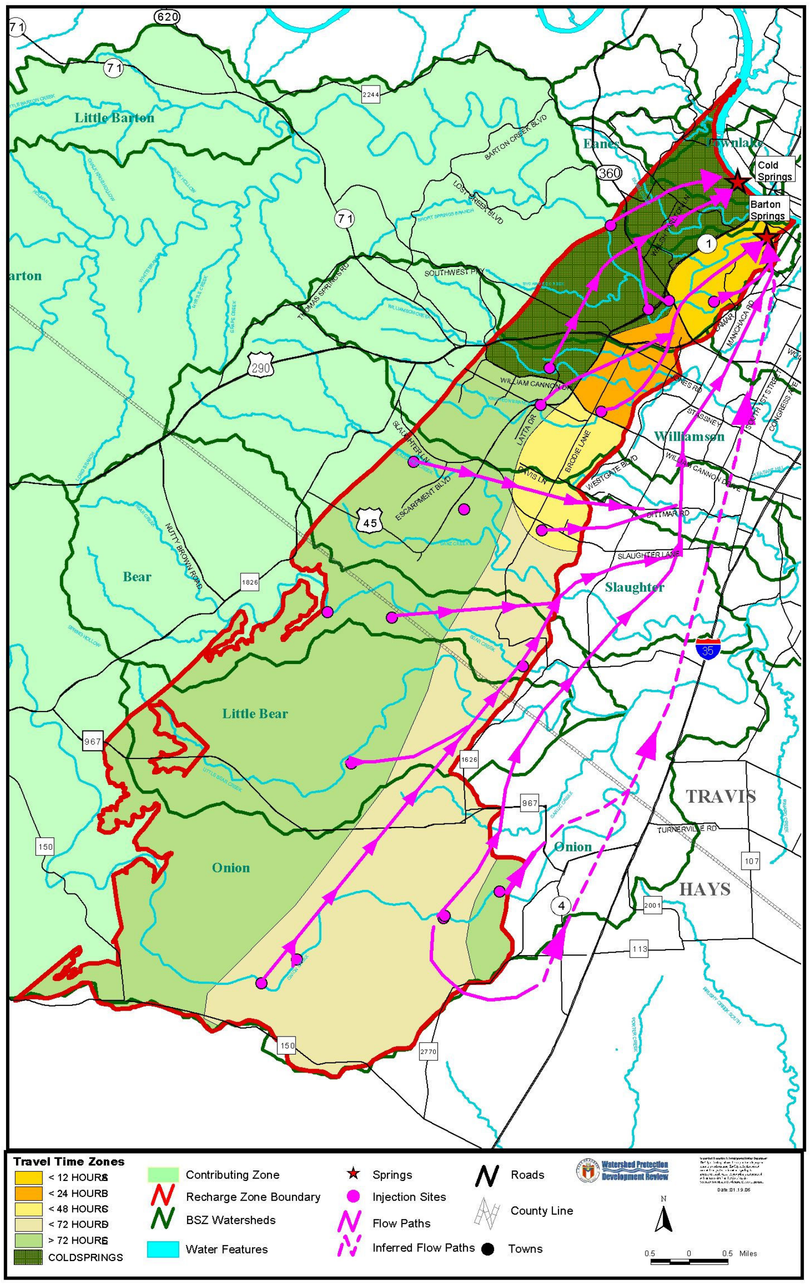
Figure 3. The six major creeks of the Barton Springs Recharge Zone. General direction of recharging water flow is indicated by arrows.



Paths of local subterranean water flow among the springs of the Barton Springs complex are poorly known. Recently, geophysical surveys of the grounds between springs were conducted to determine the potential location of caves and active flow paths beneath the three perennial springs (Parthenia, Eliza, and Old Mill). Results suggest the presence of an eastward dipping fault along the south bank of Barton Springs between Parthenia and Old Mill springs. In addition, local subsurface water flow may extend as deep as 90 ft below grade (Saribudak *et al.* 2011).

Dye tracing studies have documented rapid subterranean flow from the recharge and contributing zones to Barton Springs, ranging from 1 to 7 miles per day (Figure 4; Hauwert *et al*. 2004). These rates are dependent on water levels in the aquifer. When the water table is high, recharging water may reach Barton Springs in several hours to a few days. When the water table is low, recharging water can take weeks to reach Barton Springs.

Figure 4. Time of travel of groundwater from the recharge zone to Barton Springs along subterranean flow paths as inferred from dye-tracing data (Hauwert *et al.* 2004).



2.4 Surface Hydrology and Flow Regime

The Barton Springs complex is part of the dynamic flowing water system of Barton Creek. Parthenia Spring and Upper Barton Spring are entirely within the channel of Barton Creek, and spring water from Eliza and Old Mill flows into Barton Creek. The complex is located approximately 1,500 feet upstream of the confluence of Barton Creek and the Lady Bird Lake segment of the Colorado River. This stretch of Barton Creek is 20 to 100 feet wide and numerous smaller upland streams contributing to its flow. The natural surface hydrology of this stretch of Barton Creek varies from spates of flashy, rapidly flowing flood water to periods of slowly flowing, base flow (City of Austin 2005, 2006, 2007). At times, the only water flow in Barton Creek is spring water originating from Barton Springs.

The flow regimes of creeks and rivers are the dominant features that distinguish them from lakes and ponds (Leopold *et al*. 1992). Shallow water of streams and creeks has faster current velocity and consequently greater power to generate incipient motion of substrates and debris (Leopold *et al*. 1992), driving geomorphological changes in channels. This disturbance is an important feature of streams and rivers (Resh *et al*. 1988, Poff and Ward 1989, Gordon *et al*. 2004), and was a natural characteristic of the Barton Springs complex prior to alteration by humans. Natural variation in flow velocity drives variation in abiotic and biotic features of resilient stream ecosystems (Vogel 1994). Water flow influences every part of the aquatic ecosystem (Giller and Malmqvist 1998, Wetzl 2001), from the amount of sediment deposited (Nowell and Jumars 1984) and types of algae (Blum 1960, Reiter and Carlson 1986, Poff *et al*. 1990) to the community of invertebrates and vertebrates found there (Vogel 1994). Faster, unidirectional water flow naturally favors growth of tightly attached algae (Fritsch 1929, Korte and Blinn 1983, Stevenson 1983) and a diversity of stream-adapted invertebrates (Hynes 1972), and helps maintain high water quality (Spellman and Drinan 2001).

Historically, there were no barriers to free-flowing water in the Barton Springs complex, Barton Creek, or the lower Colorado River. Presently, the flow regimes of these systems are altered, and have been for about 150 years. All three perennial springs of the Barton Springs complex have flow regimes altered by impoundments (Figure 5). The largest spring, Parthenia Spring (also known as Main Spring), is contained within Barton Spring Pool and confined by upstream and downstream dams spanning Barton Creek. Smaller Eliza Spring (also known as Concession Spring, Polio Pit, Elks Spring, or Walsh Spring) and Old Mill Spring (also known as Sunken Garden, Paggi's Mill, or Zenobia Spring) are located on the north and south banks of Barton Creek, respectively. Old Mill Spring retains an overland outflow stream discharging directly into Barton Creek downstream of Barton Springs Pool. Outflow from Eliza Spring is directed into a buried pipe and ultimately downstream into Barton Creek. The upstream dam of Barton Springs Pool obstructs flow of Barton Creek floodwater, while base flow is diverted around Barton Springs Pool through a culvert.

Figure 5. Photographs of the Barton Springs complex showing dams and amphitheaters affecting flow regimes of the three perennial springs: Parthenia, Eliza, and Old Mill. The Barton Creek Bypass Culvert runs parallel to Barton Springs Pool and is illustrated by a dashed line. The buried outflow from Eliza Spring is also shown as a dashed line connecting with the bypass

culvert. Upper Barton Spring flows intermittently, and surface habitat is dry when combined Barton Springs' discharge falls below 40 ft^3/s.

Upper Barton Spring

Barton Springs Pool Dams

Eliza Spring

Old Mill Spring

Heavy rainfall in the Barton Springs Contributing and Recharge zones drives the flooding of Barton Creek that reaches Barton Springs. Based on U. S. Geological Survey measurements of discharge in Barton Creek upstream of Barton Springs (site 08155400) from 1999 to 2011, when floods exceed approximately 500 ft^3/s, Barton Creek overtops the upstream dam and flows through Barton Springs Pool. These floods occur on average 4.3 times per year, with maximum and minimum number of occurrences within a single year of 15 and 0, respectively. The median duration of floods of this or greater magnitude is 2.96 days (Table 1). Precipitation and antecedent conditions surrounding these flood conditions are highly variable in total volume, intensity, duration, and geographic distribution over the watershed.

Table 1. Descriptive statistics for discharge of Barton Creek and flooding of Barton Springs Pool from 1999 – 2011. Presented are the average (mean), the total number of occurrences, and average duration within each discharge category. Bold text denotes data during floods of Barton Springs Pool. Gauge height data were collected at the junction of Loop 360 and Barton Creek (site 08155300) and immediately upstream of Barton Springs Pool (BSP, site 08155400), and converted to discharge by the U.S. Geological Survey. Gauge height upstream of Barton Springs Pool is influenced by capacity and obstruction of a flood bypass culvert.

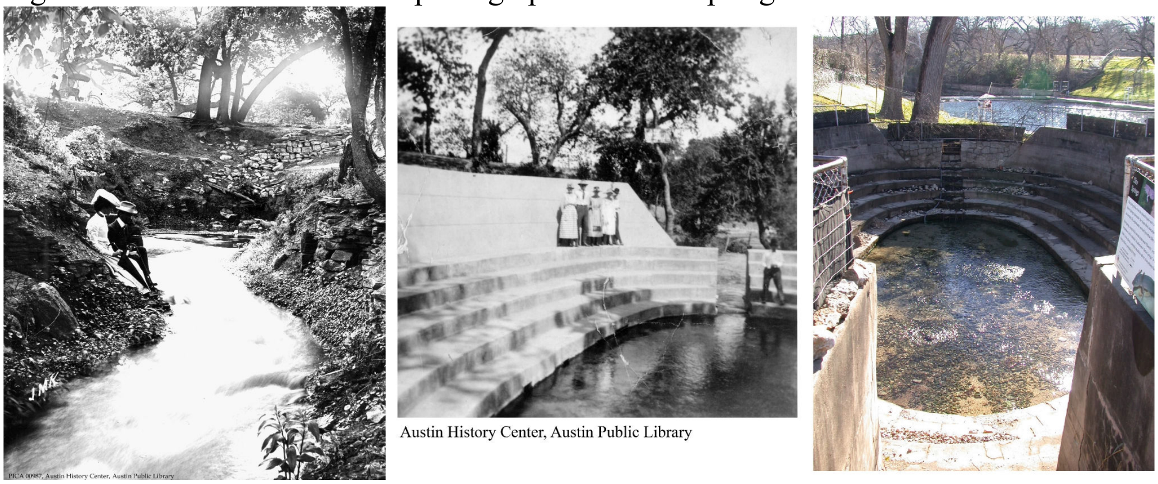
	Upstream BSP			Loop 360		
Discharge (ft^3/s)	Mean	Total Number	Duration (days)	Mean	Total Number	Duration (days)
100 - 199	9.9	31	6.88	12.8	62	2.11
200 - 299	8.7	24	5.70	9.0	36	2.50
300 - 399	6.4	22	4.97	6.7	28	1.54
400 - 499	5.7	19	3.41	5.2	24	1.25
500 – 599	4.3	15	2.96	4.1	17	1.14
600 - 699	4.0	11	2.70	4.0	15	1.05
700 - 799	3.7	11	0.23	3.8	13	0.77
800 - 899	2.3	7	2.32	3.7	12	0.53
900 - 999	1.9	5	2.53	3.5	13	0.69
≥ 1000	1.9	6	1.46	3.3	13	0.71

Flow regime of Eliza Spring has been altered since 1929 (see section 2.8 and Appendix B). Natural water flow from the spring was obstructed by construction of a concrete dam across Barton Creek downstream of the confluence of Eliza Spring and the creek. The overland stream was diverted into a buried pipe, which connected with Barton Springs Pool (Figures 5, 10). This obstruction was reversed in 1974 with the redirection of water flow from Eliza Spring into the newly constructed Barton Creek Bypass Culvert (Figure 5) that carries creek water around the Pool. In the 1950s, free water flow into the spring pool was altered with the construction of a concrete floor in the amphitheater; the resulting higher elevation of surface substrate requires obstruction of free water flow from the spring pool to maintain water in surface habitat under most aquifer conditions. Presently, if gates in the downstream dam of Barton Springs Pool are open, floodwater of Barton Creek rarely travels overland into Eliza Spring.

Flow regime of Old Mill Spring has been altered since the mid-1800s (section 2.8 and Appendix B). The construction of a mill and, subsequently, an amphitheater altered Old Mill Spring by almost completely impounding the outflow from the spring, creating a deep-water pool with low flow velocity under most aquifer conditions. Outflow was further impeded by remnants of a buried concrete pipe and the loss of the original surface stream. The natural surface outflow stream was buried beneath several feet of soil and its historic course is poorly known. The original stream channel exited the spring pool at a lower elevation than the reconstructed stream (Figure 9) and connected to Barton Creek further downstream than it does today (Figure 9). Flow of groundwater into the spring pool is obstructed by a deep layer of cobble, gravel, and sediment, which is also littered with fragments of concrete and asphalt, broken glass, rusty metal, plastic, and other trash. The exact topography of the natural limestone underlying this site is not recorded. The location and elevation of the natural fissures and caves from which groundwater is emitted to the surface is unknown. Based on anecdotal information and historical accounts (City Items 1873, as cited in Limbacher and Godfrey Architects 2008), they may be up to 10 feet deeper than the current substrate elevation. Upper Barton Spring is the only site whose surface flow regime has not been altered by dams or impoundments (Figure 5).

Figure 9. Historic and current photographs of Old Mill Spring.

Figure 10. Historic and current photographs of Eliza Spring.



2.5 Vegetation

Barton Springs is located at the junction of two terrestrial biogeographic regions of central Texas, the Edwards Plateau and Balcones Escarpment to the west, and the Blackland Prairie to the east (Griffith *et al*. 2004). The rolling hill landscape of the region has resulted in development of a large number of different soil types. Upland soils generally occur over limestone or caliche, and are shallow and rocky, especially on slopes with areas of exposed limestone. Most soils are dark colored and calcareous with surface texture varying from loam to clay (Godfrey *et al*. 1973). Soil depth and texture is highly variable in most areas and led to a corresponding diversity of vegetation (Smeins *et al*. 1976).

The natural vegetation of the Edwards Plateau uplands is characterized by oak savannas and grassy terrains, bisected by canyons and riparian areas with thick forest vegetation and a great diversity of trees and shrubs (Bray 1904, Griffith *et al*. 2004). The Blackland Prairie was dominated by tall-grass prairie and deciduous bottomland forest (Diamond and Smeins 1993, Griffith *et al*. 2004). The savanna and prairie ecosystems were maintained by fires and grazing bison (Griffith *et al*. 2004, Diamond and Smeins 1993). With the suppression of fire, the openness once characterizing portions of these regions has been severely reduced. This allowed the encroachment and increase in abundance of species once controlled by fire, such as Ashe Juniper (*Juniperus ashei*) (Griffith *et al*. 2004, Diamond and Smeins 1993). Natural savanna and tall-grass prairie are absent in much of both ecoregions today (Diamond and Smeins 1993, Hatch *et al*. 1990, Burleson 1993 as cited in Griffith *et al*. 2004).

Vegetation often observed along seeps and springs in the Edwards Aquifer are maidenhair fern (*Adiantium capillus-veneris*), tuber anemone (*Anemone edwardsiana*), and southern shield fern (*Thelypteris kunthii*) (Bezanson 2000, Amos and Rowell 1988 as cited in Griffith *et al*. 2004). Many Edwards Plateau small, headwater springs have shallow water, high canopy cover (Bray 1904), fast current, and low nutrient content (Mabe 2007). These factors likely underlie naturally low abundance and diversity of aquatic macrophytes and macroalgae (Cushing and Allan 2001, Giller and Malmqvist 1998). Larger springs located within wider, higher order streams, such as the stretch of Barton Creek that contains Parthenia Spring, likely had a greater

abundance of aquatic macrophytes than headwater springs because the canopy cover is less, current is slower, and nutrient load is greater (Wetzel 2001).
The Barton Springs complex is located within Zilker Park in Austin, Texas. This park is a combination of manicured gardens, trails, turf lawns, and nature trails through unmanaged native landscapes along Barton Creek near its confluence with the lower Colorado River (Lady Bird Lake). Growing throughout the manicured areas of the park are mature live oak (*Quercus virginiana*), ashe juniper (*Juniperus ashei*), pecan (*Carya illinoensis*), American elm (*Ulmus Americana*), cottonwood (*Populus deltoides*), and hackberry (*Celtis occidentalis*) trees. A number of smaller, mostly native trees have recently been planted in an effort to create a new generation of diverse, native trees in the park. The sports fields and other turf areas of the park are composed of Bermuda and Zoysia grasses. Non-native invasive species have become established throughout much of the vegetated areas, particularly Chinese tallow (*Sapium sebiferum*), Japonese honeysuckle (*Lonicera japonica*), heavenly bamboo (*Nandina domestica*), and privet (*Ligustrum* sp.). An integrated plan for removal of non-native, invasive species and reintroduction of native species around Barton Springs (Limbacher and Godfrey Architects 2008) was recently implemented by the City's Parks and Recreation Department.

Since the construction of dams and creation of Barton Springs Pool, the aquatic vegetation in the Plan Area has changed. Anecdotal reports indicate that patches of macrophytes were present sporadically; almost no aquatic macrophytes were present as of 2001 (Laurie Dries personal observations, City of Austin unpublished data). This was likely a result of frequent, intrusive maintenance methods used to control algae and remove flood debris (*i.e.*, dredging and chemical treatments). At present, the aquatic macrophyte community Barton Springs Pool is more abundant and diverse than ever recorded, largely a result of repeated reintroductions of native species, and use of less intrusive maintenance methods. Aquatic macrophyte species currently found in Barton Springs Pool include Delta Arrowhead (*Sagittaria platyphylla*), Water Primrose (*Ludwigia repens*), Water Stargrass (*Heteranthera dubia*), Southern Waternymph (*Najas guadalupensis*), Coon's Tail (*Ceratophyllum demersum*), Two-leaf Water Milfoil (*Myriophyllum heterophyllum*), Carolina Fanwort (*Cabomba caroliniana*), Water Celery (*Vallisneria americana*), Water Hyssop (*Bacopa monnieri*), Two-headed Water Starwort (*Callitriche heterophylla*), Upright Burrhead (*Echinodorus bertoroi*), Spikerush (*Eleocharis* sp.) and Knotty Pondweed (*Potamogeton nodosus*). Two vascular algae (*Chara* sp. and *Nitella* sp.), whose appearances resemble small, plants, have been observed occasionally throughout the Pool, and the aquatic moss, *Amblystegium riparium*, is common on limestone surfaces of Parthenia Spring.

Vegetation is sparse in Eliza Spring and Old Mill Spring. In the 1990s, both these sites had artificially deep spring pools (almost 10 feet), and the dominant, or only, vegetation was aquatic moss and algae. Since habitat restoration began for both springs, the water depth has decreased, creating more stream-like habitat with greater water velocities. Efforts to reintroduce native aquatic vegetation to Eliza Spring have been hampered by the concrete floor; vegetation cannot become well established even when planted in sediment pockets. Macrophytes that have been planted and established temporarily are water primrose, water hyssop, water celery, and spikerush. Aquatic moss has remained present in Eliza Spring, although at lower abundance. Loose, rocky substrate in Old Mill Spring continues to be removed as part of habitat restoration, making it difficult to establish macrophytes, but American waterwillow (*Justicia americana*), water primrose, and water hyssop have been reintroduced and become established along the edges of the spring pool.

The current algal community in the Barton Springs complex has not been evaluated exhaustively or quantitatively, but algal species observed in each of the springs are reported in Tables 2 and 3. Planktonic algae are rare and in low abundance within the spring sites, likely due to phosphorus concentrations below detection limits of standard tests, and a high turnover rate of water within the springs (Barton Springs Pool daily turnover between 2 and 19 times) (Alan Plummer and Associates 2000, Herrington and Scoggins 2006). Phosphorus limitation of planktonic algal growth is common to central Texas streams (Mabe 2007), although periphytic algae are common and generally abundant in all the springs in the complex (City of Austin unpublished data, Herrington and Scoggins 2006). This suggests that nutrient availability is not the only factor influencing algal growth and abundance. The types of algae observed suggest that the algal community varies among spring sites and habitat type (Alan Plummer and Associates 2000, Colucci 2009). Habitats with higher flow velocity along the substrate, such as Eliza Spring, Upper Barton Spring, and Parthenia Spring, are dominated by tightly attached periphyton and some seasonal filamentous algal blooms, with little colonization of blue-green algae. Old Mill Spring and the deeper areas of Barton Springs Pool are more characteristic of slow moving rivers or ponds (low flow velocity and increased sedimentation) and have higher relative abundances of filamentous green algae and blue-green algae (City of Austin unpublished data).

A species of red alga, *Flintiella sanguinaria*, was collected from the mouth of Parthenia Spring (Ott 1976) and has not been reported from additional localities, suggesting possible endemism to Barton Springs. Presence of this species has not been recorded since the study of Ott (1976), but algal sampling in Parthenia Spring has been sporadic.

There is evidence from both taxonomic inventories and observations that the algal community in Barton Springs Pool varies temporally and geographically. During a period of low discharge (< 30 ft^3/s) in the spring and summer of 2000, nuisance algal abundance reached levels objectionable to swimmers and recreational users. As part of development of an algae control plan, Alan Plummer and Associates (2000) conducted a study of abundance and growth of nuisance algae in the Pool. While the study was unsuccessful in documenting algal growth rates, algae found in various locations in Pool were identified (Tables 2 and 3). Compared with the inventory taken during 2005-2006 by City staff, there were significantly more genera observed at Barton Springs Pool only 5 years after the Alan Plummer and Associates study. Algal community in Barton Springs Pool prior to the 1970s was heavily influenced by the use of chlorine and copper sulfate to control algal growth. Use of copper sulfate was ceased in the 1960s. Use of chlorine was ceased in the early 1990s.

Another period of objectionable nuisance algal growth occurred in the summer of 2006, coinciding with low Barton Springs' discharge of approximately 30 ft^3/s. In response, native aquatic macrophytes were reintroduced into the Pool to increase competition with algae for nutrients and sunlight, to provide cover for algae-eating invertebrates and fish, and enhance dissolved oxygen concentrations. This resulted in significant increase in aquatic plants, from roughly 10% of surface area to over 50% (City of Austin unpublished data). During the subsequent drought period (Barton Springs discharge <25 ft^3/s), from the summer of 2008 to the fall of 2009, nuisance algal abundance never increased to the objectionable amounts observed during previous low discharge periods. This suggests that the establishment of aquatic macrophytes has succeeded in helping to control abundance of nuisance algae, regardless of nutrient concentrations.

Table 2. Genera of soft-bodied algae found from March 2005 and August 2006 in Eliza, Old Mill, and Upper Barton Spring, (summarized from City of Austin 2008b), from 2006 to 2011 in Barton Springs Pool, and reported in the Barton Springs Pool Preliminary Algae Control Plan (Alan Plummer and Associates 2000). Algae generally found attached to substrate (benthic) are denoted by the letter A, generally free-floating (planktonic) algae are denoted by the letter F. The names in bold are algae that have reached nuisance abundances in Barton Springs Pool.

	City of Austin				Plummer
Genus	**BSP**	**Eliza**	**Old Mill**	**UBS**	**BSP**
Green micro-algae					
Aphanochaete (A)	x				
Ankistrodesmus (F)			x		
Chlamydomonas (F)	x	x	x		
Closterium (F)		x	x		
Cosmarium (F)	x	x	x	x	
Gloeocystis (F)		x			
Oocystis (F)	x				
Pediastrum (F)					x
Scenedesmus (F)	x	x			x
Green macro-algae					
Chaetophora (A)	x				
Chaetosphaeridium (F)	x				
Chamaesiphon (A)		x			
Chara (A)	x				
Cladophora (A)	x	x	x	x	x
Dichotomosiphon (A)	x	x			
Hydrodictyon (A or F)	x	x		x	
Mougeotia (A or F)	x				x
Nitella (A)	x				
Oedegonium (A)	x				
Rhizoclonium (A or F)	x				
Spirogyra (A or F)	x	x		x	x
Stigeoclonium (A)	x	x	x		x
Tetraspora (A)		x	x	x	x
*Thamniochaete***					x

Table 2 (cont.). Genera of soft-bodied algae found from March 2005 and August 2006 in Eliza, Old Mill, and Upper Barton Spring, (summarized from City of Austin 2008b), from 2006 to 2011 in Barton Springs Pool, and reported in the Barton Springs Pool Preliminary Algae Control Plan (Alan Plummer and Associates 2000). Algae generally found attached to substrate (benthic) are denoted by the letter A, generally free-floating (planktonic) algae are denoted by the letter F. The names in bold are algae that have reached nuisance abundances in Barton Springs Pool.

	City of Austin				**Plummer**
Genus	**BSP**	**Eliza**	**Old Mill**	**UBS**	**BSP**
Red Algae					
Audouinella (A)	x		x		
Batrachospermum (A)	x	x	x	x	x
Hildenbrandia (A)	x	x			
Tuomeya (A)			x	x	
Yellow-green algae					
Ophiocytium (F)			x		
Tribonema (F)	x	x			
Vaucheria (A)	x	x	x	x	
Blue-green/cyanobacteria					
Amphithrix = Homeothrix (A)	x				
Anabaena (F)	x		x		
Aphanocapsa (F)	x				
Calothrix (A)	x				
Chroococcus (A)	x	x			x
Coelosphaerium (F)	x				
Lyngbya (A)	x	x	x		
Oscillatoria (F)	x	x	x	x	x
Spirulina (F)	x				x
Euglenoid algae					
Euglena (A)	x	x			

Table 3. Diatom algal genera observed between March 2005 and August 2006 in Eliza and Old Mill springs, and Barton Springs Pool (City of Austin 2008b), and algae reported in the Barton Springs Pool Preliminary Algae Control Plan (Alan Plummer and Associates 2000).

	City of Austin			Plummer
Genus	**BSP**	**Eliza**	**Old Mill**	**BSP**
Achnanthes	x	x	x	
Achnanthidium	x	x	x	
Adlafia	x			
Amphora	x	x	x	x
Bacillaria			x	
Brachysira	x		x	
Caloneis			x	x
Cocconeis	x	x	x	
Craticula	x			
Cymbella	x			x
Denticula	x	x	x	
Diadesmis	x			
Diatoma	x			x
Diatomella				x
Diploneis	x			
Encyonema	x		x	
Encyonemopsis		x		
Encyonopsis	x		x	
Eunotia	x			
Fragilaria	x	x		x
Geissleria	x		x	
Gomphoneis				x
Gomphonema	x	x	x	x
Gomphospenia	x			
Luticola	x			
Melosira	x	x		
Navicula	x	x	x	x
Nitzchia	x	x	x	
Psammothidium	x	x	x	
Pseudostaurosira	x			
Reimeria	x			
Rhoicosphenia	x	x	x	
Sellaphora			x	
Staurosira	x			
Staurosirella	x	x	x	
Surirella		x		
Synedra	x	x	x	x
Tabilleria				x
Terpsinoe	x			x

2.6 Wildlife

The fauna within the Colorado River basin are mostly transitional and the river is the southern boundary for many species (Abell *et al*. 1999). This ecoregion is home to over 100 fish species, few of which are endemic (Conner and Suttkus 1986). Many endemic karst aquatic fauna are found in spring-fed streams of the Edwards Aquifer (Culver et al. 2000); it is a global hotspot of endemic species (Culver and Sket 2000). There is one fish species endemic to the Edwards Plateau springs, the Edwards Plateau Shiner (*Cyprinella lepida*), but it occurs only in the Guadalupe and Nueces River drainages.

In addition to aquatic salamanders, records of aquatic fauna that have been or are currently found in Barton Creek and Barton Springs include 20 species of fish, 3 species of turtles and numerous invertebrates. Native fishes commonly seen in Barton Springs Pool include the Green Sunfish (*Lepomis cyanellus*), Bluegill (*Lepomis macrochirus*), Longear Sunfish (*Lepomis megalotis*), Spotted Sunfish (*Lepomis punctatus*), Largemouth Bass (*Micropterus salmoides*), Guadalupe Bass (*Micropterus treculi*), Mosquitofish (*Gambusia affinis*), and the Greenthroat Darter (*Etheostoma lepidum*). Native fishes whose ranges include Barton Creek, which are seen occasionally in Barton Springs include the American Eel (*Anguilla rostrata*), Channel Catfish (*Ictalurus punctatus*), Flathead Catfish (*Pylodictus olivaris*), Gray Redhorse (*Moxostoma congestum*), Texas Logperch (*Percina carbonaria*), Dusky Darter (*Percina sciera*), Orangethroat Darter (*Etheostoma spectabile*), Red Shiner (*Cyprinella lutrensi*), Blacktail Shiner (*Cyprinella venusta*), Texas Shiner (*Notropis amabilis*), Central Stoneroller (*Campostoma anomalum*), and the Blackstripe Topminnow (*Fundulus notatus*). Fish residing in Eliza Spring are mosquitofish, but tadpole madtoms (*Noturus gyrinus*) have been seen for short periods of time after floods. Old Mill Spring typically has no resident fish, although some sunfish occasionally migrate in and out of the spring. The Bullhead Minnow (*Pimephales vigilax*) has been found in abundance in Upper Barton Spring when it is flowing, along with other minnows mentioned above. Non-native Mexican tetras (*Astyanax mexicanus*) were found in abundance in Barton Springs Pool and Old Mill Spring in recent decades but have appeared only sporadically in recent years. Non-native fishes currently found in Barton Springs Pool are the Redbreast Sunfish (*Lepomis auritus*) and the Rio Grande Cichlid (*Cichlasoma cyanogutatum*). A single non-native Asian Grass carp (*Ctenopharyngodon idella*) was introduced into Barton Springs Pool in the 1990s and was subsequently removed.

The community of aquatic invertebrates found in the Barton Springs complex includes *Hyalella azteca* amphipods, *Dugesia* sp. planarians, physid and planorbid snails, lymnaeid limpets, and larvae of chironomid midges, baetid and heptageniid mayfly larvae, *Helicopsyche* sp. caddisfly larvae, *Pterophila* sp. moth larvae, *Argia* and *Archilestes* odonate (damselfly) larvae, and *Psephenus* sp. beetles and larvae, and red crayfish (*Procambarus clarkii*) (Geismar and Herrington 2007). Of particular importance to *E. sosorum* is the abundance of planarians, amphipods, and chironomids, which make up the largest portion of their diet in the wild (Gillespie 2011). Periods of low salamander abundance are coincident with periods of low invertebrate abundances (Gillespie 2011). Abundances of these invertebrates vary temporally and are lower during low aquifer discharge. In addition, planarians, chironomids, and ephemeropterans also vary with season (Gillespie 2011).

Herpetofauna observed in and around Barton Springs includes several species of turtles, the Red Ear Slider (*Trachemys scripta*), Texas Cooter (*Pseudemys texana*), Texas Map Turtle (*Graptemys versa*), Eastern Box Turtle (*Terrapene Carolina*), Ornate Box Turtle (*Terrapene ornata*), Yellow Mud Turtle (*Kinosternon flavescens*), Easter Mud Turtle (*Kinosternon subrubrum*), Stinkpot (*Sternotherus ordoratus*), Common Snapping Turtle (*Chelydra serpentina*), and Spiny Softshell Turtle (*Apalone spinifera*).

Species of frogs that are common in the area include the Gulf Coast Toad (*Bufo valliceps*), Woodhouse's Toad (*Bufo woodhouseii*), Blanchard's Cricket Frog (*Acris crepitans*), Spotted Chorus Frog (*Pseudacrisclarkii*), the Southern Leopard Frog (*Rana sphenocephala*), and the Rio Grande Leopard Frog (*Rana berlandieri*). Other frog species known from Travis County include the Cliff Chirping Frog (*Eleutherodactylus marnockii*), Texas Toad (*Bufo speciosus*), Green Toad (*Bufo debilis*), Red Spotted Toad (*Bufo punctatus*), Barking Frog (*Eleutherodactylus augusti*), Cope's Gray Treefrog (*Hyla chrysoscelis*), Green Treefrog (*Hyla cinerea*), Gray Treefrog (*Hyla versicolor*), Strecker's Chorus Frog (*Pseudacris streckeri*), Southeastern Chorus Frog (*Pseudacris feriarum*), Eastern Narrow-mouthed Toad (*Gastrophryne carolinensis*), Great Plains Narrow-mouthed Toad (*Gastrophryne olivacea*), American Bullfrog (*Rana catesbeiana*), and Couch's Spadefoot Toad (*Scaphiopus couchii*),

The Western Slimy Salamander (*Plethodon albagula*) may be found within Zilker Park. Other non-neotenic species known from Travis County are the Smallmouth Salamander (*Ambystoma texanum*) and the Marbled Salamander (*Ambystoma opacum*).

Lizard species observed in and around Zilker Park are the Texas Spiny Lizard (*Sceloporus olivaceous*), Green Anole (*Anolis carolinensis*), Texas Alligator Lizard (*Gerrhonotus infernalis*), Ground Skink (*Scincella lateralis*), Ornate Tree Lizard (*Urosaurus ornatus*), Greater Earless Lizard (*Cophosaurus texanus*), and non-native Mediterranean Gecko (*Hemidactylus turcicus*). Other species known from Travis County include Six-lined Racerunner (*Aspidoscelis sexlineata*), Eastern Spotted Whiptail (*Aspidoscelis gularis*), Slender Glass Lizard (*Ophisaurus attenuatus*), Eastern Collared Lizard (*Crotaphytus collaris*), Spot-tailed Earless Lizard (*Holbrookia lacerata*), Texas Horned Lizard (*Phrynosoma cornutum*), Prairie Lizard (*Sceloporus undulatus*), Great Plains Skink (*Plestiodon obsoletus*), and Four-lined Skink (*Plestiodon tetragrammus*).

Snake species observed around Barton Springs include the Coral Snake (*Micrurus fulvius tener*), Eastern Hognose Snake (*Heterodon platirhinos*), Eastern Rat Snake (*Pantherophis obsoletus*), Checkered Garter Snake (*Thamnophis marcianus*), Western Ribbon Snake (*Thamnophis proximus*), and Diamond-backed Water Snake (*Nerodia rhombifer*). Other snake species known from Travis County include Glossy Snake (*Arizona elegans*), Eastern Racer (*Coluber constrictor*), Ringneck Snake (*Diadophis punctatus*), Chihuahuan Night Snake (*Hypsiglena jani*), Prairie Kingsnake (*Lampropeltis calligaster*), Common Kingsnake (*Lampropeltis getula*), Milksnake (*Lampropeltis triangulum*), Coachwhip (*Masticophis flagellum*), Striped Whipsnake (*Masticophis taeniatus*), Blotched Water Snake (*Nerodia erythrogaster*), Broad-banded Water Snake (*Nerodia fasciata*), Rough Green Snake (*Opheodrys aestivus*), Great Plains Rat Snake (*Pantherophis emoryi*), Gopher Snake (*Pituophis catenifer*), Texas Longnose (*Rhinocheilus lecontei*), Texas Patchnose Snake (*Salvadora grahamiae*), Ground Snake (*Sonora semiannulata*), DeKay's Brown Snake (*Storeria dekayi*), Flathead Snake (*Tantilla gracilis*), Plains Blackhead Snake (*Tantilla nigriceps*), Blackneck Garter Snake (*Thamnophis cyrtopsis*), Copperhead (*Agkistrodon contortrix*), Cottonmouth (*Agkistrodon piscivorus*), Western Diamondback Rattlesnake (*Crotalus atrox*), Blacktail Rattlesnake (*Crotalus molossus*) and Texas Blind Snake (*Leptotyphlops dulcis*).

The ranges of a large number of birds include the Barton Springs area. Native bird species commonly seen around the springs in recent years include the Belted Kingfisher, Gadwal, Coot, Mallard, Green-backed Heron, Great Blue Heron, White-crowned Night Heron, Cattle Egret, Snowy Egret, Redtail Hawk, Red-shouldered Hawk, Barred Owl , Spotted Sandpiper, Killdeer, Yellow Warbler, Golden-fronted Woodpecker, Mourning Dove, White-winged Dove, and Great-tailed Grackle. Non-native house sparrows, starlings, and rock doves are abundant in the manicured areas of the park.

Over 100 taxa of macroinvertebrates have been documented as present in the springs (Geismar and Herrington 2007, City of Austin unpublished data). Non-insect invertebrates include aquatic earthworms, triclad flatworms of the genus *Dugesia,* glossiphoniid leeches, water mites, hydra, and crustaceans, including crayfish (*Procambarus clarkii),* ostracods, copepods, the amphipod *Hyalella azteca,* as well as three species of subterranean blind amphipods (*Stygobromus* sp.), and one species of blind isopod, *Lirceolus hardeni.* These subterranean invertebrates are rarely found at the surface. Gastropods (snails and limpets) documented in the springs are members of Physidae, Lymnaeidae, Planorbidae, Pleuroceridae, Ancylidae, and Hydrobiidae. Shells of the non-native Asian clam, (*Corbicula fluminea*) have been found in Parthenia Spring; live non-native snails (*Melanoides tuberculata*) found in Old Mill Spring were removed. *Stygopyrgus bartonensis*, a small, aquatic hydrobiid snail, was described based on an empty shell collected from Eliza Spring (Herschler and Longley 1986) although no additional specimens have been collected from Barton Springs. Representatives of at least 10 groups of aquatic insects have been observed in the springs: eight genera of ephemeropteran larvae (mayflies), 14 genera of trichopteran larvae (caddisflies), 18 genera of beetles, 5 families of odonates (dragonflies and damselflies), one genus of plecopteran larvae (stonefly), one lepidopteran (aquatic moths), 3 dipteran larvae (flies), 6 hemipterans, 1 megalopteran (alderflies), and 1 collembolan (springtails). Water pennies, amphipods, and chironomid larvae are nearly always present. Many of the taxa are commonly categorized as intolerant of pollution (TCEQ 2007b), suggesting that water quality of Barton Springs is generally good. Abundance of individuals within each taxon varies among spring sites and with aquifer discharge conditions. Abundance decreases as aquifer discharge decreases and some taxa disappear regardless of season (e.g., limpets, planarians, caddisfly larvae, baetid and heptageniid mayfly larvae).

2.7 Human Population

The 2010 estimate of human population size in the Barton Springs Zone is 143,382 persons and predicted to grow in the coming decades (Capital Area Metropolitan Planning Organization 2010). As of 2010, the City of Austin has a population of 790,390 people and the Austin-Round Rock-San Marcos Metropolitan Statistical Area has a population of 1,716,291 people (2010 United States Census). From 1990 to 2010, human population size in the Barton Springs Zone has increased 2.5 times and is projected to increase 1.6 times from 2010 to 2035 (Figure 6, Herrington *et al*. 2011). The majority of human population growth is projected to occur in areas that affect the Barton Creek and Williamson Creek watersheds (Figure 7), which will likely result in further urban development in the Barton Springs Zone of the Edwards Aquifer (Herrington *et al*. 2011).

Figure 6. Population growth as number of individuals in the Barton Springs Zone from US Census Bureau for 1990 and 2000 estimates and from CAMPO (2010) for 2005 to 2035.

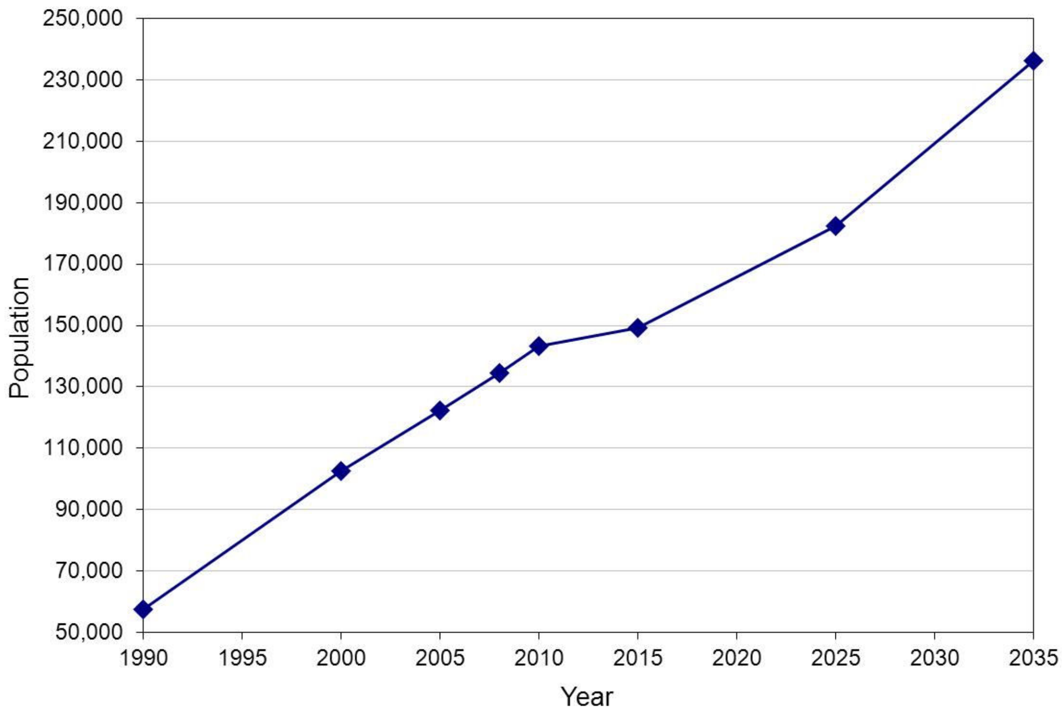
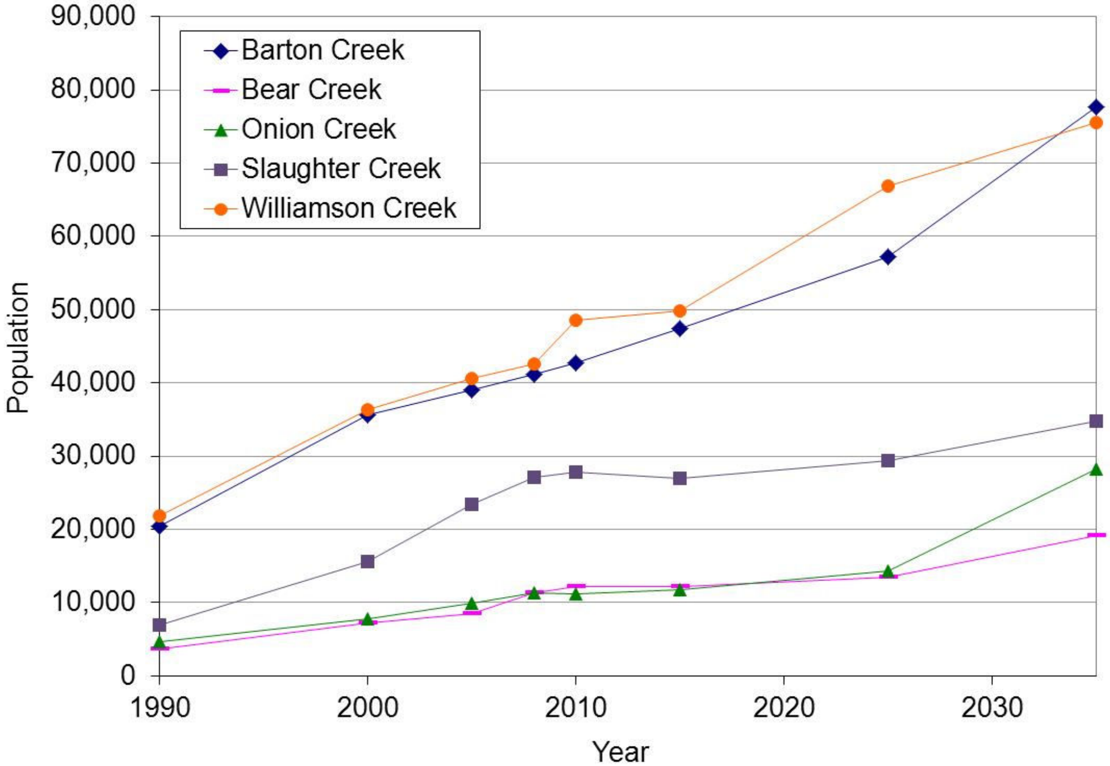


Figure 7. Population estimates from US Census Bureau from 1990 and 2000 and predicted population change (number of individuals) from year 2010 to 2035 from CAMPO (2010) in the Barton Springs Zone by watershed.



2.8 Land Use and Development Activities

Land along the riparian corridors and adjacent properties surrounding Barton Springs has been restricted to use as a public park since 1918 when the land was deeded to the City. Upstream of Barton Springs Pool, the riparian corridor is a City-owned green belt, but upland areas consist of urban land uses.

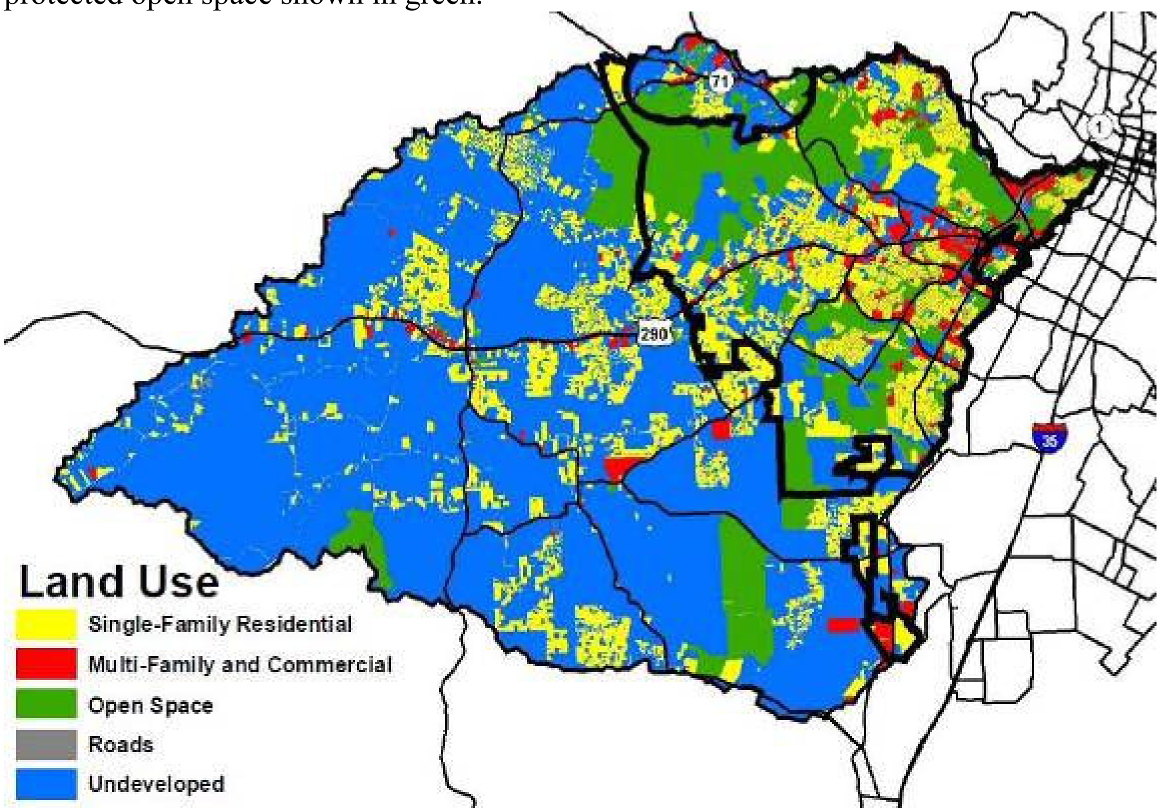
In 2003, the City delineated land use for all jurisdictions within the entire Barton Springs Zone (Figure 8) based on information in the City of Austin Watershed Protection Department GIS Database (http://coagis1.ci.austin.tx.us/website/COAViewer_dev/devviewer_disclaimer.htm). The City's jurisdiction covers 28.5% of the total land area of the Barton Springs Zone, generally equivalent to the area covered by the City of Dripping Springs (29.7%) and unincorporated Hays County (30.7%) (City of Austin Watershed Protection Department GIS Database). Based on City of Austin 2003 land use information, impervious cover within the entire Barton Springs Zone is 5.3%, and impervious cover within the area of the City's jurisdiction in the Barton Springs Zone is 9.6% (Herrington *et al*. 2011). Undeveloped land and protected open space represent approximately 54% of the total area of the Barton Springs Zone within City jurisdiction (Table 4).

Table 4. Percentage of area represented by different land use categories in the Barton Springs Zone (BSZ) within the City's jurisdiction and for all jurisdictions from 2003 City land use

analysis. (Results are based on data in the City of Austin Watershed Protection Department GIS Database.)

Land Use	Within City Jurisdiction (% of BSZ)	All Jurisdictions (% of BSZ)
Undeveloped	23	60
Single-Family Residential	31	19
Commercial/Multi-Family	8	3
Roads	7	4
Open Space	31	14

Figure 8. Year 2003 land use distribution for the Barton Springs Zone, all jurisdictions. City of Austin jurisdiction limits over the Barton Springs Zone shown in heavy bold. Permanently protected open space shown in green.



An estimated 14% of the total Barton Springs Zone area is permanently protected open space, public park land, Water Quality Protection land, or Balcones Canyonland Preserve land. Approximately 30% of land in the Recharge Zone is permanently protected open space.

The U. S. Department of Agriculture (2009) census information shows a decline from 2002 to 2007 in the acreage of farmed land for both Travis (-12%) and Hays (-15%) counties. The City has tracked land use patterns over time, though not on a consistent temporal scale. Undeveloped and agricultural land have been categorized in the same way in some older land use assessments, but may be considered together to represent the maximum total potential area in agricultural use as a means to provide a more consistent comparison. City land use data through 1995 indicate potential agricultural land use of 87% of the Barton Springs Zone while 2003 assessments yield an area of potential agricultural land use of only 40% (Herrington *et al*. 2011). Agricultural operations are probably not increasing in the Barton Springs Zone over time (Herrington *et al*. 2011).

Domestic wastewater disposal via direct discharge or land application of treated wastewater effluent may contribute to eutrophication of the Edwards Aquifer (Mabe 2007, Herrington et al. 2011). In 2009, Hays County Water Control and Improvement District 1 serving the Belterra Subdivision was granted the first wastewater discharge permit in the contributing zone of the aquifer. All other centralized wastewater disposal in the Barton Springs Zone is done under the Texas Land Application Permit (TLAP) system irrigating wastewater effluent with no intentional discharge to surface waters or by individual on-site sewage facility (OSSF) (Herrington *et al*. 2011). City of Austin wastewater collection service extends throughout the Williamson Creek watershed and in portions of the Barton and Slaughter Creek watersheds over the recharge zone within the City's jurisdiction (Herrington *et al*. 2011).

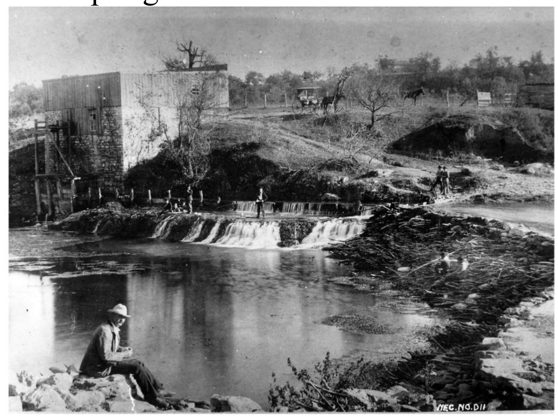
2.9 Human Historic Setting

The history of human activity near Barton Springs dates back at least 10,000 years based on numerous archaeological sites located near the perennial springs (Voellinger 1993, Nickels et al. 2010). The earliest known human inhabitants of Central Texas were small bands of Native Americans. In 1730, the establishment of a Spanish mission near Barton Springs marked the beginning of European settlement around Barton Springs. Detailed description of human history in Austin and around Barton Springs is presented by Limbacher and Godfrey Architects (2008). Presented below is a history of modifications of Barton Springs and is derived from Limbacher and Godfrey Architects (2008) and the Austin History Center archives.

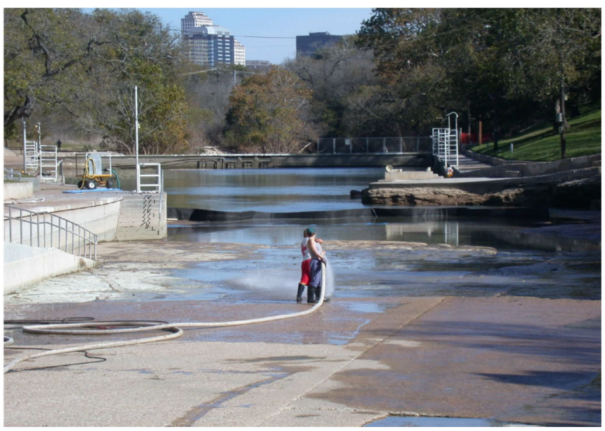
Commercial use of Barton's springs began in 1839 with the construction of a sawmill on Barton Creek (Figure 11). At least two additional mills were built in the 1870s, one on the south bank of Barton Creek downstream of Parthenia Spring and another further downstream on Old Mill Spring (Figure 9). The sawmill was accompanied by erection of a wooden timber dam across Barton Creek (Austin History Center photos C00077-A, PICA 00975), which would be washed out during floods and subsequently rebuilt. The dam across Old Mill Spring was constructed of stone with wooden gates to control water outflow (Austin History Center C03293, PICA 000976, PICA 00986). Eliza Spring was apparently unaltered until the early 1900s (Austin History Center PICA 00987b), when Andrew Zilker constructed a concrete amphitheater around the spring pool (Figure 10) to be used as a meeting place for the Benevolent and Protective Order of Elks, Austin Lodge #201 (AHC PICA 28447, PICA 00971). In 1917, Mr. Zilker negotiated transfer of his land to the City of Austin for use as a public park. Zilker Park had been created and recreational use of the springs had begun.

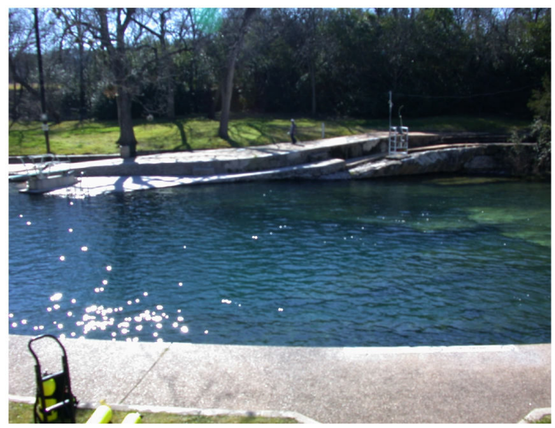
Figure 11. Historic and current photographs of Parthenia Spring.

PICA 00975 Austin History Center, Austin Public Library



C00077-A Austin History Center, Austin Public Library





Zilker Park and Barton Springs became destinations for swimming and camping, and provided drinking water during the drought of 1917. Swimming was facilitated by the annual erection of temporary rock dams across Barton Creek deepening the water (Austin History Center photo C01803), and the construction of concrete retention walls and stairways on the slopes leading to the water (Austin History Center C01818b, PICA 30171). Development of Zilker Park and Barton Springs into a formal recreation destination proceeded throughout the late 1920s and 1930s. Two permanent dams were constructed across Barton Creek upstream and downstream of Parthenia Spring (Figure 11; Austin History Center PICA 22642), creating a deep-water swimming area dubbed Barton Springs Pool. The channel downstream of Barton Springs Pool was reconfigured to place the deepest area in the middle of the new dam. The creek channel within Barton Springs Pool was widened and deepened in some areas, and uneven substrate was leveled. The natural creek banks were replaced with concrete walls, and topped with sidewalks. A flat, shallow stretch of substrate along the northwestern wall of the Pool was created to provide a beach area of “waist-deep” water for “non-expert” swimmers (Austin American Statesman September 23, 1929). A two-story bathhouse and concession stand were also constructed on the north side of the Pool (Austin History Center C01825). Finally, the outflow stream from Eliza Spring was confined to a buried concrete pipe that opened into Barton Springs Pool.

Old Mill Spring escaped further modification until 1937, when the National Youth Administration built a four-tiered amphitheater around the spring (Austin History Center PICA 20233). The innermost wall was built on top of the remains of the mill's stonework walls and across the outflow stream channel, creating a dammed, deep, swimming pool. Much of the outflow stream was diverted to a buried, underground pipe although some water flowed through small spillways to a redirected surface stream.

Prior to the mid-1940s, waters of upper Barton Creek flowed through openings in the upstream dam of Barton Springs Pool (Austin History Center PICA 01033), mingling with ground water emanating from the springs. After the large flood of 1943, a bypass system was added to Barton Springs Pool to divert floodwater into an underground concrete pipe that carried water beneath the Pool through the downstream dam into lower Barton Creek (Austin History Center PICA 20222, 20224). Sometimes during the 1950s, small concrete walls and a concrete floor were built in the shallow end to create a children's wading area separate from the rest of the Pool. Concrete was poured into large fissures of Parthenia Spring and depressions in the natural limestone substrate to create level surfaces. A concrete floor approximately one foot thick was poured on top of the natural substrate of Eliza Spring, leaving limited openings as conduits from the underground spring to the surface. The land surrounding the amphitheater was raised several feet with the addition of sand, soil, and gravel, and the height of the amphitheater walls was increased.

From 1974 to 1976, a second floodwater bypass system was built in response to lost revenue from Pool closure during flooding and concern over potential pollution of floodwater from urban development (Barton Springs Bypass Preliminary Report 1973). This system consists of a box culvert built beneath the northwestern sidewalk of the Pool extending from the upstream to the downstream dam capable of transmitting approximately 500 ft^3/s of water. The openings in the upstream dam were plugged with concrete to prevent entry of creek water into the Pool during floods, which also prevents entry of creek water during baseflow. Two spillways were added to the downstream dam. The outflow pipe from Eliza Spring was routed into the bypass culvert rather than into the Pool.

Additional modification of Barton Springs Pool occurred as part of the first Habitat Conservation Plan issued for *E. sosorum* in 1998. Plates over the openings of the downstream dam were replaced with adjustable gates, and substrate of the beach area was removed to lower its elevation. Ramps to and into the Pool were added to provide accessibility for disabled individuals. In Old Mill Spring, the buried outflow pipe was plugged to divert more water to the surface stream.

2.10 Federally Protected Species in Travis County

There are a number of federally protected species in the Austin area (Table 5, USFWS 2012). There is one plant species of concern in Travis County. Habitat for the Bracted Twistflower (*Streptanthus bracteatus*) includes thin clay soils blanketing limestone in oak-juniper woodlands (Hatch et al. 1990) although this species does not occur in the managed landscapes of Zilker Park surrounding Barton Springs. The federally protected terrestrial karst taxa live in karst features within the Edwards Aquifer formations in Travis County although none of these species is expected in the Plan Area because there are no terrestrial karst features. Some aquatic karst taxa may occur within Barton Springs, but none are protected by federal or state regulations. Habitat for the two endangered neo-tropical migratory songbirds, the Golden-cheeked Warbler, (*Dendroica chysoparia*) and the Black-capped Vireo (*Vireo atricapilla*), is in canyons and uplands of the western part of the Austin area. Although the Barton Creek Greenbelt is part of the preserve system, the land adjacent to the Plan Area is not occupied habitat (Balcones Canyonlands Conservation Preserve, Lisa O'Donnell personal communication 2011). Therefore, these species will not be affected by the project proposed here.

Table 5. Federally protected species in Travis County, Texas are listed below. Status is denoted as endangered (E), threatened (T), candidate (C), and of concern (D) (U.S. Fish and Wildlife Service 2012).

Group	Species	Common Name	Status
Amphibians	*Eurycea sosorum*	Barton Springs Salamander	E
	Eurycea waterlooensis	Austin Blind Salamander	C
	Eurycea tonkawae	Jollyville Plateau Salamander	C
Birds	*Dendroica chrysoparia*	Golden-Cheeked Warbler	E
	Vireo atricapilla	Black-Capped Vireo	E
	Grus americana	Whooping Crane	E
Insects	*Texamaurops reddelli*	Kretschmar Cave Mold Beetle	E
	Rhadine persephone	Tooth Cave Ground Beetle	E
Arachnids	*Texella reddelli*	Bee Creek Harvestman	E
	Texella reyesi	Bone Cave Harvestman	E
	Tartarocreagris texana	Tooth Cave Pseudoscorpion	E
	Leptoneta myopica	Tooth Cave Spider	E
	Circurina wartoni	Warton Cave Meshweaver	C
Plants	*Streptanthus bracteatus*	Bracted Twistflower	C

The Barton Springs Salamander (*Eurycea sosorum*) and the Austin Blind Salamander (*Eurycea waterlooensis*) are the species addressed in this habitat conservation plan. *Eurycea sosorum* was first collected from Barton Springs in 1946 (Brown 1950, Texas Natural History Collection specimens 6317-6321) and formally described in 1993 (Chippindale et al. 1993). *Eurycea waterlooensis* was first described in 2001 (Hillis et al. 2001). *Eurycea sosorum* was listed as an endangered species under the Act in 1997; endangered status was proposed for *E. waterlooensis* in 2012 (USFWS 2012).

3.0 Affected Environment

3.1 Species Description and Natural History

3.1.1 Morphology and Physiology

Eurycea sosorum and *E. waterlooensis* are generally morphologically and physiologically similar. Adults of both species are roughly 1.5 to 3.5 inches in total length (TL) and have 4 toes on their forefeet and 5 toes on their hind feet (Chippindale *et al*. 1993, Hillis *et al*. 2001, Chamberlain and O'Donnell 2003). Each species is typified by lack of lungs, three external gills on each side of the head, reduced, spindly limbs, and dorsoventrally flattened fin on the tail. They are both solely aquatic, perennibranchiate ("always gilled") species; these salamanders never metamorphose, they become sexually mature yet retain aquatic morphologies.

Typical pigmentation of *E. sosorum* is a mottled background of melanophores with scattered iridophores. There is individual variation in background color from pink, purple, and brown, to orange and red (Chippindale *et al*. 1993). Head morphology of *E. sosorum* is rounded with slightly compressed snout. It has well-developed image forming eyes and uses visual and bioelectric cues rather than olfaction to avoid predatory bass and crayfish (Gillespie 2011). These are characteristics consistent with dwelling in clear, surface water habitats. Although

Chippindale *et al*. (1993) observed compression of head and snout in *E*. *sosorum* and concluded that this species may be more adapted to subterranean life than other Edwards Aquifer epigean *Eurycea*, this may have been driven by the inclusion of data from salamanders subsequently identified as *E*. *waterlooensis* (Hillis *et al*. 2001). In general, the majority of observed wild *E*. *sosorum* have morphology and behavior suitable for life in surface waters.

Eurycea waterlooensis background pigmentation is purple, lavender, peach, or brown overlying a layer of reflective connective tissue with scattered iridiphores. It is a cave specialist, exhibiting morphological characteristics typical of troglobitic (subterranean dwelling) organisms (Chippindale *et al*. 2000, Hillis *et al*. 2001). The head is slightly enlarged with a compressed, shovel-like snout (Hillis *et al*. 2001), which can enhance detection of obstacles in dark environments by displacing more water (Poulson and White 1969). The eyes are reduced to spots beneath the skin without image-forming lenses. External morphology of eyes of juvenile *E*. *waterlooensis* are similar to that of juvenile *E*. *sosorum*, but eye structures appear to degenerate as salamanders mature, a process well documented in the cave-dwelling fish, *Astyanax mexicanus* (Jeffery 2005a, b). Such sensory characteristics are suggestive of subterranean life where absence of light renders prey or predator detection by vision impossible. However, *E*. *waterlooensis* in the wild and captivity exhibit weak responses to visual stimuli (L. Dries and L. Colucci personal observations 2004-2012).

Primary respiration in perennibranchiate salamanders is through the gills, although a substantial amount of gas exchange occurs through the skin (Boutilier *et al*. 1992, Hillman and Withers 1979). They also require water moving across their gills and bodies for optimal respiratory rates. A study of three *Eurycea* species closely related to *E*. *sosorum*, found that metabolic rates and oxygen consumption are highest in juveniles and decreases with increasing body size (Norris *et al*. 1963). Oxygenation of salamander eggs is critical to embryonic development since gas exchange and waste elimination occur through semi-permeable membranes surrounding the embryo (Duellman and Trueb 1994). In the wild, Barton Springs' *Eurycea* live in water with a narrow temperature range (see section 3.2); captive salamanders show signs of stress when water temperature exceeds 81°Fahrenheit (27.2°Centigrade). One common response of *E*. *sosorum* to stress is the formation of small gas bubbles under the skin, which are typically burped out of the body through gill slits or diffuse through the skin (D. Chamberlain personal observations).

Only a few physiological anomalies have been reported in wild *E*. *sosorum*. In 2002 and 2003, twenty-two wild adult salamanders were found with gas bubble trauma. Since 2003, seven salamanders have been observed with gas bubble trauma in the wild. Three of these had obvious external physical injuries, 2 were collected for observation and recovered in captivity, and 2 were sent for pathology work which presented diagnoses of gas bubble disease due to presumed supersaturation of total dissolved gases. In 2001, a trematode infection (*Clinostomum* sp.) was found in an adult salamander from Parthenia Spring (Chamberlain and O'Donnell 2002) and, according to a veterinary pathologist, was the cause of an extra toe on one foot in a gravid female. Pathology work on one group of captive salamanders identified an unknown myxosporidian parasite, as well as several pathogens (fungi and bacteria in the genera of *Aeromonas* and *Pseudomonas*) that are ubiquitous and are thought to be secondary infections (Chamberlain and O'Donnell 2003). In addition, four *E*. *sosorum* from Eliza Spring were sampled for chytrid fungus (*Batrachochytrium dendrobatidis*); each tested positive although none exhibited health problems (City of Austin unpublished data). Therefore, it is likely that the species can harbor the fungus without negative health consequences.

3.1.2 Life History

Eurycea sosorum and *E. waterlooensis* are carnivorous. Known prey items of *E. sosorum* include ostracods, chironomids, copepods, mayfly larvae, amphipods, oligochaetes, planarians, adult riffle beetles, snails, and leeches (Chamberlain and O'Donnell 2002, Chippindale *et al*. 1993, Gillespie 2011). *Eurycea waterlooensis* is believed to feed on blind amphipods and isopods found within the aquifer, but when they are at the surface of the springs will also consume other small invertebrates (Hillis *et al*. 2001).

Predators of *E. sosorum* in the wild include birds, fish, crayfish, aquatic invertebrates and possibly other salamanders. Most of the potential predators that are native to the Barton Springs ecosystem are opportunistic feeders. Crayfish (*Procambarus clarkii*) prey on juvenile *E. sosorum* (L. Colucci personal observation) and other predatory invertebrates may prey on salamanders or salamander larvae and eggs (Gamradt and Kats 1996). Of predatory fishes found in Barton Springs, sunfish and bass have been observed feeding on *E. sosorum*. Mosquitofish have been known to prey on frog and salamander larvae in areas where these fish have been introduced (Gamradt and Kats 1996, Goodsell and Kats 1999, Lawler *et al*. 1999), but predation on Barton Springs' *Eurycea* has not been observed. In addition, a green-throat darter (*Etheostoma lepidum*) was observed preying upon a small juvenile *E. sosorum* (D. Chamberlain personal observation 2002). Longear sunfish are known to prey on aquatic vertebrates, and largemouth bass are opportunistic predators that feed primarily on smaller fishes and crayfish. Mexican tetras are non-native fish and aggressive generalist predators.

Longevity data are currently only available for captive *E. sosorum* and *E. waterlooensis* (City of Austin unpublished). In 2010, a wild-caught female *E. sosorum* that was collected as an adult in 1996 died at a minimum age of 15 years. Her exact age is unknown because her age at collection is unknown. The oldest captive raised *E. sosorum* is a 15-year-old male that hatched in January 1997. The oldest *E. waterlooensis* in captivity is 13 years, and was collected from the wild as a juvenile in 1998.

Observations of *E. sosorum* in captivity indicate that the salamanders can spend an hour or more at a time engaged in courtship, which might make them exposed and vulnerable to predators (City of Austin 2002). Therefore, courtship probably occurs underground or at night although few salamanders have been found during night surveys of Parthenia Spring. Egg-laying events have only been observed in captivity. On average, female *E. sosorum* and *E. waterlooensis* lay 15 and 16 eggs per clutch, respectively (City of Austin unpublished). The eggs are laid singly and this process can take 12 hours or more (Chamberlain and O'Donnell 2003). The ova are white and are surrounded by several layers of a clear capsule that is permeable for gas exchange. The capsule protects the embryo and is sticky, which presumably allows the female to lay the eggs on rocks in flow. It is hypothesized that *E. sosorum* and *E. waterlooensis* lay their eggs in the aquifer below the surface because only a few eggs have ever been found in the wild.

The eggs of both *E. sosorum* and *E. waterlooensis* hatch in 3-4 weeks. Hatchlings are about half an inch total length (TL, snout to tip of tail), often still with yolk sacs and limb buds. Juvenile *E.*

sosorum become sexually mature at about 11 months (43-50 mm TL), while *E. waterlooensis* become sexually mature at about 18-23 months (48-55 mm TL) (Chamberlain and O'Donnell 2003). In captivity, *E. sosorum* has been observed reproducing to an age of at least eleven years, and wild-caught *E. waterlooensis* in captivity have reproduced to an age of at least 12 years (City of Austin unpublished).

3.1.3 Evolutionary History, Ranges, and Habitats

Salamanders are amphibians, which generally require moist or wet habitats to survive (Duellman and Trueb 1994, Petranka 1998). All *Eurycea* species are members of the family Plethodontidae, an evolutionary group of lungless brook salamanders all associated with streams and surrounding riparian habitats (Petranka 1998). Most *Eurycea* have biphasic life cycles where aquatic juveniles metamorphose into semi-aquatic or terrestrial adults (Duellman and Trueb 1994, Petranka 1998), utilizing aquatic habitat for at least some portion of their life.

The Edwards Plateau region of central Texas contains a monophyletic group (an ancestor species and all of its descendent species), of solely aquatic, perennibranchiate ("always gilled") *Eurycea* salamander species (*Paedomolge* of Hillis *et al*. 2001, Chippindale *et al*. 2000, Wiens *et al*. 2003), which includes Barton Springs' *Eurycea*. There are numerous intermittent and perennial springs throughout the aquifer that harbor endemic epigean (surface) and subterranean *Eurycea* species (Sweet 1978, Chippindale *et al*. 1993, Chippindale *et al*. 2000, Hillis *et al*. 2001, Bendik 2006). Since the region is generally arid, these springs and spring-fed streams are the only sites where presence of water is reliable. In addition, Edwards Aquifer spring-fed streams ebb and flow with the level of the water table (Brune 1981); resident perennibranchiate *Eurycea* experience natural contractions and expansions of their aquatic habitat (Sweet 1982). These conditions together are thought to have influenced the evolution of life history of Edwards Aquifer *Eurycea*, including the loss of metamorphosis and consequent dependence on epigean and/or subterranean spring-fed streams throughout the life span (Sweet 1977, Sweet 1982, Chippindale *et al*. 2000).

The Barton Springs Salamander (*Eurycea sosorum*) and the Austin Blind Salamander (*E. waterlooensis*) are both members of the Edwards Aquifer *Eurycea* group and inhabit the Barton Springs complex (Chippindale *et al*. 1993, Hillis *et al*. 2001). The three perennial and single intermittent springs in which they reside are located within 400 to 800 yards (365 to 730 meters) of one another and associated with Barton Creek (Figure 1). Thus, these species have two of the smallest ranges of any vertebrate in the United States (Chippindale *et al*. 1993, Hillis *et al*. 2001). While the ranges of these species include the same springs, each generally occupies either epigean or subterranean microhabitats.

The Barton Springs Salamander, *Eurycea sosorum*, is endemic to the surface springs and streams of the Barton Springs complex (Chippindale *et al*. 1993, City of Austin 2005, City of Austin 2006, City of Austin 2007). These salamanders are found under cover in or near the substrate. While salamanders have been found in aquatic moss, algae, plants, and leaf litter, recent data suggest that the vast majority of salamanders are found in interstitial areas beneath rocks in flowing water (Appendix A). The interstitial spaces of substrate in flowing water are critical microhabitats of other aquatic *Eurycea* species (Randolph 1978, Tumlison *et al*. 1990, Barr and Babbitt 2002, Bonett and Chippindale 2006). Flowing water prevents accumulation of excess sediment, allowing these spaces to serve as protection from aquatic and terrestrial predators (Petranka 1998) and habitat for invertebrate prey. Water flow also provides constantly renewing dissolved oxygen in a karst groundwater system where oxygen concentration is naturally undersaturated (see section 3.2.3) and favors growth of periphytic algae that supports benthic invertebrate communities.

The Austin Blind Salamander, *Eurycea waterlooensis*, is predominantly a subterranean species (Hillis *et al*. 2001). These salamanders are rarely found in epigean habitats of Parthenia, Old Mill, and Eliza Spring, typically seen under conditions of average or higher discharge from Barton Springs. When seen, it is in habitat similar to that in which *E. sosorum* is found (Appendix A). It has not been observed in surface habitat of intermittent Upper Barton Spring. It has been suggested that occurrence of this species in surface habitat is "accidental" (Hillis *et al*. 2001), possibly related to surges in groundwater flow as has been posited for the Texas Blind Salamander (*Eurycea rathbuni*) of San Marcos Spring (Longely 1978). Based on this information, it is assumed that *E. waterlooensis* inhabits the subterranean environment associated with the Barton Springs complex, but the precise lateral and depth limits of its range are unknown.

There is ample evidence to support the importance of subterranean habitat to the Barton Springs Salamander (*E. sosorum*) from field observations and evidence from closely related species. Egg deposition apparently occurs in subterranean habitat, as may courtship and mating; none of these have been observed in wild populations. Field observations and data also indicate the use of subterranean habitat by this species when water at the surface recedes (City of Austin 2005, City of Austin 2006, City of Austin 2007, City of Austin unpublished data, Appendix A). Not only have these salamanders been observed following water when it recedes from Upper Barton Spring, they have been found repeatedly in surface habitat of this spring in as little as 1 week after water flow returns. This is consistent with the observations of Tumlinson and Cline (1997), who posited that the Oklahoma Salamander (*E. tynerensis*), a perennibranchiate species that inhabits karst springs of Oklahoma, used subterranean corridors to move between bedrock-dominated springs and streams, especially when surface habitats were dry. Subterranean conduits can also serve as migration pathways among sites for the Austin Blind (*E. waterlooensis*) and the Barton Springs Salamander (*E. sosorum*). The lack of significant genetic divergence among populations of the Barton Springs Salamander (Bendik 2006) indicates that there has been enough gene flow among populations to retain a common pool of genetic variation. With the fragmentation of surface habitats in the last 100 years, subterranean migration is presently the only avenue for genetic exchange among populations. Although the extent and conditions of subterranean habitat utilization by the Barton Springs Salamander are imperfectly understood, it may be an important habitat for survival, reproduction, and migration.

Since *E. sosorum* apparently uses subterranean habitat and *E. waterlooensis* is occasionally found in epigean habitat, hybridization is possible. Molecular data indicate there has been some gene flow between species; mitochondrial DNA sequences from two of 66 wild-caught *E. sosorum* were similar to *E. waterlooensis* sequences (Chippindale 2010). There are no data indicating the presence of first generation hybrids in the wild, and most wild *E. sosorum* and *E. waterlooensis* do not exhibit obvious intermediate morphologies; each has morphological and behavioral characteristics that appear to be adaptations to their respective microhabitats (City of Austin photographic data, L. Dries personal observations 2004-2010).

The morphological, behavioral, and genetic differences between the two species suggest that pre- or post-zygotic reproductive isolating mechanisms are present (Mayr 1963, Paterson 1985, Butlin 1989, Larson 1989). In addition, interspecific predation and cannibalism in captive Barton Springs' *Eurycea* (L. Dries, D.A. Chamberlain personal observations) and overlap in diet composition (see below, Chippindale *et al*. 1993, Hillis *et al*. 2001) suggest the two species compete for resources. This suggests that selection favoring ecological niche-partitioning between epigean and subterranean habitats may also reduce the opportunity for hybridization (Paterson 1985, Dobzhansky 1970) and the risk of extinction of either species by competitive exclusion (MacArthur 1969). All of this would contribute to microhabitat specialization by both species (Pianka 1983).

The presence of two Edwards Aquifer *Eurycea* species in different microhabitats of the same large, perennial spring system is not unique to Barton Springs. There are two similar spring systems south of the Colorado River that harbor *Eurycea* species pairs, San Marcos and Comal Springs. Each of these also contains an epigean and a subterranean species (Appendix A Figure 2). Epigean *E*. *nana* (San Marcos Salamander) and *E*. *neotenes* (Texas Salamander) are syntopic with subterranean *E*. *rathbuni* (Texas Blind Salamander) and undescribed *Eurycea* sp. (potentially *E*. *rathbuni*; Chippindale 2010), respectively. The subterranean species are genetically distinct from their surface counterparts, and form a separate evolutionary group (Chippindale *et al*. 2000, Hillis *et al*. 2001, Wiens *et al*. 2003, Bendik 2006, Appendix A Dries Figure 2).

Other predominantly epigean central Texas *Eurycea* species that inhabit smaller, intermittent springs have been encountered in caves and other subterranean habitat (Chippindale *et al*. 2000, Bendik 2006). *Eurycea tonkawae*, for example, depends on subterranean habitat to persist when surface spring flow ceases, which occurs more frequently in smaller springs than larger downstream perennial springs. Several headwater springs were dry for months during the drought of 2008 – 2009, yet, when flow returned to the springs after the drought, so did *E*. *tonkawae* (City of Austin, unpublished data). There are also several populations of *E*. *tonkawae* that appear to inhabit caves exclusively and recent evidence shows that they are genetically similar to surface populations (P.T. Chippindale, personal communication). This is not an uncommon occurrence among central Texas *Eurycea* inhabiting intermittent spring sites, as numerous putatively "epigean forms", such as *E*. *latitans* and *E*. *pterophila,* inhabit caves and subterranean waters as well as surface springs (Sweet 1978, Sweet 1984, Bendik 2006).

3.2 Habitat Description

3.2.1 Epigean (Surface) Habitat

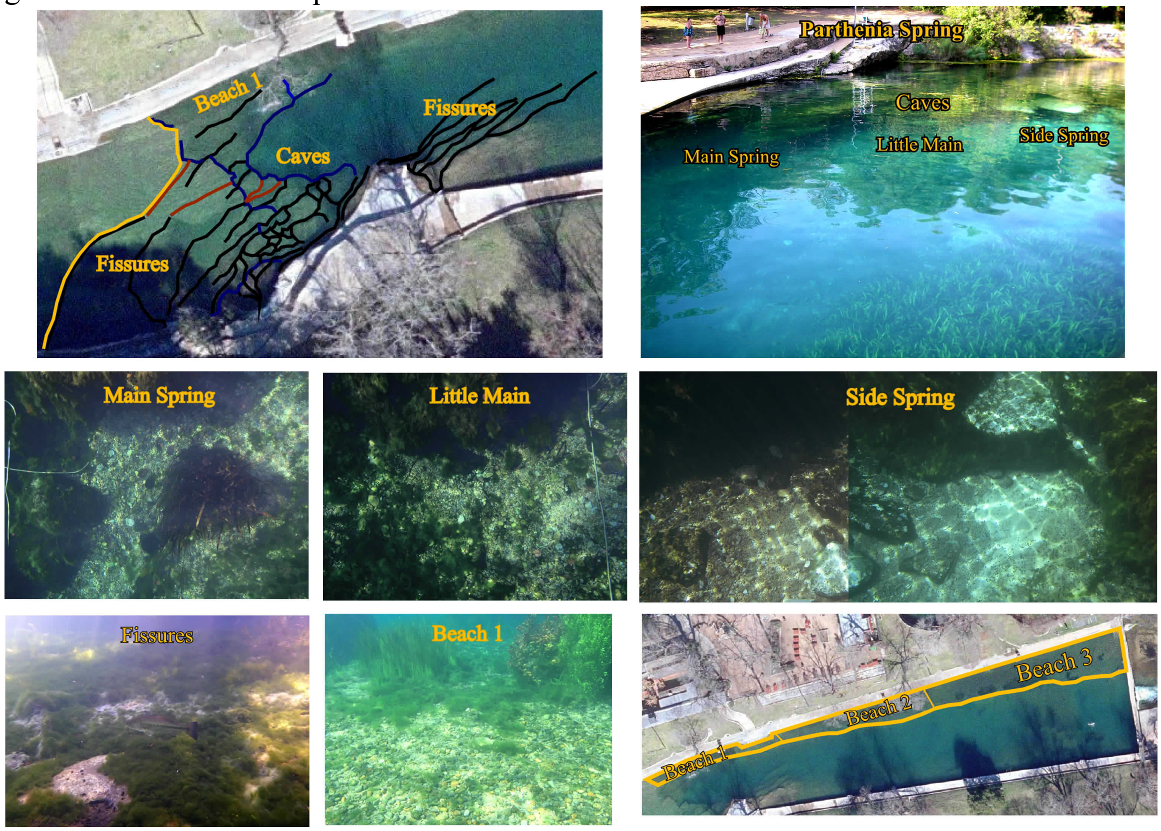
Epigean habitat of *E*. *sosorum* and *E*. *waterlooensis* is located in perennial Eliza Spring, Old Mill Spring, and Parthenia Spring. In general, epigean habitat of Barton Springs' *Eurycea* consists of rocky substrates and mossy limestone faces where groundwater is flowing from the aquifer. *Eurycea sosorum* habitat also includes intermittent Upper Barton Spring. Historically, surface streams and Barton Creek provided connections among epigean habitats of each spring site, creating an un-fragmented, continuous habitat (see Appendix A Dries 2012). In the last 150 years, construction of dams and amphitheaters has altered the natural topography and geomorphology, resulting in partial or complete isolation of surface habitats of all four springs. The surface habitats within each spring site as they exist today are described below followed by a description of subterranean habitat of the Barton Springs complex.

3.2.1.1 Parthenia Spring/Barton Springs Pool

Parthenia Spring is the largest spring; its flow comprises approximately 90% of total discharge from the Barton Springs complex. This spring is located between the upstream and downstream dams spanning Barton Creek that create Barton Springs Pool. Within Barton Springs Pool, the natural banks of the creek have been converted to concrete walls, except for the rimrock outcrop of the fault system along the southern bank. Parthenia Spring is located in this outcrop (Figure 12).

Protected salamander habitat within Barton Springs Pool consists of one large, contiguous area around Parthenia Spring and extending along the north wall of the Pool to the downstream dam (Figure 1). Parthenia Spring spans the width of the Pool channel and consists of a set of hydrologically connected openings from which groundwater flows directly from the aquifer to the surface. There is a continuous cave along the base of a vertical face, and numerous fissures scattered across 6850 ft^2 of higher-elevation bedrock, and extending 150 ft both upstream and downstream of the cave (Chippindale *et al*. 1993).

Figure 12. Photographs of Parthenia Spring and habitat of the cave mouths and fissures where groundwater exits the aquifer.



Topography and composition of the channel substrate in front of the cave is bedrock sloping downward southeasterly from 35 to 45 feet downstream of the cave mouth, where it levels out (SAM 2009). The bedrock in this area has an overlying layer of gravel, cobble, and boulder. Bedrock that contains fissures gently slopes northwesterly both upstream and downstream of the cave and has little or no overlying rocks (Figure 12). Small gravel and cobble are present in the cracks and crevices. The area of protected habitat along the north wall is known as the Beach. It originates from an upstream fissure running perpendicular to the channel extending to the downstream dam (Figure 12) and is bounded by the north wall of the Pool and a submerged concrete pipe to the south. It is a flat, man-made shelf created by successive excavations of the natural creek bank and possibly part of the adjacent creek channel. The most recent excavation of the Beach occurred in 2000. The substrate consists of a single layer of loose gravel and cobble overlying an impervious layer of compacted caliche. There are no visible or known fissures or points of groundwater discharge in this substrate. Water depth of Parthenia Spring varies from 2 to 18 feet during normal Pool operating conditions. The deepest areas are associated with the cave, while in the fissures area water depth varies from 2 to 6 feet. During drawdowns of the water elevation in the Pool for cleaning or floods, water depth varies from 12 to 0 feet; although water may continue to flow in the fissures, some of the intervening bedrock is above the water surface.

Since groundwater flows out through the cave and fissures of Parthenia Spring, these features and the areas immediately downstream have the fastest water flow at the substrate (City of

Austin unpublished data). In contrast, water velocity decreases with increasing distance from Parthenia Spring. The upstream area of the Beach is nearest to the springs and has the fastest water flow in the Beach (Colucci 2009). The rest of the Beach has lower flow velocity; under low Barton Springs' discharge (25 to 30 ft^3/s.) velocity at the substrate in this area is at or near zero ft/s (Colucci 2009) (see section 6.0 Conservation Plan for proposal to redraw salamander habitat based on this information). When coupled with the artificially deep water, the flow regime in Barton Springs Pool resembles a pond rather than a stream, with predictable changes in biotic community composition and sediment transport dynamics (City of Austin 2005, City of Austin 2006, City of Austin 2007, City of Austin unpublished data).

The benthic habitat associated with Parthenia Spring and the adjacent Beach area generally consists of gravel, cobble, and boulders covered with periphyton. Loose, nuisance algae are not abundant except during droughts. The sedimentary layer varies temporally and geographically, depth ranges from 0 to 14 inches (mean sediment depth from 2004 to 2011 was 1.67 inches) and percent of substrate covered by sediment ranges from 27 to 100%. Moss (*Amblystegium riparum*) is abundant on vertical faces of the cave, and horizontal and vertical surfaces of the fissures. There are scattered patches of native aquatic macrophytes (Water Celery, Water Stargrass, Delta Arrowhead, Water Primrose, Carolina Fanwort, Coon's Tail, Spikerush, Water Hyssop, and Upright Burrhead; see Section 2.4). Macrophyte abundance in the fissures varies as plants are dislodged during floods and periods of high recreational use.

Habitat in the downstream portions of the Beach consists of a mixed rock substrate, 90 to 100% of which is covered by sediment that exceeds 1 to 2 inches deep. Consequently, loose, nuisance algae are abundant, while periphytic algae are rare (Colucci 2009) and concentrated in areas closest to Parthenia Spring (City of Austin unpublished data). Large, dense stands of Delta Arrowhead (*Sagittaria platyphylla*, *S. graminea*) and Water Stargrass (*Heteranthera dubia*) are found in this area, as are patches of Water Primrose (*Ludwigia repens*), and Coon's Tail (*Ceratophyllum dermersum*).

3.2.1.2 Eliza Spring

Eliza Spring is a small spring pool (800 ft^2) confined within a concrete amphitheater with outflow directed into a buried 24-inch corrugated metal and reinforced concrete pipe, which discharges into the bypass culvert that carries Barton Creek water around Barton Springs Pool. The natural surface stream is no longer present. The natural surface habitat of the spring pool is covered by a 6 to 8-inch thick concrete floor. The elevation of rocky substrate beneath the concrete floor is 1 to 2 feet lower than the top of the floor. The elevation and topography of limestone bedrock and spring openings are unknown, although a large rock outcrop is visible in photographs taken before the concrete floor was constructed. Groundwater enters surface habitat through a series of seven, 8-inch diameter holes in the concrete floor, and 15 rectangular openings in the riser from the floor to the first amphitheater bench (Figure 5).

Eliza Spring has the strongest hydrological connection with Parthenia Spring. Changes in water elevation in Barton Springs Pool are accompanied by similar changes in Eliza Spring. The cave of Parthenia Spring is roughly 15 feet below the surface substrate of Eliza Spring (SAM 2009). When water depth in Barton Spring Pool decreases, hydraulic pressure exerted by surface water against the spring openings also decreases according to Bernoulli's principle **(**Prasuhn 1938).

Consequently, hydraulic head pressure in Eliza Spring is insufficient to push water up through the concrete floor into surface habitat. This redirection of groundwater occurs until Barton Springs' discharge exceeds 75 ft^3/s (City of Austin unpublished data), when presumably hydraulic head pressure is high enough that re-direction does not occur or is undetectable.

Surface habitat in the spring pool is maintained as a layer of gravel and cobble, one to two rocks deep lying on top of the concrete floor. Since 2003, the water depth has been maintained at 1 to 2 feet except during isolated events (*e.g*., storms, Barton Springs Pool drawdowns). Both of these strategies help minimize sediment accumulation by increasing flow velocity at any given discharge and reducing obstructions that capture suspended materials. Rocky substrate beneath the concrete floor is generally sediment-laden gravel and cobble.

A variety of native aquatic plant species have been reintroduced into the spring since 1998. The most successful species have been Water Primrose (*Ludwigia repens*), Water Hyssop (*Bacopa monnieri*), and Water Celery (*Vallisneria americana*). Abundance of macrophytes is managed, although it also varies with abundance of crayfish. Leaf litter contributing to the aquatic ecosystem is composed primarily of one cottonwood (*Populus deltoids*), one young American elm (*Ulmus americana*), and mustang grape (*Vitis mustangensis*) leaves. The cottonwood provides the most canopy cover for Eliza Spring, while a large American elm provided some cover. Both trees were deemed "over-mature" with significant trunk rot (Davey Resource Group 2009). Half of the cottonwood has been removed, with the other half to be removed in the near future. The large American elm was removed in spring of 2012 because it was deemed an imminent public safety risk (Davey Resource Group 2009, Gardner 2009). A young American elm will begin to provide some shade over the spring pool in the next few years. The mustang grape vines growing along the fence and walls of the Eliza Spring amphitheater provide a significant portion of leaf litter, but minimal canopy cover. Elm and willow (*Salix nigra*) saplings are growing through the walls and benches of the amphitheater, shading small parts of the spring pool. With further growth, these saplings may damage the stability and longevity of historic amphitheater.

3.2.1.3 Old Mill Spring

Old Mill Spring is a spring pool confined to a circular stonework wall, and a reconstructed overland stream flowing from the pool to Barton Creek downstream of Barton Springs Pool (Figure 5). The walls were constructed atop soil/fill with terraces of limestone and concrete leading into the center of the spring pool. Substrate is composed of gravel, cobble, and a few boulders, with large patches of compacted sand and sediment. The thickness of this layer of rocky substrate is unknown. Groundwater percolates up through the substrate in numerous locations. Water flows from the spring pool to the stream through a concrete pipe and under the stonework wall. The overland stream exits from the northeastern side of the spring pool and extends approximately 80 feet to a small five-foot man-made waterfall where the spring water cascades into Barton Creek. The existing channel flows almost straight northwest, meeting Barton Creek at a 90˚ angle. The stream channel width varies from 2 to 5 feet. Substrate is composed of gravel, cobble, and a few boulders over compacted clay.

Water depth in the spring pool varies geographically, from 2 inches around the perimeter to about 5 feet in the center. Water elevation in the spring pool varies temporally with discharge.

Elevation decreases approximately 1 foot when combined Barton Springs discharge is 20 ft^3/s or less. Water depth in the stream varies geographically and temporally from 0 to 2 feet. The stream is typically dry when site-specific discharge is 0.1 ft^3/s or less, which also corresponds with a Barton Springs' discharge of 20 ft^3/s or less. Hydraulic connection of this spring with Parthenia Spring is weaker than Eliza Spring. Drawdowns of Barton Springs Pool under permitted conditions do not affect water depth in this spring unless Barton Springs' discharge is at or below 20 ft^3/s.

While loose, floating aquatic moss (*Amblystegium riparium*) was more abundant in the spring pool in the 1990s, it has been less abundant since habitat reconstruction began in 2005. Scattered patches of moss are attached to rocks and more abundant during average to high flow conditions, as are patches of red algae, *Batrachaspermum* sp*.* There are transient blooms of *Cladophora* sp., *Spryogyra* sp*.,* and cyanobacteria, typically more pronounced during low discharge. Periphyton is generally abundant in the stream at all times, and abundant in the spring pool during the favorable conditions of faster water flow and low sediment cover. Repeated reintroduction of native aquatic macrophytes has resulted in establishment of Water Primrose (*Ludwigia repens*), American Water-willow (*Justicia americana*), and Water Celery (*Vallisneria Americana*) in the spring pool.

Surrounding the spring pool are several mature pecans (*Carya illinoensis*), at least one mature and several young American elms (*Ulmus Americana*), two mature cottonwoods (*Populus deltoids*), and several young hackberry trees. These trees provide most of the leaf litter that enters the spring pool. The cottonwoods, pecans, and elms provide leaf litter to the stream with additional input from two young sycamores (*Plantanus occidentalis*). Many of the mature trees are recommended for removal due to decay of the trunk and poor root systems (Davey Resource Group 2009). Future long-term canopy cover depends on replacement (natural or planted) of removed trees.

3.1.2.4 Upper Barton Spring

Upper Barton Spring is the only intermittent spring associated with the Barton Springs Complex and is located in the southeast bank of Barton Creek (Figure 5). When the combined discharge of Barton Springs is less than 40 ft^3/s, Upper Barton Spring goes dry. This is the only spring that has not been altered significantly and still retains a natural appearance and function. It is located along a walking trail that is frequented by humans and domestic dogs that sometimes make minor alterations to the spring for wading.

The spring consists of one primary upwelling emerging near the base of a hackberry tree (*Celtis* sp.) on the northwest side of the spring and one minor upwelling emerging beneath a boulder on the southeast edge of the spring. Substrate at the primary upwelling consists of loose gravel whereas the rest of the habitat is loose gravel and cobble over gravel and cobble embedded in compacted clay. The water depth in the spring ranges from an inch to almost 2 feet deep.

Spring water exits the spring pool via three outflows: upstream (relative to Barton Creek flow), midstream which splits into a path flowing perpendicular into Barton Creek and a path flowing parallel to the creek, and downstream (with respect to Barton Creek flow) which cascades over boulders and turns 90˚ to flow directly into Barton Creek. When Barton Creek is under high flow conditions, Upper Barton Spring becomes submerged in Barton Creek and all spring flow follows the flow direction of the creek.

There are no established aquatic or wetland macrophytes in Upper Barton Spring, but Spikerush (*Eleocharis* sp.) and Pennywort (*Hydrocotyle umbellate*) have been observed within the spring in the past. Algae are often limited to periphyton and tightly attached algae, except in areas where water becomes stagnant. Leaf litter is composed of primarily of hackberry, sycamore, and elm leaves. Until a recent invasive species removal project, *Ligustrum* sp. was contributing a significant amount of leaf litter to Upper Barton Spring. Poison ivy (*Toxicodendron radicans*) and Virginia creeper (*Parthenocissus quinquefolia*) are also established around the spring and provide some leaf litter to the aquatic ecosystem.

3.2.2 Subterranean Habitat

Karst landscapes are formed by dissolution of rock by weakly acidic solutions and contain features such as sinkholes, springs, cavities, and conduits (Culver and Pipan 2009). The subterranean habitat of karst landscapes consists of openings and cavities in solid rock, larger than a few millimeters in diameter, and containing areas of complete darkness ("caves" as defined by Culver and Pipan 2009). Perennial and intermittent springs of karst aquifers generally arise from permanently water-filled zones (phreatic and epiphreatic, Culver and Pipan 2009). Although the exact geometry of the karst landscape beneath Barton Springs is poorly known, the geologic structure of the aquifer and the nature of recharge processes provide some insight. Barton Springs emanates from a fault zone of vertically displaced bedding planes with a few fractures. The majority of recharge occurs through sinking streams and sinkholes and water flows quickly through subterranean habitat to Barton Springs (see section 2.3). This suggests that the subterranean environment of the Barton Springs Zone of the Edwards Aquifer is a branched set of cavities and conduits (Palmer 2005) progressively converging into the Barton Springs complex (*i.e*., similar to the progression from small headwaters to large rivers). Since Parthenia, Eliza, and Old Mill are perennial springs, they are presumably connected to deeper subterranean flow paths of the permanently saturated (phreatic) zone. Intermittent Upper Barton Spring is at a higher elevation than the other springs and presumably is fed by a shallower flow path. The reappearance of *E. sosorum* in Upper Barton Spring after dry periods indicates that there are connections to deeper, water-filled cavities below the water table.

Subterranean habitat within the Barton Springs complex likely consists of a system of interconnected water-filled cavities and conduits with close hydrological connections to the surface springs (Palmer 2005). Among spring sites, inferred groundwater flow paths and water chemistry vary, particularly under low discharge (Hauwert *et al*. 2004) (but see section 3.2.3 below).

The defining feature of subterranean environments is the lack of sunlight, which makes photosynthetic activity impossible and thereby influences the entire ecosystem (Culver and Pipan 2009). Algae, plants, and some bacteria cannot survive without sunlight, depriving the ecosystem of the primary production, which limits abundance and diversity of subsurface biotic communities. These communities rely on transport of organic carbon from surface waters into the subterranean habitat. Thus, the interface between subterranean and surface habitats both in upland recharge features and within the Barton Springs complex is critical for sustaining subterranean and spring-dwelling flora and fauna.

3.2.3 Water Chemistry and Quality

Karst aquifers are characterized by the presence of conduits in the bedrock that allow rapid transport of water. Subterranean and spring water chemistry of these systems is dominated by the dissolution of the host rock (most often carbonate bedrock) and surface water recharge. As recharging surface water travels underground through the aquifer, its chemistry changes (Culver and Pipan 2009). Acidity of rainwater is buffered by reaction with limestone, resulting in neutral or nearly neutral pH in groundwater at Barton Springs. In some systems, chemistry of groundwater at exit springs is more stable than upstream subterranean water because it has had more time underground to equilibrate with surrounding limestone (Culver and Pipan 2009). Therefore, gathering baseline data is imperative to understanding the chemical and physical changes in the aquifer waters. The water chemistry of Barton Springs has been the subject of previous investigation (Mahler *et al*. 2006, Herrington and Hiers 2010, Mahler et al. 2011). Regular monitoring of groundwater at Barton Springs is conducted as part of compliance with the City's Texas Pollutant Discharge Elimination System (TPDES) Municipal Separate Stormwater System (MS4) permit and is included in the conservation program of this Plan. What follow is a summary of the data available, focusing on characteristics of major biological relevance.

3.2.3.1 Conventional Parameters

Water temperature in Barton Springs is within a narrow, relatively cool range due to equilibration of groundwater temperatures with surrounding rock along the underground flow paths leading to the springs. The average water temperature of Barton Springs is approximately 21˚C (70˚F), with a small range of variation under normal conditions (Table 6; Mahler *et al*. 2006, Gillespie 2011). The greatest variation in temperature is observed in Old Mill Spring, which is likely caused by the extremely diminished discharge of cool groundwater into surface habitat of the spring pool during drought. In general, regression analyses of available data indicate statistically significant increasing trends in water temperature for Parthenia and Upper Barton springs, with no discernible trends for Old Mill or Eliza Springs (Herrington and Hiers 2010).

Table 6. Average temperature from January 2004 through October 2011 reported in degrees Celsius. Parthenia data are based on monthly averages at USGS site #08155500. Data were collected monthly in Eliza, Old Mill, and Upper Barton springs by the City.

Spring Site	Mean ± SD	Minimum	Maximum	N
Parthenia	21.19 ± 0.66	18.63	22.18	94
Eliza	21.07 ± 0.71	18.4	22.1	72
Old Mill	20.94 ± 2.30	10.8	26.2	66
Upper Barton	21.14 ± 0.55	19.2	22.3	43

Conductivity varies at the springs, with increasing conductivity as discharge decreases (Johns 2006) and decreasing conductivity with storm events. Parthenia, Eliza, and Upper Barton springs average approximately 600 µS/cm, while Old Mill Spring averages approximately 700 µS/cm, likely due to the increased influence of the saline zone on this particular flow path (Johns

2006, Mahler *et al*. 2006). The average pH of groundwater at Parthenia Spring is 7.1, with limited variation as a result of carbonate dissolution buffering water acidity (range: 6.8 - 7.3; Mahler *et al*. 2006).

3.2.3.2 Dissolved gasses

In general, dissolved oxygen concentration (DO) in all springs decreases as discharge from the Barton Springs complex decreases (Turner 2009, Mahler *et al*. 2011). Dissolved oxygen concentration also varies among springs. Since dissolved oxygen solubility is higher at lower water temperatures, its concentration is also influenced by water temperature. Average DO is highest in Upper Barton Springs, followed by Parthenia, Eliza, and Old Mill Spring (Table 7). Parthenia Spring DO varies less than other springs. Lower DO concentrations occur during droughts (Appendix A). Lowest DO values among the perennial springs are observed in Eliza and Old Mill springs. During droughts, groundwater discharge at each of these sites declines to less than 2 ft^3/s and 1 ft^3/s, respectively (see section 5.3.2). Upper Barton Spring ceases to flow completely and surface habitat dries when Barton Springs' discharge drops below 40 ft^3/s. Thus, there are no regular measurements of DO at Upper Barton Spring during droughts. The lowest concentration recorded at this site is 1.6 mg/L, which was measured in a small pool at the spring mouth just prior to complete disappearance of water.

Distribution of dissolved oxygen concentrations in subterranean habitat is poorly known. A preliminary study documented DO concentrations in subterranean groundwater of the confined aquifer zone feeding Barton Springs during low Barton Springs discharge (26 – 32 ft^3/s) (Lazo-Herencia *et al*. 2011). Groundwater sampled from approximately 1.5 miles upstream of Barton Springs contained 3.6 mg/L of dissolved oxygen, while groundwater from 3 to 6 miles upstream contained from 0.2 to 3.2 mg/L. During this period, dissolved oxygen in Parthenia and Eliza Spring was 4.2 mg/L. These results are consistent with the study of Winograd and Robertson (1982) showing that dissolved oxygen concentrations in confined subterranean ground waters of carbonate aquifers were generally lower than concentrations in recharge and discharge surface springs. Mean dissolved oxygen in ground waters of a highly fractured carbonate aquifer in Nevada was approximately 2 mg/L, while mean concentrations of upstream discharge springs was approximately 3 mg/L (Winograd and Robertson 1982). In upstream recharge springs, dissolved oxygen varied from 4.5 to 8.5 mg/L (Winograd and Robertson 1982). It also decreases with distance from recharge features (Winograd and Robertson 1982) and with depth of aquifer (White et al. 1990). Ground water from the unconfined aquifer area within 3 miles of Barton Springs contained more dissolved oxygen (5.5 to 6.6 mg/L). While subterranean flow paths in this area lead predominantly to Cold Spring (Hauwert *et al*. 2004) rather than the Barton Springs complex, more groundwater from the unconfined zone may flow to Barton Springs during drought (Lazo-Herencia *et al*. 2011). Dissolved oxygen concentrations in surface habitat of Eliza Spring are slightly higher than those from immediately below the concrete floor, and in general, there is more dissolved oxygen in the outflow stream of Old Mill than in the spring pool (City of Austin unpublished data). All of this information suggests that during drought, dissolved oxygen concentrations in surface habitats of the Barton Springs complex are likely to be higher than in subterranean habitat. These higher concentrations may be a result of mixing of ground water from unconfined and confined zones and entrainment of additional oxygen after ground water exits into surface habitats with flowing water.

Table 7. Average dissolved oxygen (mg/L) from January 2004 through October 2011. Parthenia data is monthly averages at USGS site #08155500. Data were collected monthly in Eliza, Old Mill, and Upper Barton springs by the City.

Spring Site	**Mean ± SD**	**Minimum**	**Maximum**	**N**
Parthenia	6.02 ± 0.83	4.5	7.55	82
Eliza	5.55 ± 1.18	3.61	8.83	70
Old Mill	5.37 ± 1.66	1.04	9.07	67
Upper Barton	7.21 ± 1.16	4.75	12.6	40

Dissolved carbon dioxide concentrations average around 50 mg/L for Barton Springs, with the highest average concentration (57 mg/L) measured at Upper Barton Spring (Table 8). Concentrations and saturation of dissolved oxygen, carbon dioxide, and nitrogen have been monitored since 2002, demonstrating consistent undersaturation of oxygen, high supersaturation of carbon dioxide, and low supersaturation of nitrogen in all springs of the complex (City of Austin unpublished data). Under-saturation of oxygen and supersaturation of carbon dioxide and nitrogen are natural outcomes of geochemical and biological processes in karst aquifers with organic inputs from the surface (Wetzel 2001, Kalff 2002, Palmer 2005, Culver and Pipan 2009). Saturation of all three gasses can vary with the gas composition and temperature of recharging rainfall, and rate of biological and chemical reactions in the aquifer.

Table 8. Average dissolved carbon dioxide from January 2004 through October 2011 reported in mg/L. All data were collected monthly by the City.

Spring Site	**Mean ± SD**	**Minimum**	**Maximum**	**N**
Parthenia	51 ± 12.0	35	93	49
Eliza	52 ± 8.8	38	81	69
Old Mill	47 ± 14.6	10	87	65
Upper Barton	57 ± 14.4	36	110	40

3.2.3.3 Major ions

Concentrations of ions vary slightly among the springs of the Barton Springs complex (Mahler *et al*. 2006, 2011, Herrington *et al*. 2005). The highest concentrations were in water from Old Mill Spring, reflecting the increased influence of the saline zone, while the lowest concentrations were from Upper Barton Spring resulting from a different groundwater flow path (Mahler *et al*. 2006). Eliza Spring and Parthenia Spring are similar, with intermediate concentrations of ions.

Total suspended solids can carry nutrients bound to suspended particles (Masters 1991), which could increase aerobic microbial processing and contribute to reductions in dissolved oxygen (Wetzel 2001). When suspended solids settle, sediment accumulation in and on the substrate increases (Geismar 2005), reducing the amount of interstitial space that can be inhabited by salamanders and other benthic fauna and flora. Limited data show that concentrations of suspended solids are greatest in Old Mill Spring and substantially less in Parthenia and Eliza springs (Table 9). Restoring the natural flow regime of Old Mill Spring may help reduce settling of suspended sediments by reducing water residence time.

Table 9. Average total suspended solids from all available data (July 1995 through November 2011) reported in mg/L. Data were collected by the City in conjunction with bi-weekly TPDES sampling. No data have been collected at Upper Barton Spring.

Spring Site	Mean ± SD	Minimum	Maximum	N
Parthenia	1.56 ± 1.34	0.09	11	211
Eliza	1.36 ± 0.98	0.5	2.6	5
Old Mill	4.20 ± 6.40	0.8	15.6	5

3.2.3.4 Storm flow

Groundwater chemistry of the Barton Springs complex during base (non-storm) flow differs from that during storm flow (Mahler *et al*. 2006, Gillespie 2011, Mahler *et al*. 2011). Due to the rapid flow of water through karst aquifers, storm flow can result in pulses of altered water chemistry (Mahler *et al*. 2006). Mahler and others (2006) found that during average discharge conditions, storm pulses peaked at 2 days for Parthenia, Eliza and Old Mill Spring and 1 day for Upper Barton Spring. Storm flow generally dilutes major ions in groundwater (Mahler *et al*. 2011), with concentrations returning to pre-storm concentrations after about 6 days (Mahler *et al*. 2006). Historic data show that storm flow diluted nitrate concentrations in Parthenia Spring, but recent data show increases in nitrate concentrations of surface waters in the recharge zone (Mahler *et al*. 2011) and in Barton Springs (Herrington and Hiers 2010).

Direct exposure of Barton Springs' surface habitats to storm water is rare and is derived from local runoff or basin-wide runoff leading to flood flows in Barton Creek. Storm water runoff is controlled and diverted around Barton Springs with engineered structures in the surrounding topography. Storm water carried by floods flows through Parthenia and Upper Barton springs when Barton Creek discharge exceeds approximately 500 ft^3/s. Water must overtop the upstream dam of Barton Springs Pool to reach Parthenia Spring. Eliza and Old Mill springs are isolated from most floods by their locations outside the channel of Barton Creek.

The City (Appendix B) investigated potential changes in water quality in Barton Springs Pool if flow from Barton Creek through Barton Springs Pool were restored. Using the volume of water contained in Barton Springs Pool and average turnover time, the study estimated dilution of creek water constituents and resultant concentrations in Barton Springs. The results indicate that the potential influence of creek water on water quality in Parthenia Spring during baseflow would be undetectable. During floods, storm water inundates the Pool for short periods of time, during which water quality decreases (increased metals, ammonia, orthophosphorus, nitrates, pH, and TSS) as storm water overwhelms groundwater. However, this is a transient effect that is mitigated by opening the gates in the dam as flooding begins. This reduces the storage capacity of the Pool and increases flow velocities, enhancing transit of materials and dilution with groundwater and minimizing water quality degradation from floods.

3.3 Status of *Eurycea sosorum*

Assessment of the health and size of wild populations of *E. sosorum* is based on City data collected from all four springs, perennial Parthenia (within Barton Springs Pool), Eliza, and Old Mill Spring, and intermittent Upper Barton Spring (Appendix A, City of Austin 2005, City of Austin 2006, City of Austin 2007, City of Austin 2008, City of Austin 2009, City of Austin 2010, City of Austin 2011). Salamander abundance and density data from 1993 to the present are used as indices of population size, which includes data prior to federal listing in 1997. The status of *E. sosorum* is based on information gleaned from all four populations, even though ecological conditions and salamander population sizes and dynamics vary among sites due to both natural and anthropogenic factors. Much of the information comes from data collected in Eliza and Parthenia Spring where salamander abundances were large enough to detect some demographic patterns. This approach assumes that the influence of environmental conditions on salamander populations is similar among sites, but may vary in magnitude. (Detailed site-specific analyses are presented in Appendix A.)

3.3.1 Population Size and Dynamics

Inferences of population size and dynamics are based on censuses of salamander abundance in each spring site conducted roughly every month since the early 1990s (Parthenia – 1993, Eliza and Old Mill – 1995, Upper Barton – 1997). (Details of data collection and analyses are provided in Appendix A.) Mean observed surface population size and range for the period of record for each spring site are calculated (Table 10). Site-specific *Eurycea sosorum* abundance has varied from 0 to 1234 salamanders, with densities ranging from 0 to 1.5 per ft^2. Presently, Eliza Spring harbors the largest population of salamanders, followed by Parthenia, Upper Barton, and Old Mill Spring. The highest abundance of salamanders in the perennial spring sites occurred from April to June of 2008. The highest abundance in Upper Barton Springs occurred in April of 2010. Salamander abundances in Old Mill and Upper Barton Spring are typically low with similar mean densities. Juveniles have been found in all spring sites, indicating reproduction occurs in all sites, with evidence of recruitment in Eliza and Parthenia Spring (Appendix A Dries 2012).

Table 10. Mean, standard deviation (SD), and standard error (se) of *E. sosorum* salamander abundance and density in each spring site for the period of record are listed below. Minimum (Min.), maximum (Max.), and range of annual sum of salamander abundance, and number of surveys (N) are also listed.

	Abundance (#)						**Density (#/ft^2)**				
	Mean	SD	se	Min-Max	N	Sum	Mean	SD	se	Min-Max	N
Eliza (1995-2011)	190.5	255.4	20.6	0-1234	154	16-8441	0.35	0.34	0.030	0-1.54	103
Parthenia (1993-2011)	44.5	59.3	4.5	1-447	171	75-1598	0.03	0.03	0.002	0.0-0.18	154
Old Mill (1998-2011)	15.4	19.7	1.7	0-97	134	7-385	0.02	0.02	0.002	0-0.09	134
Upper Barton (1997-2011)	8.0	12.9	1.3	0-100	92	0-309	0.02	0.02	0.002	0-0.15	92
All Sites	17.7	14.3	1.5	0-60	97	91-489	0.03	0.03	0.003	0-0.09	89

Before HCP											
All Sites After HCP	83.7	171.9	8.1	0-1234	454	206-10380	0.11	0.23	0.010	0-1.54	394
All Sites Combined All Years	72.1	158.1	6.4	0-1234	551	39734	0.09	0.21	0.009	0-1.54	483

Analysis of temporal patterns of change in *E. sosorum* abundance in Eliza and Parthenia springs using multivariate auto-regressive state-space (MARSS) models do not indicate any significant increasing or decreasing trends in population size of salamanders greater than 1 inch TL (young adults and adults combined) from 2004 to 2011 (Appendix A Bendik and Turner 2011). Eliza Spring has higher mean adult population size and lower variability. There is evidence of density-dependent adult population growth in both sites, although the relationship is stronger in Eliza Spring. The lack of significant directional trends in population size coupled with density dependence suggests that adult salamander populations in the Eliza and Parthenia Spring have fluctuated around equilibrium sizes from 2004 to 2011. Differences in mean population size and variability suggest that the equilibrium values may not be the same and that the Eliza Spring adult population may be more robust to fluctuations than the population of Parthenia Spring.

Lack of a decreasing trend in population size in these two sites is encouraging and suggests these populations have the potential to persist. However, these results should be interpreted with caution. The analyses also did not assess temporal patterns in the populations of juveniles or young adults. Bendik and Turner (2011, Appendix A) purposely excluded data collected during habitat reconstruction of Eliza Spring in 2003 in order facilitate comparison with Parthenia Spring. Finally, although the assessed time series encompassed 7 years of monitoring data, they only include 61 and 71 data points for Parthenia and Eliza Spring, respectively. Such a short time period may not be adequate for assessing the long-term viability of this species.

3.3.2 Environmental Factors Influencing Salamander Abundance

The ultimate driver of the quality of the aquatic atmosphere in surface habitat of the Barton Springs complex is flow regime. Flow regime is generally shaped by channel topography, including dams and other impoundments, and aquifer discharge. These factors are major determinants of temporal and geographic variation in current velocity distribution, turbulence, and water residence time, all of which influence particle transport, and concentration of dissolved or suspended materials (Leopold *et al*. 1992, Lampert and Sommer 1997, Spellman and Drinan 2001, Wetzl 2001, Kalff 2002). Flow regime of surface water also interacts with discharging groundwater (Malard *et al*. 2002), helping shape the distinctive nature of springs as transitional habitats between subterranean and surface waters (Botosaneanu 1998, Culver and Pipan 2009).

Flow regime also drives many aspects of subterranean habitat. The influence of flow regime on subterranean habitat is determined by the geologic structure of the aquifer and the nature of recharge processes (Palmer 2005, Culver and Pipan 2009). Barton Springs emanates from a fault zone of vertically displaced bedding planes with some fractures with the majority of recharge occurring through sinking streams and sinkholes. Water flows quickly through subterranean habitat to Barton Springs (see section 2.3). This suggests that the subterranean environment of the Barton Springs Zone of the Edwards Aquifer is a set of branches of cavities and conduits (Palmer 2005) progressively converging into the Barton Springs complex (*i.e.*, similar to the progression from small headwaters to large rivers). Thus, flow regimes of recharging creeks and their sinkholes influence subterranean aquatic habitat in similar ways as in surface habitats. Flow regime and its effects can have direct and indirect effects on *E. sosorum* and *E. waterlooensis*.

Discussion of the status of *E. sosorum* and *E. waterlooensis* focuses on environmental factors with demonstrable effects on salamander abundance and population dynamics. We focus on one critical aspect of water quality, dissolved oxygen concentration, and the influence of current velocity, aquifer discharge, and impoundments. Therefore, we consider below the relationships among dissolved oxygen, discharge, and *E. sosorum* abundance. This is followed by a discussion of the results of habitat reconstruction designed to partially restore stream-like flow regimes in Eliza and Parthenia Spring.

3.3.2.1 Dissolved Oxygen

One of the major determinants of physiological health of aquatic salamanders in general (Hillman and Withers 1979) is dissolved oxygen concentration, with demonstrated effects on metabolic rate, mortality, growth rate, and behavior, of adult and juvenile *E. sosorum* and *E. nana* (Norris *et al*. 1963, Woods *et al*. 2010, see section 3.1.1). Dissolved oxygen concentration exerts a direct influence on salamander abundance because it is used to convert food into the metabolic energy (Eckert *et al*. 1988). Both survival and reproduction of all animals on Earth depend on metabolic energy; its allocation to each depends on the amount available and the life history of the animal (Pianka 1983, Harris and Ludwig 2004, Takahashi and Pauley 2010). For long-lived animals that reproduce more than once in a lifetime, such as *E. sosorum* and *E. waterlooensis*, when dissolved oxygen is high, metabolic energy can be created in abundance and allocated to both survival and reproduction (Pianka 1983, Krebs and Davies 1993). Conversely, when dissolved oxygen is low, metabolic energy is limited and generally will be allocated to survival, with reproduction delayed until environmental conditions improve (See citations in Dries 2012, Appendix A). This gives rise to two predictions for Barton Springs' *Eurycea* that can be useful in inferring population status based on variation in salamander abundance. When dissolved oxygen is high, salamanders should reproduce and juvenile abundance should increase. Conversely, when dissolved oxygen falls below a reproduction threshold, reproduction should cease or decrease drastically, and juvenile abundance should decrease. Ultimately, when dissolved oxygen falls below the adult survival threshold, adult abundance should decrease. This is the pattern observed for *E. sosorum* in all spring sites (Appendix A Dries 2012).

3.3.2.2 Discharge, Water Current Velocity, and Salamander Abundance

Measured discharge from the Barton Springs complex has ranged from 10 – 120 ft^3/s, with an average of 54 ft^3/s (Smith and Hunt 2010), although there are few extended periods of average flow. Salamanders detect flow velocity in their particular location in habitat, rather than an average flow rate. However, discharge can be a useful correlate for general flow conditions driving aspects salamander habitat quality. In the Barton Springs complex, variation in discharge is accompanied by variation in aspects of water quality, including dissolved oxygen, dissolved carbon dioxide, water temperature, conductivity, pH, and suspended sediment. This allows for examination of patterns of variation in salamander abundance and reproduction in the context of discharge variation as a surrogate for water quality.

In general, annual mean *E. sosorum* abundance varies with discharge. The higher the total discharge from the Barton Springs complex, the greater the number of salamanders (Turner 2009, Gillespie 2011), and the greater the reproduction and recruitment (Appendix A Dries 2012). The timing of increases in abundance of juveniles and adults indicates that the majority of reproduction and recruitment occurs during non-drought periods. Proximate mechanisms that trigger periods of reproduction in *E. sosorum* in the wild are not well understood. However, increased dissolved oxygen concentration is an obvious factor influencing reproduction in other long-lived, k-selected species (Pianka 1983). Gillespie (2011) posited that reproduction might also be triggered by transient drops in water temperature, which typically follow winter rainfall. Since drops in water temperature in flowing, surface waters increase dissolved oxygen concentration (Boyle 1662, Wetzl 2001, Kalff 2002), the interaction of the two mechanisms may be a cue for reproduction rather than either separately.

Drought exerts detrimental effects on salamander habitat and abundance. As discharge drops, dissolved oxygen decreases (Turner 2009). At discharge values below 25 ft^3/s, dissolved oxygen in Eliza and Old Mill Spring drops to concentrations that affect juvenile salamander growth, and juvenile and adult survival (Woods *et al*. 2010, Appendix A Dries 2012). The effects of droughts on salamander abundance and reproduction seem to persist even after high or average discharge conditions return (Appendix A Dries 2012). In the 12 months following the drought of 2008-2009, abundance, reproduction, and recruitment did not return to pre-drought levels in any salamander population. This suggests that drought indirectly affects salamanders and the ecosystem even after higher discharge returns. The ultimate effects of frequent, extended droughts on *E. sosorum* and *E. waterlooensis* may be dependent on not only the duration and frequency of low discharge (Smith and Hunt 2010), but also the nature of intervening non-drought periods.

3.3.3 Habitat Restoration by Flow Regime Reconstruction

The dominant feature distinguishing creeks and rivers from lakes and ponds is flow regime (Leopold *et al*. 1992). It influences every part of the aquatic ecosystem (Wetzl 2001, Giller and Malmqvist 1998), from the amount of sediment (Nowell and Jumars 1984) and type of algae (Poff *et al*. 1990, Reiter and Carlson 1986, Blum 1960) to the community of invertebrates and vertebrates (Vogel 1994). Faster water flow naturally favors growth of tightly attached algae (Stevenson 1983, Korte and Blinn 1983, Fritsch 1929) and high diversity of stream-adapted invertebrates (Hynes 1972), and helps maintain high water quality (Spellman and Drinan 2001). The dams separating Barton Springs Pool from Barton Creek, and the amphitheaters impounding Eliza and Old Mill Spring shifted the ecological character to pond-like conditions less suitable for stream-adapted *E. sosorum*. The 1998 Habitat Conservation Plan for Barton Springs recognized the detrimental influence of these habitat modifications on the status of *E. sosorum* by including habitat restoration as a conservation measure. Since 2003, the major goal of restoration has been to temporarily or permanently reconstruct more natural stream-like flow regimes in Eliza, Parthenia, and Old Mill springs. To begin to reverse the pond-like conditions, stream-like conditions were reconstructed in Eliza Spring in 2003. Habitat reconstruction changed physical aspects of habitat as well as dynamics of water flow. Both efforts were followed by significant increases in *E. sosorum* salamander abundance, density, and recruitment, as well as average population size.

Reconstruction of flow regime in Eliza Spring caused improvement in some physical habitat characteristics, confirming the hypothesized relationship of two factors to salamander population health. First, water current velocity increased (Appendix A Dries 2012), becoming more typical of the shallow, flowing streams in which the majority of *Eurycea* species are found (Wells 2007, Petranka 1998). Increased velocity changes the character of the substrate habitat (Leopold *et al.* 1992, Giller and Malmqvist 1998, Wetzl 2001) and influences abundance and presence of the invertebrate prey of *E. sosorum* (Gillespie 2011). Second, sediment depth and percent area covered by sediment both decreased (Dries 2012 Appendix A), resulting in a greater amount of rocky substrate with clean interstitial spaces. These results support previous inferences (City of Austin 2004) that *E. sosorum* fares better in habitats with flowing water and less sediment-laden substrate.

Flow regime reconstruction in Parthenia Spring is constrained by maintenance of deep water for swimming. Since 2004, reconstruction has focused on clearing obstructions to water flow from the fissures and mouths of the spring. Temporary reconstruction of flow regime has occurred with every drawdown of water level in Barton Springs Pool, because reducing water depth increases current speed. In 2004 and 2005, a series of partial drawdowns were conducted, in addition to annual full drawdowns for cleaning and floods, resulting in more short periods of improved flow regime. There were record high abundances of Barton Springs' salamanders in 2006 and 2008, with the majority of salamanders found near the large spring mouths. While the relationship with flow regime is unclear, this area generally has the fastest water flow (1-2 ft/s), the least sediment accumulation, within the rocky substrate, and the greatest abundances of invertebrate prey relative to other areas.

Gradual reconstruction of flow regime at Old Mill Spring has been ongoing since 2006. Available habitat area has increased with the elimination of unnatural outflow through an underground pipe, widening and lowering the elevation of the outflow stream, and removing several feet of accumulated rock, trash and sediment in the spring pool. These changes allow for higher flow velocities under all conditions, and more wetted surface habitat at average Barton Springs' discharge. These efforts were followed by record high salamander abundance in 2008, but it has not persisted. The potentially beneficial effects of habitat reconstruction may have been overcome by the detrimental effects of drought.

3.3.4 Habitat Management in Barton Springs Pool

The management of the aquatic environment of the Pool has changed considerably since listing of *E. sosorum* in 1997 and implementation of the 1998 Habitat Conservation Plan associated with the 10(a)(1)(B) permit for Barton Springs. For example, less destructive cleaning methods are used, Pool water level drawdowns are restricted, and habitat areas are cleaned and managed by federally permitted biologists only. All of these activities were intended to help improve salamander abundance.

The status of the *E. sosorum* population in Parthenia and Eliza Spring has improved since the species was added to the federal endangered species list in 1997 (COA 2005 - 2011). Salamander abundance, and density increased significantly after 1997. While there was no evidence of recruitment before listing, there have been several periods of recruitment after 1997. This indicates that, in general, reproductive success of adults has improved, and juveniles are recruited into the adult population, leading to an increase in average population size. *Eurycea sosorum* abundance in Old Mill Spring has not improved since listing, which is likely influenced by the severe effects of drought at this site. Although some habitat improvements have been made at this site, restoration of suitable flow regime has not been completed. The *E. sosorum* abundance in Upper Barton Spring has increased since listing, but no evidence of recruitment has been found.

Despite the recent severe droughts, Eliza and Parthenia Spring harbor the largest *E. sosorum* populations. At this time, these populations are more resilient and have the best potential to weather adverse conditions. The Eliza Spring population provides the best opportunity to collect additional data and understand how the species responds to environmental change, both natural and anthropogenic, and therefore how to best protect and foster recovery of *E. sosorum*. Abundance of *E. waterlooensis* has been the largest in Old Mill Spring. That site could provide the best or only opportunity to understand this species and foster its recovery. The total number of sites where these species currently reside is very small (3 perennial, 1 intermittent), and populations are small. It is unlikely that either species can persist if additional habitat is lost (Schlosser and Angermeier 1995). All four sites must continue to be protected and their habitat restored to natural conditions as much as possible.

3.4 Status of *Eurycea waterlooensis*

Since *E. waterlooensis* resides in subterranean habitat of the perennial springs, Eliza, Parthenia, and Old Mill, it is difficult to infer the status of the populations and the species. Lack of information on life history characteristics in wild populations further hampers assessment of population size, reproduction, and recruitment. Therefore, presented here is a summary of City of Austin data on *E. waterlooensis* encountered during monthly surveys of surface habitats (Table 11). This species is most commonly found in Old Mill Spring. Abundance and density are significantly higher in Old Mill relative to Eliza and Parthenia springs. It has never been found in Upper Barton Spring.

Table 11. Mean, standard deviation (S.D.), and standard error (s.e.) of abundance and density of *E. waterlooensis* salamanders in all spring sites from 1998 – 2010 are listed below. Minimum (Min.), maximum (Max.), and annual sum of salamander abundance are also listed.

	Abundance (#)							Density (#/ft^2)		
Year	**Mean**	**S.D.**	**s.e.**	**N**	**Min.**	**Max.**	**Sum**	**Mean**	**S.D.**	**s.e.**
Old Mill Spring										
1998	0.7	1.0	0.3	9	0	2	6	0.0005	0.001	0.0003
1999	0.3	1.0	0.3	9	0	3	3	0.0003	0.001	0.0003
2000	0.5	0.8	0.3	8	0	2	4	0.001	0.001	0.0004
2001	9.1	12.4	3.9	10	0	37	91	0.008	0.009	0.003
2002	9.1	6.6	2.2	9	1	21	82	0.007	0.005	0.002
2003	15.5	15.3	4.8	10	0	43	155	0.012	0.011	0.004
2004	8.8	5.3	1.8	9	0	16	79	0.007	0.004	0.001
2005	1.5	1.8	0.6	8	0	5	12	0.001	0.001	0.0005
2006	0.4	0.7	0.2	9	0	2	4	0.0003	0.001	0.0002
2007	0.2	0.4	0.2	6	0	1	1	0.0001	0.0003	0.0001
2008	1.8	2.4	0.8	8	0	6	14	0.001	0.002	0.001
2009	0	0	0	12	0	0	0	0	0	0
2010	0.1	0.3	0.1	11	0	1	1	0.00005	0.0002	0.00005
Eliza Spring										
1998	0	0	0	9	0	0	0	0	0	0
1999	0	0	0	9	0	0	0	0	0	0
2000	0	0	0	10	0	0	0	0	0	0
2001	0	0	0	8	0	0	0	0	0	0
2002	0	0	0	8	0	0	0	0	0	0
2003	0	0	0	10	0	0	0	0	0	0
2004	1.1	1.1	0.4	7	0	3	8	0.001	0.001	0.001
2005	1.4	2.3	0.7	10	0	6	14	0.001	0.003	0.001
2006	3.7	4.5	1.4	10	0	12	37	0.005	0.006	0.002
2007	1.5	1.6	0.5	11	0	5	17	0.002	0.001	0.001
2008	1.0	1.5	0.4	12	0	4	12	0.001	0.002	0.001
2009	0.1	0.3	0.1	10	0	1	1	0.0001	0.0004	0.0003
2010	0	0	0	8	0	0	0	0	0	0

Table 11. (cont.). Mean, standard deviation (S.D.), and standard error (s.e.) of abundance and density of *E. waterlooensis* salamanders in all spring sites for 1998 - 2010 are listed below. Minimum (Min.), maximum (Max.), and annual sum of salamander abundance are also listed.

	Abundance (#)							Density (#/sq ft)		
Year	**Mean**	**S.D.**	**s.e.**	**N**	**Min.**	**Max.**	**Sum**	**Mean**	**S.D.**	**s.e.**
Parthenia Spring										
1998	0.1	0.3	0.1	10	0	1	1	n/a	n/a	n/a
1999	0.0	0.0	0.0	10	0	0	0	n/a	n/a	n/a
2000	0.0	0.0	0.0	9	0	0	0	n/a	n/a	n/a
2001	0.0	0.0	0.0	7	0	0	0	n/a	n/a	n/a
2002	0.3	0.5	0.2	9	0	1	3	n/a	n/a	n/a
2003	0.6	0.9	0.3	8	0	2	5	0.00030	0.0004	0.00020
2004	0.1	0.3	0.1	9	0	1	1	0.00005	0.0001	0.00005
2005	0.1	0.4	0.1	7	0	1	1	0.00005	0.0001	0.00005
2006	0.3	0.7	0.2	9	0	2	3	0.00010	0.0003	0.00009
2007	0.7	0.8	0.3	6	0	2	4	0.00030	0.0004	0.00020
2008	0.2	0.7	0.2	9	0	2	2	0.00010	0.0003	0.00010
2009	0.1	0.4	0.1	7	0	1	1	0.00004	0.0009	0.00004
2010	1.1	2.0	0.8	7	0	5	8	0.00030	0.0004	0.00010
Upper Barton Spring										
1998 - 2010	0.0	0.0	0.0	100	0	0	0	0.0	0.0	0.0
All Sites Combined										
1998 - 2010	1.1	4.1	0.2	530	0	43	583	0.001	0.004	0.0002

4.0 Covered Actions and Biological Impacts

City actions in this amended HCP that are expected to impose incidental take of *E. sosorum* and *E. waterlooensis* are:

- 4.1. Public use of Barton Springs Pool and Upper Barton Spring
- 4.2. Routine Cleaning: Removal of nuisance algae, excess sediment, and other natural materials from Barton Springs Pool, Eliza Spring, Old Mill Spring and Upper Barton Spring
- 4.3. Drawdowns of water level in Barton Springs Pool and Eliza Spring for routine cleaning
- 4.4. Drawdowns of water level in Barton Springs Pool and Eliza Spring for post-flood cleaning
- 4.5. Removal of flood-debris from Barton Springs Pool by vacuum dredging
- 4.6. Removal of spring water from Barton Springs Pool for irrigation of pool grounds and routine cleaning
- 4.7. Maintenance of manicured lawns along riparian corridor of Barton Springs Pool, Eliza Spring, and Old Mill Spring
- 4.8. Maintenance of historic structures and anthropogenic flow regime alterations
- 4.9. Salamander habitat reconstruction

Of the nine specific actions listed above, most (items 4.1 – 4.8) are associated with operation and maintenance of Barton Springs Pool and Upper Barton Spring for public use. Actions 4.1 through 4.6, and 4.9 were covered under the 1998 HCP, while 4.7 and 4.8 were not. Effects of salamander population monitoring are covered under federal 10(a)(1)(A) permit TE-833851. Habitat reconstruction is included as a covered action in this amended HCP because, although reconstruction activities will result in long-term improvement in habitat and species viability, they may impose short-term detrimental effects on salamanders and their habitat. (A comparison of conservation measures from the 1998 HCP with this amended HCP is presented in Table 22 in section 6.0.)

The potential biological impacts of these actions on *E. sosorum* and *E. waterlooensis* can be direct or indirect, detrimental or beneficial, and can occur over short or long periods of time. Each action is described in more detail below. The potential and expected detrimental and beneficial effects, the processes by which these effects are likely to be effected, and how each species is likely to respond are discussed for each action. A summary of the nature of the predicted effects of each action is presented in Table 12. While most short-term impacts are detrimental to varying degrees, long-term impacts are generally beneficial. Furthermore, detrimental effects are generally mild, consisting of harassment of salamanders, rather than mortality.

Table 12. Actions in this Plan that are expected to have direct or indirect detrimental effects on salamander populations in each spring are summarized below. Short-term and long-term effects are included, with detrimental effects indicated by a minus sign (–) and beneficial impacts are indicated by a plus sign (+). Direct (D) and indirect (I) effects are also noted. Shaded cells indicate no expected effects.

	Parthenia		**Eliza**		**Old Mill**		**Upper Barton**	
	Short Term	Long Term	Short Term	Long Term	Short Term	Long Term	Short Term	Long Term
Public Use/ Recreation	– D, I	– D, I					– D, I	– D, I
Routine Cleaning	– D, I	+ D, I	– D, I	+ D, I	– D, I	+ D, I	– D, I	+ D, I
Drawdowns: Routine Cleaning	–/+ D, I	+ D, I	–/+ D, I	+ D, I				
Drawdowns: Post-Flood Cleaning	–/+ D, I	+ D, I	–/+ D, I	+ D, I				
Flood Debris Removal	– D	+ I						
Spring Water Withdrawal: Irrigation, Routine Cleaning	–/+ D	+ I						
Lawns Along Riparian Corridor	–/+ I	–/+ I	–/+ I	–/+ I				
Historic Structures/ Flow Regime Alteration	– I	– I	– I	– I	– I	– I		
Habitat Restoration	– D, I	+ D, I	– D, I	+ D, I	– D, I	+ D, I		

4.1 Public Use of Barton Springs Pool and Upper Barton Spring

Operation and maintenance of Barton Springs Pool and Upper Barton Spring for recreation include unnatural direct and indirect disturbances of salamander habitat. The predominant direct habitat disturbance in Parthenia Spring is alteration of substrate in habitat, typically when users move or drop rocks in deep water areas in front of the spring mouths, or remove vegetation or algae in shallow water of the fissures and the Beach. Artificial overhead lighting around the

Pool is used from dark until 10 pm, and therefore, could be an indirect disturbance of salamanders by altering habitat. In Upper Barton Spring, construction of rock dams across the outflows is common, as is substrate alteration (e.g., disturbance of substrate around groundwater upwellings, movement of rocks, wading through the spring pool).

4.1.1 Effects of Public Use of Barton Springs Pool and Upper Barton Spring

Public use of Barton Springs Pool and Upper Barton Spring could disturb salamanders and their habitats. Direct disturbance of salamander habitat by recreational users can threaten survival of individual salamanders (*e.g*., crush salamanders, expose them to predation, interrupt normal feeding) or reproduction (*e. g*., interrupt courtship and breeding). In the Pool, most of the direct detrimental effects occur in front of the orifices of Parthenia Spring, areas of the highest abundances of salamanders. Indirect disturbance could be imposed by overhead lighting around the Pool, but the lighting is not bright enough to penetrate the water column down to substrate in salamander habitat. Since these salamanders reside in the interstitial spaces of substrate or mossy vegetation, they would not be exposed to artificial light and are not likely to be disturbed by it.

Exposure of salamanders to disturbance varies annually with the intensity and frequency of recreational. During the revenue generating months (mid-March through October), recreational use is higher with highest attendance from June through August. Attendance tapers off in September and October followed by the least use from November through early March. Although there is more recreation and potentially more disturbance of salamander habitat during revenue generating months, there is no statistically significant difference in *E. sosorum* abundance in Parthenia Spring during that period (Mann-Whitney $U = 2466.0$, $z = -1.472$, $p = 0.14$). Likewise, salamander abundance during peak attendance is not statistically different from the rest of the year (Mann-Whitney $U = 2306.5$, $z = -1.297$, $p = 0.20$). These results suggest that recreation is not imposing large amounts of direct or indirect disturbance of salamanders or their habitat in Parthenia Spring. There are no significant differences in abundance during any of these periods in other spring sites. Finally, while recreational use over the years has steadily increased, salamander abundances in all spring sites have varied from low to high, suggesting that recreational use is not a driving force underlying population dynamics of *E. sosorum* or *E. waterlooensis*.

Since Old Mill and Eliza Spring are intentionally closed to public recreation, habitat disturbance from recreation only affects two salamander sites, Parthenia Spring and Upper Barton Spring. Potentially detrimental effects of direct substrate disturbance in Parthenia and Upper Barton Spring are expected to be short term and minimal, affecting individual salamanders rather than entire populations. Disturbances likely result in a low level of harassment or mortality compared to the total abundance of salamanders in the affected habitat. In the Pool, the localized nature of these disturbances and the deeper water in the areas most affected limits the frequency of occurrence and the severity of effects. Noise currently experienced by salamanders in all spring sites does not appear to compromise survival or reproduction. All of this information suggests that habitat disturbance from recreation is not likely to adversely affect the long-term viability of *E. sosorum* or *E. waterlooensis*.

Finally, public use of Barton Springs Pool provides an indirect benefit to protection of endemic salamanders and their habitat by fostering and reinforcing a commitment in the human community to protecting the environment of Barton Springs from degradation. Barton Springs Pool is known as the jewel or soul of Austin; threats to its health are met with strong, vociferous resistance from the public. As a cultural icon, public use of Barton Springs Pool generates support, both financial and political, for protection of the entire Barton Springs Complex and the aquifer that feeds it. Maintaining public use provides long-term benefits that counterbalance detrimental effects of habitat disturbance.

4.2 Routine Cleaning: Removal of Nuisance Algae, Excess Sediment, and Other Natural Materials from Barton Springs Pool, Eliza Spring, and Old Mill Spring

Substrate in salamander habitat of Parthenia Spring, Eliza Spring, and Old Mill Spring is cleaned of unnatural accumulation of sediment and nuisance algae as necessary. The method of removal is directing water through substrate to flush out unwanted excess material. Spring water is re-circulated through submersible pumps and directed through hoses with adjustable nozzles, allowing for manipulation of water pressure. At present, cleaning of habitat of Upper Barton Springs has not been necessary, as natural water flow has inhibited accumulation of excess material. However, it is included because removal may become necessary in the future.

Substrate in shallow areas of the Pool and outside of salamander habitat is cleaned weekly at a minimum to remove slippery and aesthetically unappealing materials (algae and sediment). Cleaning is done mechanically using underwater buffers, power-washers, and brooms. Underwater buffing systems consist of rotating plastic brushes to dislodge material with an integrated vacuum pump to remove dirty water and material from the Pool. Push brooms dedicated for Pool use only are used to sweep along substrate and dislodge material. Power-washers are hand-operated and fueled by gasoline or electricity. They deliver very high water pressure through a wand to clean walls, stairways, and shallow substrate. A fire hose system is used to deliver high-pressure water to the substrate in deep areas of the Pool to dislodge and suspend loose materials and carry them downstream. No toxic chemicals (e.g., chlorine, copper sulfate) have been applied directly onto substrate since the issuance of the original incidental take permit in 1998, and will not occur under this amended HCP. In this amended HCP, a new pump system will be installed that can draw spring water from the Pool to be used in power washers and the fire hose system, eliminating under most circumstances the use of drinking water that contains disinfectants toxic to most aquatic wildlife.

4.2.1 Effects of Routine Cleaning: Removal of Nuisance Algae, Excess Sediment, and Other Natural Materials from Barton Springs Pool, Eliza Spring, and Old Mill Spring

Routine cleaning of salamander habitat imposes direct and indirect effects on protected salamanders. These effects are caused by disturbance of substrate in order to remove excess sediment, macrophytes, and nuisance algae. Excess sediment deposition in salamander habitat can have direct and indirect effects on salamanders and their prey. Sediment smothers benthic algae, reducing food available for salamander prey. It fills interstitial spaces in substrate, depriving salamanders of critical cover. It can reduce dissolved oxygen concentrations directly and indirectly, affecting salamander respiration and metabolism. Sediment can also carry organic pollutants into habitat. Onsite inputs of pesticides and other contaminants threaten water quality in Barton Springs. The complex is in a heavily urbanized area with consequent increased potential for runoff to carry pollutants directly into Barton Springs. Thus, routine cleaning is critical to long-term maintenance of high quality salamander habitat.

Though routine cleaning of salamander habitat improves long-term habitat quality, overly vigorous or intrusive cleaning methods could cause mortality and harassment of salamanders. Hence, the degree of effect is dependent on the cleaning methods used. The cleaning methods in this amended HCP were chosen to minimize detrimental effects. Only spring water will be used in all cleaning equipment, within and outside of salamander habitat, to avoid harm or mortality of salamander from toxic chemicals in drinking water. Water pressure used to clean within salamander habitat will impose disturbance that is less than or equal to that imposed by flood flow. Direct effects of habitat cleaning will be localized and transient.

Routine cleaning in areas outside of designated salamander habitat could affect salamanders and their habitat indirectly by generating noise, introducing dissolved toxic chemicals, or pushing dislodged material into salamander habitat. All of the cleaning equipment generates noise, which may be detectable underwater (Clark *et al*. 1996). The resulting pressure levels and frequencies of sound and vibration that reach salamander habitat are unknown and may vary greatly depending on location of origin (*e.g*., sound attenuation with distance), and the substance(s) sound travels through (*e.g*., through water only, or through air, water, and rock). Noise generated by cleaning equipment could affect *E. sosorum* or *E. waterlooensis*. Whether these salamanders respond to sounds and vibrations from cleaning equipment is unknown. Aquatic vertebrates, including plethondontid salamanders, can detect and respond to sound and vibrations underwater (Moyle and Chech 1988, Fay and Simmons 1999, Hilton 1952, Monath 1965). Studies assessing the impacts of noise on aquatic biota have generally been limited to fish and terrestrial amphibians (Knudsen *et al*. 1994, Smith *et al*. 2004, Sun and Narins 2005, Warkentin 2005, Wysocki *et al*. 2006, Haemmerle *et al*. 2009). Aquatic salamanders are sensitive to seismic vibrations (Smotherman and Narins 2004). Peak sensitivities in electrophysiological studies of aquatic adult *Notopthalmus viridescens* and larval *Ambystoma maculatum* were 150 Hz and 200 Hz, respectively (Ross and Smith 1980). Haemmerle *et al*. (2009) observed no behavioral differences in *Rana catesbiana* tadpoles and *Ambystoma gracile* larvae during pile driving (between 188 dB and 204 dB in water). Although the sound pressure levels achieved in *E. sosorum* or *E. waterlooensis* habitat by cleaning activities are unknown, they are likely much lower than those observed for pile-driving impact hammers of Haemmerle *et al*. (2009).

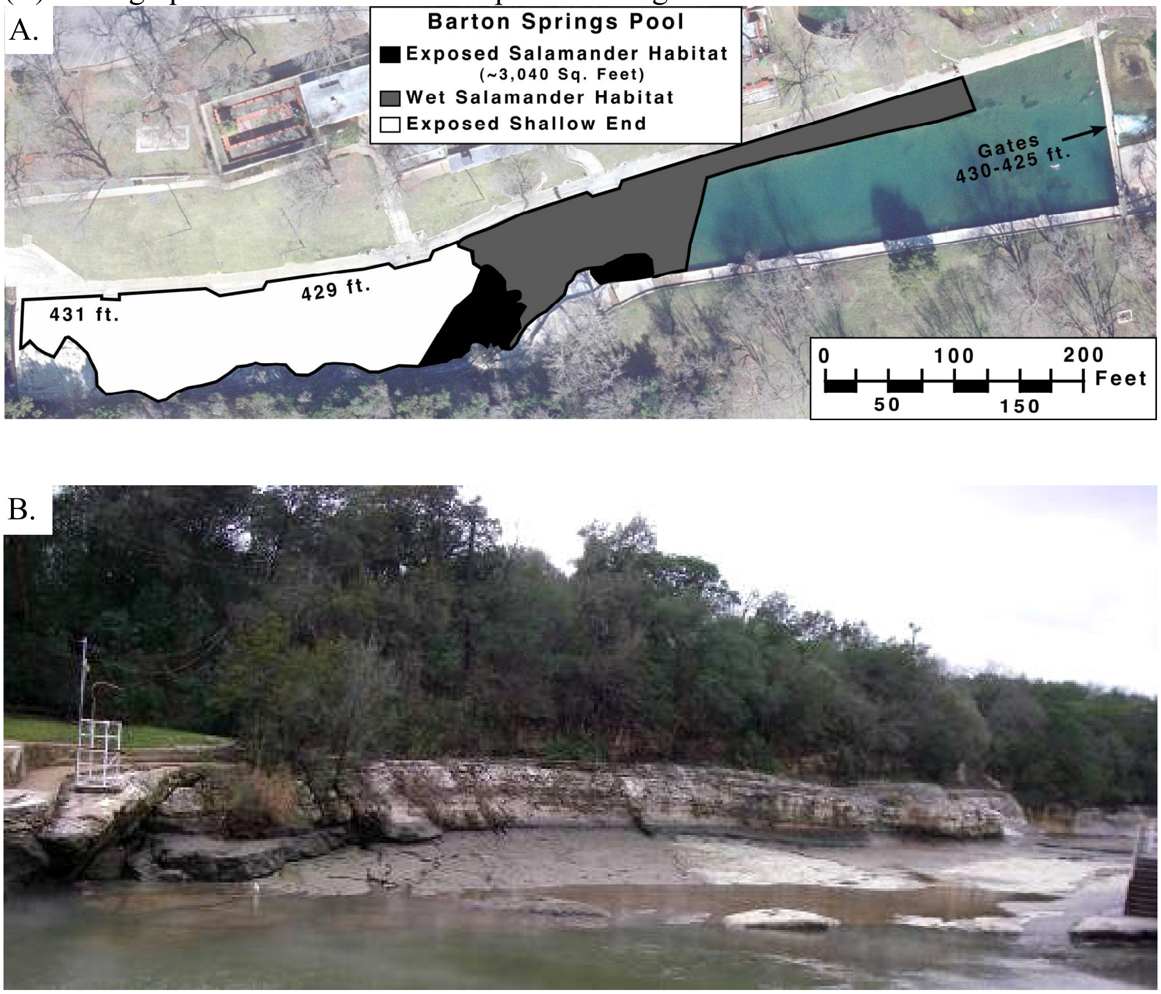
If sound or vibrations from cleaning activities adversely affect either salamander species, these effects are likely to be most pronounced within the Parthenia Spring populations because cleaning activities in and around Barton Springs Pool occur more frequently than in other sites. A comparison of salamander abundance and density in Parthenia Spring during surveys since 2003 revealed no significant differences between cleaning and non-cleaning days (abundance: Mann-Whitney U = 323.0, z = -0.724, p = 0.47; density: U = 326.0, z = -0.307, p = 0.76). The sound produced by pressure washers in air (up to 85dB) does not appear to influence concurrently observed salamander abundance underwater. Although *Eurycea* salamanders have the morphology to detect vibration, they may habituate to low levels of noise or may simply not detect it. Salamanders in captivity are exposed to constant noise from equipment maintaining water flow in the aquaria. Despite this, captive *E. sosorum* and *E. waterlooensis* continue to survive and reproduce. Currently, there is little evidence that demonstrates that Barton Springs' *Eurycea* are subjected to detrimental levels of noise. Therefore, the effects of sound on the covered species, if any, are expected to be minimal.

4.3 Drawdowns of Water Level in Barton Springs Pool and Eliza Spring for Routine Cleaning

Drawdowns of water level in Barton Springs Pool are used to facilitate routine cleaning of shallow areas of the Pool. They can also reduce the potential effects of toxic contaminant spills by allowing the pollutant to flow out of the Pool more quickly. Drawdowns are conducted by opening gates in the downstream dam of the Pool, a mechanical process done by hand. This allows water to flow downstream through the dam, exposing upstream substrate that is at higher elevation (Figure 13, Figure 14). Once water level in Barton Springs Pool is drawn down, shallow substrate can be cleaned more efficiently and quickly because it is no longer underwater. Cleaning is accomplished using a skid steer loader with a mechanical brush and power washers to scrub substrate clean of algae, sediment, and other materials. A fire hose is then used to wash the dislodged material downstream to a containment area upstream of wetted salamander habitat from which the water is pumped out of the Pool into the bypass culvert. The City proposes to continue to conduct drawdowns when Barton Springs' discharge is 54 ft^3/s or greater. Full drawdowns would be limited to a maximum of 4 per year, as in the 1998 HCP, and up to 8 partial drawdowns per year would be added.

When water level is drawn down, exposed areas include some of the fissures of salamander habitat in Parthenia Spring (Figure 13, Figure 14). During Pool drawdowns, water level in Eliza Spring also recedes and surface habitat can become exposed. Water level in Old Mill Spring may recede few inches during drawdowns, but surface habitat does not become exposed. Water level in Upper Barton Spring is unaffected by drawdowns of Barton Springs Pool when Barton Springs' discharge is 54 ft^3/s or higher.

Figure 13. (A) Barton Springs Aerial Map of Areas Exposed During Full Drawdown, (B) Photograph of Fissures Habitat Exposed During Full Drawdown.



There are several conservation measures in the 1998 HCP that are included in this amended HCP that minimize detrimental effects of drawdowns on resident salamanders. Gates in the downstream dam are adjustable so a desired water level reduction can be chosen, from a few inches to a maximum of 5 feet. The precise amount of decrease in water level in the Pool is predicted using a regression equation that incorporates discharge. Adjustable gates also provide a mechanism to control the rate of water level recession. Drawdowns are conducted only when surface habitat of Eliza Spring can remain submerged and when Barton Springs' discharge is 54 ft^3/s or greater. As water recedes in the Pool, habitat in the fissures of Parthenia Spring is searched for stranded salamanders; any found are relocated to submerged habitat. In addition, spring water is re-circulated through hoses over fissures habitat as water level recedes. Recirculation of spring water keeps habitat moist to protect any stranded salamanders until they are found and helps provide avenues for salamanders to retreat naturally into deeper, wetted habitat.

Figure 14. (A) Aerial Diagram of Area Exposed During 2-ft Partial Drawdown at Barton Springs' discharge of 60 ft^3/s, (B) Shallow End Area Exposed, (C) Fissures Habitat Exposed, and (D) Eliza Spring Habitat.

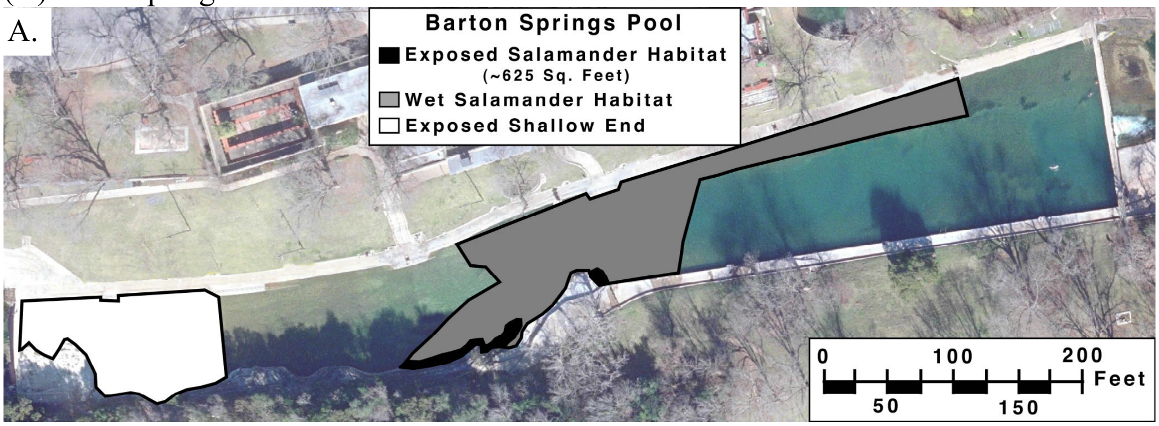


Figure 14 (cont.). (A) Aerial Diagram of Area Exposed During 2-foot Partial Drawdown at Barton Springs' discharge of 60 ft^3/s, (B) Shallow End Area Exposed, (C) Fissures Habitat Exposed, and (D) Eliza Spring Habitat.

C.

D.

4.3.1 Effects of Drawdowns of Water Level in Barton Springs Pool and Eliza Spring for Routine Cleaning

Barton Springs' *Eurycea* inhabit springs with surface habitats that naturally expand and contract with variation in aquifer discharge, water recession in Parthenia and Eliza Spring during drawdowns for routine cleaning is faster than would occur during natural decreases of the water table. The unnaturally rapid changes in water depth and surface area of wetted habitat during drawdowns could have direct and indirect, short-term detrimental impacts on protected salamanders. The unnatural timing of drawdowns with higher aquifer discharge rather than with lower discharge could have short- and long-term detrimental effects. Short-term effects of drawdowns would be least severe if retreating surface water elicits a behavioral response in salamanders; and indeed *E. sosorum* follows receding water to deeper, wetted habitat (Dries 2009). This behavior has also been observed in other central Texas perennibranchiate *Eurycea* that occur in habitats where receding surface water is a common occurrence (*e.g.*, *E. tonkawae*, the Jollyville Plateau Salamander) (N. Bendik personal communication 2010). This behavior is likely an innate response to natural environmental variability. Occasional drawdowns, if conducted at an appropriate rate of water recession, are unlikely to cause mortality or non-lethal take of salamanders of either species. This is supported by the City's data; during drawdowns from 2003 through 2009, only 8 salamanders have been observed stranded in Parthenia Spring and Eliza Spring combined. In the entire period of record of drawdowns, stranded or dead salamanders have only been found in the first day as water retreats (City of Austin 2004, City of Austin 2005, City of Austin 2006, City of Austin 2007). Occasional, accidental exposure of surface habitat in Eliza Spring has occurred but did not result in any stranded salamanders or other adverse effects (Dries 2009). These data indicate that the predominant short-term effect of drawdowns would be non-lethal.

Pool drawdowns are unlikely to have short-term effects on the entire population of salamanders of Parthenia Spring because salamander abundance is typically low in the area of habitat exposed (fissures). Since drawdowns are prohibited if they would cause exposure of surface habitat in Eliza Spring, this population is only minimally affected, little mortality or non-lethal take occurs. Surface habitats of Old Mill and Upper Barton springs are not exposed during drawdowns under the conditions proposed in this HCP, so resident salamanders would not be at risk of mortality or harassment. Since *E. waterlooensis* is not commonly observed in surface habitat of any of the spring sites and abundance in epigean habitat is very low, mortality or harassment of these salamanders is expected to be extremely small.

Long-term detrimental effects of drawdowns for cleaning arise from their frequency and timing, and the environmental conditions under which drawdowns are conducted. Although habitat contraction driven by natural variation in discharge influenced the evolution of life history in *E. sosorum*, anthropogenic activities of the present day influence timing and degree of habitat contraction experienced by extant salamanders. Under natural conditions, water would slowly recede from surface habitat as aquifer discharge decreased. Recession of water would be slow, long, and persistent (months), rather than rapid (1-2 days) and transient (1-21 days). Routine drawdowns for cleaning are conducted under average or higher discharge conditions, regardless of whether discharge is increasing or decreasing. Moreover, drawdowns are not conducted when discharge is below average ($< 54\ ft^3/s$) when water would be naturally receding. Finally, water remains drawn down for unnaturally short periods of time. From a salamander's point-of-view water recedes when it shouldn't, it recedes faster than normal, and water returns sooner than it should. While this maintains evolutionary selection for following receding water, it may also relax selection for traits associated with response to environmental variation in discharge. For example, natural slow recession of water may be a signal of impending drought, which may in turn trigger delayed reproduction or altered feeding behavior. Unnatural water recession may impose artificial selection for retreat when conditions at the surface favor reproduction.

Although the timing, frequency and duration of drawdowns could have direct and indirect detrimental effects, these may be counterbalanced by beneficial effects of temporary flow regime improvement. Ultimately, allowing natural variation in water depth in Barton Springs Pool that is consistent with environmental variation would reduce the need for drawdowns and counteract potential long-term evolutionary effects on *E. sosorum* and *E. waterlooensis*.

4.4 Drawdowns of Water Level in Barton Springs Pool and Eliza Spring for Post-Flood Cleaning

Some material entrained in floodwater is deposited within the confines of the Pool when Barton Creek floods and flows through Barton Springs Pool. Because the natural flow regime is altered by dams upstream and downstream of Parthenia Spring, more material is deposited than would normally occur if there were no dams. Excess deposition of silt, sediment, woody debris, and rocks degrades quality of salamander habitat and the rest of the Pool. Maintaining high quality aquatic habitat after floods requires human intervention. There are two general strategies taken to respond to floods. First, as soon as flood water begins to flow over the upstream dam, gates in the downstream dam are opened fully to allow flood water to pass through the Pool more naturally. This helps inhibit unnatural, premature deposition of material within confines of Barton Springs Pool. Two, as flood water recedes, dam gates are left open and water level in the Pool is allowed to decrease until it reaches approximately 5 feet below normal operating conditions to facilitate cleaning both within and outside of salamander habitat. These drawdowns are similar to those for routine cleaning.

Drawdowns in response to floods have the advantage of helping limit the amount of material that settles on substrate as floodwater recedes, as well as enhancing the efficiency of cleaning. A post-flood drawdown reduces the water depth, resulting in faster groundwater flow from Barton Springs' regardless of discharge. Faster water flow enhances natural flushing of silt and debris from Parthenia Spring, particularly in the fissures. The City proposes to continue to conduct flood-related drawdowns for every flood.

4.4.1 Effects of Drawdowns of Water Level in Barton Springs Pool and Eliza Spring for Post-Flood Cleaning

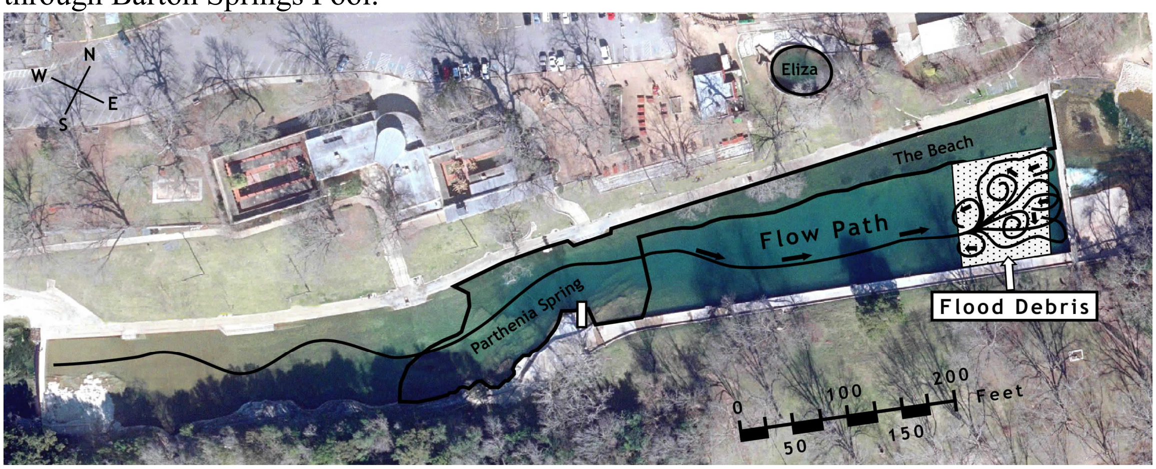
As with routine drawdowns for cleaning, flood related drawdowns have the potential to strand salamanders in the fissures of Parthenia Spring as it becomes exposed. Although small, there is also the potential for surface habitat in Eliza Spring to become exposed. Actions taken to protect salamanders during routine drawdowns are also employed during flood related drawdowns. In addition, gates in the downstream dam are not opened until floodwater begins flowing over the upstream dam. This ensures that there is water flowing through shallow habitat in Parthenia Spring if water level fluctuates during the early stages of the flood. Once the flooding has ceased and water level continues to recede, habitat is searched for stranded salamanders.

While a potential biological disadvantage of routine drawdowns is that their occurrence isn't predictable from natural environmental cues, flood related drawdowns are intimately tied with large-scale environmental change. Floods occur after significant rainfall, which also increases groundwater flow from Barton Springs. Both of these environmental changes are things salamanders could detect and to which they may respond. The potential detrimental short-term effect of these drawdowns is stranding of salamanders, but this is less likely in the presence of reliable environmental cues. Short-term detrimental effects are balanced by short-term increase in flow velocity, which inhibits deposition of silt and can increase dissolved oxygen. They are also balanced by beneficial role of floods in the ecosystem. Floods provide an avenue for natural colonization of aquatic flora and fauna from Barton Creek, they drive maintenance of natural geomorphology of creek channels, and maintain dynamic environmental variation characteristic of a spring-fed creek.

4.5 Removal of Flood Debris from Barton Springs Pool by Vacuum Dredging

Flooding of Barton Creek affects Barton Springs Pool when there is enough water to overtop the upstream dam (approximately 500 ft^3/s). As these floods flow through Barton Springs Pool, they deposit material. This material accumulates until it reaches volumes that affect patterns of water flow through the Pool (Figure 15). The material also reduces water depth in the deepest channel, which is an undesirable condition for swimmers and Pool staff. Shallower water can create unsafe conditions for lifeguards to enter the water from their posts to rescue someone in distress. Lifeguard stands are elevated 8 to 10 feet above the water surface to allow for view of larger areas of the Pool. Entering the Pool from these heights is more dangerous when the water below is shallow.

Figure 15. Aerial photograph showing location of flood debris accumulation associated with regular vacuum dredging removal. Also shown are flow paths of flood waters as they pass through Barton Springs Pool.



The City proposes to remove flood debris as necessary, using a vacuum dredging technique that has been successful in the past. This consists of a vacuum pump anchored to a floating platform that is placed in the water of the Pool over the area to be dredged. An intake hose is lowered into the water until it is flush with the substrate. Vacuum suction is used to remove the targeted material plus water into holding tanks outside the water and slopes that drain to the Pool. Collected gravel and silt are allowed to settle to the bottom of the tank, and the overlying clean water is released through an adjustable valve. Water is filtered further if necessary, and discharged into appropriate storm water control tributaries and swales, and ultimately is returned to Barton Creek downstream of the Pool. All water treatment and discharge is conducted in compliance with City, State, and federal regulations. Once overlying water has been released from the holding tanks, the remaining solid material is loaded into trucks and immediately transported to a holding site for reuse by the City on other projects. Access for the pump and other equipment will be through the south grounds of Barton Springs Pool. The platform for the pump may be floated from the upstream end of the Pool to the flood debris location.

4.5.1 Effects of Removal of Flood Debris from Barton Springs Pool by Vacuum Dredging

The long-term effects of this action are beneficial but there may be minor detrimental impacts on salamanders or their habitat. Vacuum dredging in Barton Springs Pool will not have any direct effects because it occurs outside of habitat areas. Short-term, indirect effects will be negligible. The substrate disturbed during dredging is limited to rocks that are 5 inches or less in diameter and sediment in the immediate area around the intake hose (< 5 ft^2). Dredging occurs approximately 300 feet downstream of salamander habitat of Parthenia Spring, which ensures that suspended material will not re-settle in salamander habitat. Drawdown of water in the Pool is not necessary for this type of dredging. Therefore, there will be no risk of stranded salamanders in the Pool or Eliza Spring. The project boundary may abut a small area of the Beach, designated as salamander habitat under the 1998 HCP. In this amended HCP, the City proposes to exchange this area with higher quality habitat near Parthenia Spring (See section 6.0, measure 6.1.1.2 and Appendix B). Therefore, the project boundary will not be adjacent to salamander habitat. The only potential detrimental effect on salamanders is noise, which doesn't exceed that of recreation and cleaning.

Regular removal of accumulated flood debris will improve flow regime through Barton Springs Pool by reducing turbulence and multi-directional water flow at the downstream dam. This will help inhibit deposition of sediment and other materials during future floods. Furthermore, during a vacuum dredging event in 2006, there were no observed detrimental effects on salamanders or their habitat in Parthenia or Eliza Spring.

4.6 Removal of Spring Water from Barton Springs Pool for Irrigation of Pool Grounds and Routine Cleaning.

The City proposes to use spring water to irrigate the grounds immediately adjacent to Barton Springs Pool and Eliza Spring. In addition, this pump will provide spring water to fire hoses and power washers used for routine cleaning of aquatic habitat under nominal conditions. A pump will be installed on the north bank of the Pool near the downstream dam. The intake system will be placed on the upstream side of the downstream dam near the center of the channel. The intake system will be placed low enough in the water column to allow for operation when water elevation of the Pool is drawn down or during natural changes in water elevation. The intake will be located approximately 100 feet downstream of salamander habitat and will be designed to inhibit entrapment of wildlife and patrons.

4.6.1 Effects of Removal of Spring Water from Barton Springs Pool for Irrigation of Pool Grounds and Routine Cleaning

Withdrawing spring water from Barton Springs Pool for routine cleaning will have beneficial effects on salamanders and their habitat because it will eliminate the use of chlorinated City drinking water in power washers and fire hoses. Water from power washers and fire hoses mixes with the spring water in the Pool, introducing toxic disinfectants. Although the concentrations of these disinfectants are low once mixed with spring water, the risk of unobserved, long-term detrimental effects on aquatic life is unknown. Use of spring water from the Pool to clean the Pool eliminates the introduction of these contaminants, and thereby eliminates the risk.

Use of spring water for irrigation has the potential to impose detrimental long-term effects if withdrawal deprives salamanders and other aquatic life of sufficient water for survival and reproduction. However, the amount of water withdrawn will not exceed 6,006,000 gallons/year, and all irrigation will follow the City's water conservation regulations. There are short- and long-term benefits to irrigation of Pool grounds. Ensuring healthy vegetation along the riparian corridor provides indirect benefits to salamander habitat. Terrestrial vegetation is an important source of organic input into aquatic habitat. Leaves from trees that fall into the water provide food and shelter for aquatic invertebrates that are prey of aquatic salamanders. Decaying vegetation can inhibit growth of nuisance algae. The canopy created by trees shades the water, helping to maintain cooler water temperature during hot summers. This can have a significant effect on salamander survival because cooler water can hold more oxygen.

Irrigation will also help maintain grassy vegetation forming the lawns around the Pool and Eliza Spring. Although a manicured lawn is not natural part of riparian corridors, presence of this vegetation prevents erosion and transport of soil into Parthenia Spring during rainstorms. This provides an indirect benefit by helping prevent accumulation of excess sediment in substrate of salamander habitat.

4.7 Maintenance of Manicured Lawns Along the Riparian Corridors of Barton Springs Pool and Eliza Spring

The riparian corridors of Barton Springs Pool and Eliza Spring are maintained as a combination of expanses of manicured grassy lawns and scattered large, old trees. This type of terrestrial environment enhances public use of Barton Springs Pool and grounds around Eliza Spring. Lawn maintenance consists of irrigation, mowing, and occasional mulch application. No chemical fertilizers are used. Fallen woody materials are typically removed and deposited outside Pool grounds. Offspring of existing trees are not allowed to grow; each ailing, elderly, and dead tree is replaced by the City with at least one younger, smaller tree of a species native to this region of central Texas.

4.7.1 Effects of Maintenance of Manicured Lawns Along the Riparian Corridors of Barton Springs Pool and Eliza Spring

Natural vegetation around springs and their outflow streams is typically much more dense and diverse that what is present today around Barton Springs Pool, Eliza Spring, and Old Mill Spring. Sparse tree canopy affects water temperature of the springs. During hot, dry weather, solar radiation can cause the upper layer of the water column to become warmer. Since warmer water cannot hold as much dissolved oxygen, it can directly affect salamander health. Loss of canopy cover also deprives aquatic ecosystems of natural organic materials that feed aquatic invertebrates and fuel numerous ecosystem processes. This can have indirect effects on aquatic salamanders by reducing abundance and diversity of prey.

The amount of canopy cover and natural riparian vegetation varies among spring sites. Parthenia and Eliza Spring have the least riparian vegetation, followed by Old Mill Spring. Thus, effects are variable and dependent on additional factors such as water depth, aquifer discharge, flow regime, and historic structures. Solar irradiance decreases with increasing depth below water surface (Wetzel 2001). In general, effects of increased sunlight will be greater in shallower water, but also mediated by flow of cool groundwater from the springs (Hynes 1972). Water temperature will also be the warmest during droughts when there is less cool aquifer water exiting the springs. Another factor that can interact with increased water temperature from direct sun is flow regime. Freely flowing water can help mitigate increased water temperature at the surface by preventing warming of the entire water column in a spring pool. Unimpeded flow regimes enhancing mixing of cooler water exiting the aquifer with water at the interface with hot air.

Increased water temperature resulting from a lack of canopy vegetation affects Eliza and Old Mill Spring more severely than Parthenia Spring because water depths are shallower and allowed to fluctuate with the aquifer water table. In Barton Springs Pool, the top layer of water affected by hot weather affects only a small portion of habitat of Parthenia Spring (approximately a few hundred square feet in the fissures). Old Mill Spring has little canopy cover, moderately impeded water flow, and the least discharge from the aquifer; it experiences the highest water temperatures during drought. Eliza Spring also has little canopy cover but water is generally free flowing; consequently, increases in water temperature are less. Lack of natural inputs of organic material from terrestrial vegetation (allochthonous inputs) is most severe in Parthenia Spring. City staff partially counteract this problem by manually placing some of the leaves raked from the lawns around Parthenia Spring in aquatic habitat.

There are no data that can be used to quantify take from maintenance of manicured lawns specifically. However, the ongoing, long-term detrimental effects on Barton Springs' *Eurycea* are an inherent part of take arising from public use.

4.8 Maintenance of Historic Structures and Anthropogenic Flow Regime Alteration of Parthenia Spring, Eliza Spring, and Old Mill Spring

There are historic amphitheaters around Eliza and Old Mill springs, and concrete dams and walls of Barton Springs Pool upstream and downstream of Parthenia Spring (see section 2.8 for detailed descriptions of these structures.) In addition, water depth in Barton Springs Pool is maintained at a constant water depth under all aquifer discharge conditions to create a desirable environment for swimming. Water depth is decreased during drawdowns only (see actions 4.3 and 4.4 for descriptions).

4.8.1 Effects of Historic Structures and Anthropogenic Flow Regime Alteration of Parthenia Spring, Eliza Spring, and Old Mill Spring

An examination of the effects of anthropogenic flow regime alterations is critical to understanding the need for habitat reconstruction to improve the long-term fates of *E. sosorum* and *E. waterlooensis*. In general, the impoundments are physical barriers to surface migration among sites resulting in fragmentation of surface habitats. Impoundments alter natural flow regimes resulting in increased silt deposition, and ultimately, alter the natural variation of the ecosystem and its inherent resilience to environmental perturbations. The effects of flow regime alteration are constant and cumulative and are not localized; they affect all of salamander habitat. Consequently, they affect entire populations of salamanders and therefore are a threat to the long-term persistence of endemic *Eurycea* species (see section 2.3).

The dams, concrete, and masonry structures built around Eliza, Parthenia and Old Mill springs alter natural flow regimes and thereby the spring ecosystems in ways that negatively affect salamander populations. Impoundments that alter the natural flow regime change the natural temporal variation in water depth and current speed. Water depth is not allowed to increase and decrease naturally with aquifer discharge; it is maintained at relatively constant depths. The historic amphitheaters around Eliza and Old Mill Spring affect the proximity and amount of vegetation around the spring pools and outflow streams. The series of tiered, concrete benches around the perimeter of the spring pool in Eliza Spring and tiered walls around Old Mill Spring limit proximity of canopy vegetation to no closer to Eliza or Old Mill Spring than 6 feet and 3 feet, respectively. The concrete walls of Barton Springs Pool also prevent development of a natural terrestrial and emergent aquatic plant community on the banks of Parthenia Spring.

In Old Mill and (to a greater extent) Parthenia Spring, impoundments create unnaturally deep water, which is more suitable for increased densities of predatory fish. Increased pressure from novel resident predators can increase salamander mortality, can alter salamander behavior (Gillespie 2011), and ultimately, can lead to lower population sizes. Smaller populations are less resilient to demographic and environmental stochasticity (Muller 1950, Bell 1982, Lynch and Gabriel 1990, Lynch 1996, Maynard Smith 1998). These impoundments, by reducing the water velocity, also enhance sediment deposition that fills interstitial spaces used as microhabitat by salamanders (see section 3.3.3). Finally, some of the ecological effects of dams on the aquatic environment in Barton Springs Pool are undesirable and unpleasant for recreation, particularly overabundance of planktonic or loosely attached nuisance periphytic algae, and turbid water caused by excess sediment.

4.9 Salamander Habitat Reconstruction

Included in this Plan are several habitat reconstruction projects designed to reverse the anthropogenic flow regime and habitat modifications of the past which have resulted in loss and fragmentation of surface habitat by eliminating of surface connections among sites and degradation of aquatic habitat quality. The modification of flow regimes and surface habitat fragmentation is largely a result of man-made structures and impoundments originally constructed to enhance public use of Parthenia Spring, Eliza Spring, and Old Mill Spring. Site-specific habitat reconstruction focuses on removal or modification of these structures (see Appendix B for detailed description of projects).

Reconstruction in Eliza Spring will consist of restoration (or "daylighting") of the outflow stream and of the natural substrate of the spring pool. In 1929, the outflow from this spring pool was diverted into a concrete pipe and buried beneath several feet of fill soil. In the 1940s, a concrete floor was laid over the natural substrate of the spring Pool. Both of these modifications will be reversed over the term of this amended HCP.

Reconstruction in Old Mill Spring will consist of replacement of a portion of the masonry wall that impedes outflow from the spring pool with adjustable operable gates. This will remove the permanent obstruction of water flow to the outflow stream and provide a mechanism of maintaining water in the spring pool if necessary. The gates will be reminiscent of the dam gates from the mill that once operated at the site. In addition, excess rock, trash, and debris in the spring pool will be gradually removed to restore the natural elevation of the spring pool and enhance directional flow of water from the springs.

4.9.1 Effects of Salamander Habitat Reconstruction

The short-term effects of habitat reconstruction will be disturbance of salamander habitat for discrete periods of time. These effects will be outweighed by the long-term cumulative and beneficial effects. Reconstruction in all three perennial spring sites will increase the size of habitat and improve habitat quality, which will increase carrying capacity and potential salamander population size. Larger population sizes allow for more resilience of populations to environmental perturbations such as drought. Mortality rates affect large populations much less than small populations simply because the total number of animals unaffected is larger. Therefore, the ultimate benefit of habitat reconstruction is the promotion of long-term species persistence.

Habitat reconstruction in Eliza and Old Mill springs will have short-term, detrimental impacts on resident salamander populations; therefore, they are included in the assessments of biological impacts and take. However, the ongoing, long-term detrimental impacts of flow regime alteration are expected to disappear once habitat reconstruction in Eliza and Old Mill springs is completed. The ultimate effects of these projects over the 20-year span of this amended HCP will be beneficial.

The ongoing, long-term detrimental effects of the dams around Parthenia Spring are unquantifiable with currently available data. These long-term effects are unlikely to be completely eliminated over the term of this permit because they are an inherent part of maintenance of Barton Springs Pool as a swimming area. Partial restoration of natural flow regime is possible through changes in operation of dam gates and modifications to the dams. An investigation to identify appropriate modification of the dams is underway. However, implementation of dam modifications is not expected to occur during the 20-year period of this amended HCP. Hence, take from dam modification has not been included.

4.10 Cumulative Effects of Actions in this Plan

Long-term cumulative effects of all the actions in this HCP are expected to be beneficial. The effects of recreational use are not expected to significantly hamper viability and recovery of *E. sosorum* or *E. waterlooensis*. Anthropogenic noise and disturbance from recreation, cleaning, drawdowns, and flood debris removal in Barton Springs Pool and recreation in Upper Barton Spring will likely have some detrimental effect on resident salamanders. However, these actions will be localized and transient, not likely to result in severe effects on salamander survival. Furthermore, under some environmental conditions, some actions may occur at the same time. For example, when Barton Springs' discharge is high enough to permit a drawdown of Barton Springs Pool, habitat cleaning can be conducted while water is drawn down, reducing the annual frequency of habitat and salamander disturbance. The limited number and short duration of drawdowns and episodes of habitat cleaning render both actions unlikely to detrimentally affect reproduction. The most significant potential long-term baseline effect of harassment from all actions combined would be an unnatural delay or decrease in reproduction.

Take of *E. waterlooensis* from actions in this HCP will be smaller than that of *E. sosorum* because these salamanders exist primarily in subterranean areas where they are buffered from activities at the surface.

4.11 Additional Threats

The major threats to the persistence of *E. sosorum* and *E. waterlooensis* are degradation of quality of both ground and surface waters and depletion of groundwater in the Barton Springs Segment of Edwards Aquifer (USFWS 1997, USFWS 2005). Each of these threats and potential sources as they relate to Barton Springs are discussed below.

4.11.1 Water Quality Degradation

The Edwards Aquifer has been ranked most vulnerable to degradation from anthropogenic contamination statewide based on its hydrogeological structure (Texas Groundwater Protection Committee 2003). The water quality of the Barton Springs complex is primarily determined by quality of surface water in the in the recharge zone. Surface waters influence Barton Springs because they recharge the aquifer and mix with the groundwater as it travels to downstream springs. The quality of groundwater emanating from Barton Springs is positively related to quality of recharging waters (Mahler *et al*. 2006). The character of that relationship varies with amount of groundwater discharge and surface conditions (storms *vs*. base flow) (Mahler *et al*. 2011, Johns 2006; see section 3.2.3). Surface waters in Barton Creek also influence the Barton Springs complex when they flow through Parthenia and Upper Barton springs during floods and base flow (see section 3.2.3), although base flow has been diverted around Barton Springs Pool since 1974. Eutrophication and pollutants associated with runoff from urban areas are most likely to negatively affect Barton Springs.

Eutrophication, or nutrient enrichment, may be driven by anthropogenic additions of nitrogen compounds (Wetzel 2001). Elevated concentrations of nitrogen or phosphorus, increased dominance of blue-green algae (*Cyanophyta*), or increases in the amount of algae indicate nutrient enrichment (Masters 1991). Additional signs of eutrophication or transient nutrient enrichment are chronic reduction in dissolved oxygen concentrations and localized dissolved oxygen sags from increased biological oxygen demand (Wetzel 2001, Masters 1991). Dissolved oxygen concentrations in Parthenia Spring appear to be decreasing over time (Turner 2009, Herrington and Hiers 2010); on average, discharge-corrected dissolved oxygen concentrations have decreased 1 mg/L since 1998 (Turner 2009). Orthophosphates in Parthenia Spring are typically below analytical detection limits, but nitrate concentrations are increasing over time (Herrington and Hiers 2010, Mahler *et al*. 2011). During some dry conditions, the load of nitrate in groundwater discharging from Parthenia Spring is greater than the load in recharging surface streams, while during some wet conditions, the load in recharging waters is greater (Mahler *et al*. 2011). While these patterns suggest nutrient enriched recharging water, they are also consistent with variation in microbial conversion of organic nitrogen into gaseous nitrogen as water travels underground (Bandursky 1965, Lloyd *et al*. 1987, Poth 1986, Clark *et al*. 1991, West and Chilton 1997) although the amount of denitrification in the aquifer if any is unknown. Empirical studies indicate that surface waters in creeks in the contributing zone are sensitive to nutrient enrichment (Herrington and Scoggins 2006, Mabe 2007, Turner 2010, Mahler et al. 2011). Theoretical investigations suggest that increased nutrient enrichment of surface waters in the recharge zone could increase nutrient concentrations in Barton Springs (Herrington 2008a, Herrington 2008b, Richter 2010). Distance and time underground, in addition to variation in available oxygen, temperature, and pH influence microbial processes and rates of chemical conversion and could also influence nutrient concentrations in surface habitat (Wetzel 2001, Kalff 2002).

Entry of chemical pollutants into surface waters also contributes to water quality degradation. Concentrations of heavy metals have been above levels of concern in storm flow dominated groundwater emerging at Parthenia Springs (City of Austin 2011b). Some pesticides and herbicides have been detected in Barton Springs. Higher concentrations occur during storm flow, while they were only occasionally detectable during base flow (Mahler *et al*. 2006). Atrazine was the most commonly detected pesticide in groundwater in the Barton Springs complex with concentrations above analytical detection limits in 72% of 217 samples from 1982 to 2012 with a maximum detected value of 3.19 micrograms/L from Upper Barton Spring during a storm event in 2001 (City of Austin unpublished data).

Storm water runoff is a well-documented source of pollutants and nutrients to the Barton Springs complex (Mahler *et al*. 2006, Mahler *et al*. 2011). Increasing urbanization contributes to reductions in the quality of runoff in the Barton Springs Zone (Herrington et al. 2011). Greater amounts of impervious cover are directly related to higher amounts of runoff, flashier flooding, and less soil-mediated percolating recharge (Leopold 1968), all of which contribute to entry of pollutants and nutrients into ground water (Herrington *et al*. 2007). Disturbance of the landscape during construction can also contribute to transport of pollutants and excess suspended solids into waterways (USEPA 1999). Additional anthropogenic sources of increased nutrients and pollutants in groundwater and surface water include leaking wastewater infrastructure, land application of wastewater effluent, livestock operations, and domestic pets (Herrington *et al*. 2011, see section 2.7). A final source of aquatic pollutants is accidental spills of wastewater, treated drinking water from broken distribution lines or from vehicles transporting hazardous chemicals on surrounding roadways.

Water quality degradation can occur in many ways and can affect salamanders and their habitat differently depending on the type of pollution. Nutrient loads can alter the ecology of salamander habitat and contaminants can affect salamanders directly or indirectly through effects on prey or other species in the aquatic community. Amphibians are sensitive to many pollutants (Birge *et al*. 2000), including heavy metals (Linder and Grillitsch 2000), pesticides (Howe *et al*. 1998, Larson *et al*. 1998, Diana *et al*. 2000, Hayes 2000), and organic compounds (Sparling 2000, Bryer *et al*. 2006). Contaminants may have acute or chronic, lethal or sub-lethal effects on aquatic juvenile and adult salamanders (Bommarito *et al*. 2010). Both juvenile and adult *E. sosorum* and *E. waterlooensis* are more vulnerable to chronic exposure to waterborne contaminants than metamorphic species because these salamanders remain aquatic throughout their life.

Chronic anthropogenic addition of nutrients (nitrogen and phosphorus compounds) to aquatic ecosystems can have a variety of direct and indirect effects on protected salamanders. Excess nutrients can exert direct toxic effects on a variety of aquatic fauna. High concentrations of nitrates and nitrites alter embryonic development (Ortiz-Santaliestra and Sparling 2007), decrease larval survival (Marco *et al*. 1999), and reduce adult male body size and expression of secondary sexual characteristics in metamorphic newts (Secondi *et al*. 2009). Camargo *et al*.

(2005) reviewed scientific literature on the effects on nitrates on both marine and freshwater fauna, concluding that nitrate concentrations higher than 2 mg/L are detrimental to freshwater amphibian, fishes, and invertebrates. While concentrations of nitrate in Parthenia Spring are typically below this threshold (Mahler *et al*. 2011), continued urbanization could increase the anthropogenic additions of nitrogenous compounds to Barton Springs.

Excess nutrient enrichment can also dramatically alter freshwater ecology (Wetzel 2001, Masters 1991). It drives rapid growth of aquatic flora and persistent algal overabundance and may alter algal community composition affecting other characteristics of the aquatic biological community. Excess nutrients promote cycles of transient blooms of planktonic or nuisance periphytic algae, followed by high algal mortality and decomposition ultimately resulting in increased biological oxygen demand (Masters 1991) and reductions in dissolved oxygen concentration. Thus, excess nutrient input from anthropogenic sources imposes indirect effects on salamanders by altering physical and chemical characteristics of habitat.

4.11.2 Reduction in Water Quantity: Drought and Groundwater Withdrawal

While lack of rainfall feeding the aquifer is part of the natural climatic variation under which *E. sosorum* and *E. waterlooensis* evolved, present-day droughts are magnified by anthropogenic activities. All three perennial springs are impounded by dams or other obstructions and discharge from each of the springs is differentially affected by upstream withdrawal of groundwater. Therefore, droughts are semi-natural factors because their severity can be affected by anthropogenically driven increases in frequency or duration. These changes are likely to magnify effects on *E. sosorum* and may compromise persistence of the species if they occur faster than the species can evolve.

Droughts also affect water quality. Increases in water temperature and decreases in dissolved oxygen were the most notable changes in the Barton Springs complex during recent droughts (Appendix A Dries 2012). Reduction in dissolved oxygen concentration in the Barton Springs complex is correlated with decreasing discharge (Woods *et al*. 2010, Turner 2009), with Old Mill and Eliza Spring experiencing the greatest reductions in dissolved oxygen (Woods et al. 2010). Increased water temperature in Old Mill and Eliza Spring (City of Austin unpublished data) during droughts has driven dissolved oxygen down to concentrations detrimental to salamander health (Appendix A Dries 2012). Evaporation under low discharge conditions when the spring pool of Old Mill Spring becomes an isolated pond may increase the concentration of salts and pollutants.

Decreases in discharge are associated with reduction in current velocity of water and generally causes decreases in dissolved oxygen in rivers and streams (Lampert and Sommer 1997, Giller and Malmqvist 1998, Wetzel 2001). The maximum concentration of oxygen that can be dissolved in water is inversely dependent on water temperature (Boyle 1662, Levine 1978, Wetzel 2001); the warmer the water, the less dissolved oxygen it can hold.

Since dissolved oxygen and temperature can influence every aspect of the aquatic community (Cushing and Allan 2001, Giller and Malmqvist 1998 references therein; Wetzl 2001 and references therein), drought-related reductions in spring discharge can have strong effects on resident flora and fauna. Drought has significant effects on *Eurycea sosorum* populations; it is clear that *E. sosorum* adults reduce or delay reproduction in the wild under extended adverse environmental conditions (See section 4.2.2). One response of adult salamanders is an apparent retreat to subterranean habitat. The cumulative effects of anthropogenically-enhanced drought may only become apparent if populations do not rebound as expected after the drought ends. Unfortunately, the time frame of post-drought resumption of reproduction is unknown. City data indicate that *E. sosorum* populations have not fully recovered yet from the 2008-2009 drought as there was little reproduction and recruitment in the subsequent year. Droughts are also correlated with lower abundances of aquatic invertebrates in Barton Springs (Geismar and Herrington 2007, Gillespie 2011).

A potential factor of anthropogenically-enhanced drought that would influence viability of *E. sosorum* is whether subterranean habitat serves as a refuge from poor surface habitat conditions. While subterranean water temperature is likely to be cooler and less variable, dissolved oxygen concentrations are not likely to be higher than in surface habitats (Lazo-Herencia *et al*. 2011, Winograd and Robertson 1982). Retreat into subterranean habitat by *E. sosorum* isn't likely to counteract the effects of low dissolved oxygen concentrations in surface habitat. An unknown potential effect of retreat to subterranean habitat for extended periods of time is a change in the natural overlap in ranges of *E. sosorum* and *E. waterlooensis*. One possibility is that as *E. sosorum* retreats into subterranean habitat, *E. waterlooensis* retreats deeper into the aquifer, thereby maintaining natural overlap. This may subject *E. waterlooensis* to lower dissolved oxygen concentrations. Dissolved oxygen from a ground water sample taken from a well at 295 ft underground and roughly 1 mile upstream of Barton Springs (Lazo-Herencia *et al*. 2011) was 3.5 mg/L, while in surface habitat of Barton Springs it was 4.2 mg/L. Dissolved oxygen content of water from deeper portions of the aquifer under Barton Springs is unknown, but has been shown to decrease with increasing depth underground in other confined carbonate aquifers (Winograd and Robertson 1982). Alternatively, as *E. sosorum* retreats, overlap with *E. waterlooensis* could increase. In this case, as density of salamanders of both species increases, interspecific competition for resources also increases while abundance of resources decreases. The natural histories of both species suggest that there is potential for niche overlap and direct competition for resources. The two species have some overlap in diet as both eat amphipods and other aquatic invertebrates (Chippindale *et al*. 1993, Hillis *et al*. 2001, Chamberlain and O'Donnell 2002, Chamberlain and O'Donnell 2003). Moreover, abundance of aquatic subterranean fauna is generally much lower than similar surface fauna, predominantly a result of lack of photosynthetic primary production in the dark (Culver and Pipan 2009). Since both species are known to prey on each other, an increase in range overlap would also increase predation risk (Sket 1986). These conditions of limited resources, increased competition and predation risk can lead to competitive exclusion and extinction of one species. Anthropogenically derived degradation of surface water habitat is cited as the ultimate cause of competitive exclusion of a subterranean isopod (*Asellus aquaticus cavernicolous*) by a surface isopod (*Asellus aquaticus aquaticus*). Eutrophication of surface water drove the surface isopods into subterranean habitat, which increased competition with the subterranean isopods for resources, and ultimately resulted in extirpation of the subterranean species (Sket 1977). Conversely, degradation of subterranean habitat that drives underground fauna into surface habitat can also increase competition and drive competitive exclusion processes.

Anthropogenically increased range overlap can increase the chance of interspecific hybridization, resulting in reductions of reproductive fitness of both species. Loss of reproductive fitness directly compromises viability of species. Whether potential competition, predation risk, or hybridization between *E. sosorum* and *E. waterlooensis* are mediated by character displacement, pre-mating reproductive isolation or tandem range displacement is unknown.

5.0 Take Assessment

Actions in this HCP expected to cause incidental take can be categorized as recurrent, or discrete and finite. Recurrent actions are those expected to occur multiple times over the duration of the permit. Some may occur multiple times annually (habitat cleaning, maintenance drawdowns, flood drawdowns, public use), while others occur less than annually (flood debris removal). The frequency and magnitude of occurrences of these actions are dependent on environmental conditions and will vary from year-to-year. For example, within a given year maintenance drawdowns might not be conducted because aquifer discharge is not above the permitted threshold, yet habitat cleaning may occur more frequently. On the other hand, when Barton Springs' discharge is 54 ft^3/s or greater drawdown and habitat cleaning may occur simultaneously. The number of flood-related drawdowns is dependent on whether flooding occurs and deposition of flood debris might not be sufficient to warrant bi-annual removal. Annual and inter-annual variation in weather affects the amount of recreation use of Barton Springs Pool and Upper Barton Spring. During drought, there is little recreational impact at Upper Barton Spring because it isn't flowing, while recreational use of Barton Springs Pool typically increases with hot, dry weather. Consequently, actual take of protected salamanders will also vary annually. Rather than try to estimate future frequency of occurrence of all maintenance actions under all environmental conditions, take has been estimated as if all of these actions were to occur the maximum number of times annually.

Salamander abundance and density also vary with environmental conditions, thus, annual take will vary with salamander abundance, as it does with recurrent actions. Using mean abundance or density plus 1 standard deviation to calculate take incorporates the range of variation based on salamanders found in a single day. Incorporation of the range of variation will overestimate actual take when salamander abundance is low, and underestimate take when abundance is very high. However, the ranges of abundance and density are calculated from data collected over a series of single-day surveys, they do not reflect cumulative number of salamanders observed over an entire year. Since this HCP estimates annual take from recurrent actions as the sum of take from each occurrence, the range of annual cumulative salamander abundance should be considered also. This approach allows for assessment of cumulative effects on the species over the duration of the permit assuming maximum take. Assuming maximum rather than minimum take incorporates the uncertainty of future annual environmental conditions.

Finally, abundance and density of *E. sosorum* varies among sections within Parthenia and Eliza Spring. In Parthenia Spring, abundance and density differ significantly among the spring mouths (Main, Little Main, Side Spring), the fissures (Main Fissure, Fissures), and the Beach (Kruskal-Wallis $H_{abundance} = 197.56$, $p < 0.0001$; $H_{density} = 260.7$, $p < 0.0001$). The majority of salamanders in Parthenia Spring are found in the rocky substrate near the spring mouths (Figure 12, Table 13), consequently mean density is higher in these sections relative to fissures and beach areas. In contrast, only a portion of the upstream 3,900 $feet^2$ of the Beach (Beach 1 and Beach 2) has suitable habitat and salamander densities are very low. Take due to actions that affect particular areas of Parthenia Spring habitat is calculated based on area-specific salamander densities. Take from actions that affect all of habitat in Parthenia Spring (*e.g.*, habitat cleaning) is calculated based on overall salamander densities. Take in Parthenia Spring was calculated based on salamander density or number stranded in the areas affected by the action. Salamander abundance in Eliza Spring is significantly higher in quadrants III and IV combined (Mann-Whitney $U = 8861.5$, $z = -2.960$, $p = 0.0031$) than in I and II combined (Table 13). For proposed concrete removal in Eliza Spring, salamander abundance was calculated per quadrant to best estimate take. There are no significant differences in abundance of *E. sosorum* among sections within Old Mill and Upper Barton Spring, therefore, the entire area of surface habitats of each spring were used to calculate take.

It also should be noted that over 60% of the proposed lethal take is due to discrete, finite habitat reconstruction projects, rather than recurrent actions. Once these projects are completed, there is no more take associated with them for the remaining duration of the permit.

5.1 Take Rationale

It is extremely difficult to determine precisely the number of salamanders that will be harmed or harassed annually by actions in this amended HCP. (Effects of population monitoring are covered under a federal 10(a)(1)(A) permit.) In particular, it is nearly impossible to accurate predict take from recreational disturbance. To date, there have been no documented salamander mortalities from recreational disturbance of habitat, although there is little possibility of finding the body of a dead salamander before it deteriorates, flows downstream, or is eaten. In Barton Springs Pool, patrons are explicitly prohibited from disturbing salamander habitat but 100% compliance is unlikely. In estimating take due to recreation, key factors would include the number of people in a habitat area as well as the number of salamanders present in that area and the likelihood that a foot or a dropped boulder and a salamander are in the same location at the same moment. Salamander abundance in the future is assumed to reflect past abundances. However, take is a function of the number of salamanders as well as the frequency of harm. While periodic surveys provide adequate estimates of salamander abundance in these areas, there is not enough information on the frequency of interactions between swimmers and salamanders in these areas to generate a precise, quantitative estimate of take from recreation. Swimmer disturbance of habitat may occur at relatively low frequencies even when recreational use is high and area disturbed is localized. Therefore, a dual approach for estimating lethal and non-lethal take is used.

In determining lethal take, it is possible to detect lethal effects of disturbance if that disturbance is observed. Lethal take is estimated based on area of habitat where potentially lethal activities occur (dropping rocks, disturbing substrate). Annual cumulative localized disturbance is assumed to be equal to the total area in front of the orifices of Parthenia Spring multiplied by average salamander density. Conservation measures are estimated to be 95% effective at reducing take, leaving only 5% of the product as lethal take.

In determining non-lethal take, harassment cannot be accurately and directly detected even if disturbance is observed. Therefore, harassment take is expressed as all of the salamanders present in total habitat area, rather than a numerical estimate. The actual level of annual take is anticipated to be much lower per month than the average salamander density, although the interactions between humans and salamanders are extremely variable. No incidental take from recreation is expected at Eliza or Old Mill Spring because public access is intentionally restricted at these sites.

Habitat reconstruction projects are discrete, finite actions. These projects may be conducted as small-scale, gradual and incremental improvements over extended periods of times (*e.g.*, substrate restoration in Old Mill Spring, multiple phases of concrete removal in Eliza Spring), but once the project is completed those activities are not anticipated to occur again over the duration of the permit. Since these projects are site-specific, appropriate conservation measures will be implemented to ensure that take will not exceed the estimates provided in this HCP.

Conservation Measures Effectiveness

Since 1998, take from recurrent activities has been minimized by following conservation measures in the 1998 Habitat Conservation Plan, and by refining materials, methods and techniques used to implement those measures (*e.g*., reducing water pressure for cleaning, gradual drawdowns of water, relocating stranded salamanders). These minimization efforts resulted in substantially less lethal take of *E. sosorum* and *E. waterlooensis* than occurred before permit implementation in 1998. Based on the success of these efforts, take estimates for this HCP assume lethal take resulting from recurrent activities will be reduced by 95% because of the continuation of these minimization efforts. Take from discrete, finite projects will also be minimized by implementation of additional project-specific conservation measures. These are expected to reduce the proportion of lethal take from 100% to 10% for discrete projects. This reduction is based on the success of conservation measures from previously completed projects, scientific information, and experience with similar activities. It also incorporates the additional uncertainty in short-term detrimental effects of new projects by assuming a 5% reduction in effectiveness of conservation measures.

5.2 Take Calculation Methods

The methods of calculating take are divided into three sections: take from recurrent actions, take for habitat reconstruction projects, and take for recreation. Recurrent activities and discrete projects utilize summary statistics of salamander monitoring data or take observed during implementation of the previous Habitat Conservation Plan. Summary statistics from salamander monitoring are based on salamander abundance data from each habitat area of Parthenia Spring, Eliza Spring, Old Mill Spring, and Upper Barton Spring (Table 13). Observed non-lethal take data are derived from observations following flood debris removal and drawdowns from 2003 through 2010 (Table 14); no lethal take was observed during these activities. Potential take from all sites is calculated with data from 2003 through 2010 (Table 14). Density of salamanders per sample was used to calculate the grand mean, standard deviation, and standard error. For each activity, lethal and harassment take are totaled and rounded up to the nearest whole number when the value is greater than or equal to 0.5 (Equation 3).

Table 13. Salamander density and abundance by section in Parthenia Spring and Eliza Spring, and all sections combined of Old Mill Spring and Upper Barton Spring, based on census survey data from 2003-2010. Mean and one standard deviation (S.D.) shown, with number of surveys (N). Maximum number of salamanders is the total number of salamanders found in a single survey. Densities in primary habitat of Parthenia Spring were calculated using total area of designated habitat, which includes area not surveyed regularly. There was only 1 survey that included Beach 2 and 3 during this period thus, mean and standard deviation were not calculated (n/a). Maximum number of salamanders found in any survey shown.

Spring Site:	**Area**	**Density (#/ft²)**			**Abundance (#)**		**Max**
Habitat Section	**(ft²)**	**Mean**	**S.D.**	**N**	**Mean**	**S.D.**	**no.**
		Eurycea sosorum					
Parthenia: All Habitat		0.012	0.028	59	74.4	86.0	447
Parthenia: Fissures	6850	0.003	0.011	88	1.0	2.4	19
Parthenia: Spring Mouths	4025	0.016	0.033	182	24.2	53.0	412
Parthenia: Beach 1	1300	0.0003	0.001	6	0.3	0.8	2
Parthenia: Beach 2	2600	0	n/a	1	0.0	0	0
Parthenia: Beach 3	7100	0	n/a	1	0.0	0	0
Eliza: Whole Spring	800	0.43	0.35	78	348.9	274.5	1234
Eliza: Quad I	225	0.57	0.37	71	125.9	80.9	361
Eliza: Quad II	225	0.43	0.38	72	93.5	78.9	363
Eliza: Quad III	175	0.43	0.42	74	75.2	73.5	359
Eliza: Quad IV	175	0.48	0.38	73	84.3	66.7	286
Old Mill Spring	2042	0.01	0.02	73	15.1	21.7	73
Upper Barton Spring	0-550	0.02	0.03	47	6.1	11.7	100
		Eurycea waterlooensis					
Parthenia: All Habitat		0.0001	0.0003	59	0.40	0.91	5
Parthenia: Fissures	6850	0.0002	0.001	88	0.05	0.26	2
Parthenia: Spring Mouths	4025	0.0001	0.0003	182	0.11	0.41	183
Parthenia: Beach 1	1300	0.0001	0.0003	6			
Parthenia: Beach 2	2600	0	n/a	1	0.14	0.38	7
Parthenia: Beach 3	7100	0	n/a	1	0	0	0
Eliza: Whole Spring	800	0.001	0.003	78	1.14	2.24	12
Eliza: Quad I	225	0.001	0.003	71	0.23	0.70	5
Eliza: Quad II	225	0.001	0.004	72	0.26	0.86	6
Eliza: Quad III	175	0.003	0.009	74	0.55	1.5	11
Eliza: Quad IV	175	0.001	0.003	73	0.25	0.62	3
Old Mill: Whole Spring	2042	0.003	0.006	73	3.6	8.0	43
Upper Barton Spring	0-550	0	0	47	0	0	0

Table 14. Observed non-lethal take from flood debris removal projects and drawdowns from 2003 through 2010 are presented below. The cumulative sum of salamanders of each species observed stranded or otherwise affected is listed. Also provided are the mean, one standard deviation (S.D.), number of incidents (N), and range for each species. There was no observed lethal take from any of these activities.

	E. sosorum					***E. waterlooensis***			
Spring	**Sum**	**Mean**	**S.D.**	**N**	**Range**	**Sum**	**Mean**	**S.D.**	**Range**
Flood Debris Removal									
Parthenia	0	0		2	0	0	0	0	0
Drawdowns: Cleaning									
Parthenia	13	0.43	1.2	30	0-5	0	0	0	0
Eliza	1	0.04	0.2	30	0-1	0	0	0	0
Drawdowns: Floods									
Parthenia	0	0		21	0	0	0	0	0
Eliza	0	0		21	0	0	0	0	0

5.2.1 Take calculation for recurrent activities

Recurrent activities that may impose take include drawdowns, habitat cleaning, floods, and flood debris removal. Total annual take for each species per activity was calculated by multiplying the area of habitat disturbance times the density of salamanders present in that specific area of habitat (Table 13) and multiplied by the number of maximum allotted recurrences for each year (Equation 1).

Total annual Take for each species per activity was calculated by multiplying the area of habitat disturbance times the density of salamanders present in that specific area of habitat and multiplied by the number of maximum allotted recurrences for each year (Equation 1).

Eq. 1 Annual Take calculated for full drawdowns of Barton Springs Pool
(Area affected) * (density + 1 S.D of *E. sosorum*) * (# of events/year)
example: 3040 ft^2 * 0.014 *E. sosorum*/ ft^2 * 4 events/year = 170.24 = 170 *E. sosorum*/year

Non-lethal take in the form of harassment is estimated by calculating 95% of Equation 1 (Equation 2) because 5% of total take from recurrent activities is assumed to be lethal and thus the 95% remaining total take is assumed to be non-lethal.

Eq. 2 Non-lethal take for full drawdowns of Barton Springs Pool
(Equation 1) * (95%)
example: 170 *E. sosorum*/year * 0.95 = 161.5 = 162 *E. sosorum*/year

Lethal take is estimated by calculating 5% of Equation 1 (Equation 3).

Eq. 3 Lethal take for full drawdowns of Barton Springs Pool
(Equation 1) * (5%)

example: (170 *E. sosorum*/year) * 0.05 = 8.5 = 9 *E. sosorum*/year

5.2.2 Take calculation for habitat reconstruction projects

Habitat reconstruction projects that may impose take include removal of concrete from habitat areas, reconstruction of the Eliza Spring outflow stream, substrate restoration in Eliza and Old Mill springs, and flow regime improvements. Total annual take for each species per activity was calculated by multiplying the area of habitat disturbed times the average density of salamanders present in that habitat area over the period of record (Equation 4).

Eq. 4 Take calculated for Eliza Spring stream reconstruction
(Area affected) * (density + 1 S.D. of *E. sosorum*)
example: 350 ft^2 * 0.85 *E. sosorum*/ft^2 = 297.5 *E. sosorum*

Non-lethal take in the form of harassment is calculated by calculating 90% of Equation 4 (Equation 5) because 10% of total take from reconstruction activities is assumed to be lethal and thus the 90% remaining total take is assumed to be non-lethal.

Eq. 5 Non-lethal take calculated for Eliza Spring stream reconstruction
(Equation 4) * (90%)
example: 297.5 *E. sosorum* * 0.90 = 267.7 *E. sosorum*

Lethal take is calculated by finding 10% of Equation 4 (Equation 6). For each activity, lethal and harassment take are totaled and rounded up to the nearest whole number when the value is greater than or equal to 0.1.

Eq. 6 Lethal take for Eliza Spring stream reconstruction
(Equation 4) * (10%)
example: 297.5 *E. sosorum* * 0.10 = 29.8 *E. sosorum*

5.3.3 Take calculation for recreation

Non-lethal take for recreation is expressed as all of the salamanders present in the total habitat area. The actual level of annual take is anticipated to be much lower per month than the average salamander density, although the interactions between humans and salamanders are extremely variable. Lethal take is estimated based on area of habitat where potentially lethal activities occur (dropping rocks, disturbing substrate). Conservation measures are estimated to be 95% effective at reducing take in Parthenia Spring, where lifeguards are present during increased recreation periods, and only 80% effective at reducing take in Upper Barton Spring where no lifeguards are present.

Eq. 7 Lethal take for Parthenia Spring Recreational Disturbance
(Area affected) * (density + 1 S.D. of *E. sosorum*) * (5%)
example: 2485 ft^2 * 0.049 *E. sosorum*/ft^2 *0.05 = 6.1 = 6 *E. sosorum*

No incidental take from recreation is expected at Eliza or Old Mill Spring because public access is intentionally restricted at these sites. No take of *E. waterlooensis* at Upper Barton Spring is estimated from recreation as no *E. waterlooensis* have been observed at this site. Take from the fissures and beach areas of Parthenia Spring are estimated to be less than 1 salamander per year, as very few *E. waterlooensis* have been observed in these areas (a grand total of 5 from 2002 to 2010). Take from areas abutting large spring mouths (sections: Main Spring, Side Spring, Little Main Spring) is estimated to be up to 1 per year based on abundance in this area.

5.3 Incidental Take of Covered Species

Incidental take of *E. sosorum* and *E. waterlooensis* from recurrent and discrete actions is presented below in Tables 15 – 21.

Table 15. Estimates of *E. sosorum* annual incidental take in Parthenia Spring from recurrent actions. Salamander density in each habitat section is the mean density plus one standard deviation (SD). Take is the product of density, area of affected or exposed habitat, and maximum number of occurrences annually. Conservation Measures (CMs) are assumed to be 95% effective in reducing lethal take. Total number of future annual flood drawdowns is unknown, therefore no number is provided. Density values are taken from Table 13. Maximum sum of salamanders in one year = 1598 (Table 10).

***Eurycea sosorum* Parthenia Spring**							
Action (habitat affected)	**Habitat Area (ft^2)**	**Density Mean + 1 SD ($no./ft^2$)**	**Actions Annually (max)**	**Lethal Take (no.)**		**Harassment Take w/CMs (no.)**	**Total Take (no.)**
				No CMs	**With CMs**		
Drawdowns Maintenance	Exposed						
Full (fissures)	3040	0.014	4	170	9	161	170
Partial (fissures)	625	0.014	8	70	4	66	70
Algae Control (fissures)	1	0.014	6	0	0	0	0
Drawdowns Floods							
fissures	0	0.014	unknown	0	0	0	0
Habitat Cleaning	Affected						
All habitat	21,875	0.040	1	875	44	831	875
Recreation							
Spring mouths	2,485	0.049	1		6	All salamanders in area*	6
Riparian Irrigation							
all habitat	0			0	0	0	0
Flood Debris Removal				0	0	0	0
Subtotal Parthenia					**63**	**1058**	**1121**

*not included in total

Table 16. Estimates of annual *E. sosorum* incidental take from recurrent actions in Eliza and Old Mill. Take is the product of area, summary statistic, affected habitat, and maximum number of occurrences annually. Conservation Measures (CMs) are assumed to be 95% effective in reducing lethal take. Density is number per square foot.

Eurycea sosorum							
Action (habitat affected)	**Area (ft^2)**	**Summary statistic**	**No. Actions / Year (max)**	**Lethal Take (no.)**		**Harassment Take w/CMs (no.)**	**Total Take (no.)**
				No CMs	**With CMs**		
Eliza Spring							
Drawdown	Exposed	No. Stranded +1 SD					
Full	n/a	0.24	4	0	**0**	**0**	**0**
Partial	n/a	0.24	8	0	**0**	**0**	**0**
Algae Control	n/a	0.24	6	0	**0**	**0**	**0**
Habitat Cleaning	Affected	Mean Density +1 SD					
All Habitat	800	0.78	1	624	**31**	**593**	**624**
Subtotal Eliza					**31**	**595**	**624**
Old Mill Spring							
Drawdown	Exposed	No. Stranded +1 SD					
Full	0	0	4	0	**0**	**0**	**0**
Partial	0	0	8	0	**0**	**0**	**0**
Algae Control	0	0	6	0	**0**	**0**	**0**
Habitat Cleaning	Affected	Mean Density + 1 SD					
All Habitat	1800	0.03	1	54	**3**	**51**	**54**
Subtotal Old Mill					**3**	**51**	**54**

Table 17. Estimates of annual *E. sosorum* incidental take from recurrent actions in Upper Barton Spring. Take is the product of area, summary statistic, affected habitat, and maximum number of occurrences annually. Conservation Measures (CMs) are assumed to be 80% effective in reducing lethal take from recreation and 95% effective in reducing lethal take from habitat cleaning. Density is number per square foot.

Eurycea sosorum							
Action (habitat affected)	**Area (ft^2)**	**Summary statistic**	**No. Actions / Year (max)**	**Lethal Take (no.)**		**Harassment Take w/CMs (no.)**	**Total Take (no.)**
				No CMs	**With CMs**		
Upper Barton Spring							
Drawdown	Exposed	No. Stranded +1 SD					
Full	0	0	4	0	**0**	**0**	**0**
Partial	0	0	8	0	**0**	**0**	**0**
Algae Control	0	0	0	0	**0**	**0**	**0**
Habitat Cleaning	Affected	Mean Density + 1 SD					
All Habitat	650	0.05	1	33	**2**	**31**	**33**
Recreation							
All Habitat	650	0.05	1	33	**7**	**26**	**33**
Subtotal					**9**	**57**	**66**

Table 18. Estimates of *E. sosorum* Incidental take from discrete habitat restoration projects in this Plan in Eliza, Old Mill, and Parthenia Spring. Summary statistic in each habitat section is the mean density plus one standard deviation (SD). Take is estimated as the product of density and affected habitat area; Conservation Measures are assumed to be 90% effective in reducing lethal take.

Eurycea sosorum						
Activity	**Area** (ft^2)	**Density + 1 SD** ($no./ft^2$)	**Lethal Take** (no.)		**Harassment Take w/ CMs** (no.)	**Total Take** (no.)
			No CMs	**With CMs**		
Eliza Spring						
Stream Reconstruction						
Quads III & IV	350	0.86	301	**30**	**271**	**301**
Concrete Floor Removal						
Phase I (Quad I)	75	0.94	71	7	64	71
Phase I (Quad II)	75	0.81	61	6	55	61
Phase II (Quad I)	150	0.94	141	14	127	141
Phase II (Quad IV)	25	0.86	22	2	20	22
Phase III (Quad II)	150	0.81	122	13	110	122
Phase III (Quad III)	25	0.85	21	2	19	21
Phase IV (Quad IV)	150	0.86	129	13	116	129
Phase V (Quad III)	150	0.85	128	13	115	128
Floor Removal Subtotal			**696**	**70**	**626**	**696**
Total Eliza Spring				**100**	**897**	**997**
Old Mill Spring						
Habitat Reconstruction						
All Habitat	1800	0.03	54	**6**	**48**	**54**
Total Old Mill Spring				**6**	**48**	**54**
Parthenia Spring						
Concrete Removal						
Fissures	1000	0.014	14	**1**	**13**	**14**
Total Parthenia Spring				**1**	**13**	**14**

Table 19. Presented below are estimates of *E. waterlooensis* incidental take in Parthenia Spring annually from recurrent actions in this Plan. Salamander density in each habitat section is the mean density plus one standard deviation (SD). Take is the product of density, area of affected or exposed habitat, and maximum number of occurrences annually. Conservation Measures (CMs) are assumed to be 95% effective in reducing lethal take.

Eurycea waterlooensis							
Action (habitat affected)	**Habitat Area (ft^2)**	**Density Mean + 1 SD ($no./ft^2$)**	**Actions Annually (max.)**	**Lethal Take (no.)**		**Harassment Take w/CMs (no.)**	**Total Take (no.)**
				No CMs	**With CMs**		
Parthenia Spring							
Drawdowns Maintenance	Exposed						
Full (fissures)	3040	0.0012	4	15	**2**	**13**	**15**
Partial (fissures)	625	0.0012	8	6	**1**	**5**	**6**
Algae Control (fissures)	1	0.0012	6	0	**0**	**0**	**0**
Drawdowns Floods							
fissures	0	0.0012	unknown	0	**0**	**0**	**0**
Habitat Cleaning	Affected						
all habitat	21875	0.0004	1	9	**1**	**8**	**9**
Recreation							
spring mouths	2485	0.0004			**1**	All salamanders in area*	**1**
Riparian Irrigation							
all habitat	0	0.0004		0	**0**	**0**	**0**
Subtotal Parthenia					**5**	**26**	**31**

*not included in total

Table 20. Presented below are estimates of *E. waterlooensis* incidental take in Eliza, Old Mill, and Upper Barton Spring annually from recurrent actions in this Plan. Take was calculated as the product of area, summary statistic, affected habitat, and maximum number of occurrences annually. Conservation Measures (CMs) are assumed to be 95% effective in reducing lethal take. Density is number per square foot.

Eurycea waterlooensis							
Action (habitat affected)	**Area (ft.^{2})**	**Summary statistic**	**No. Actions Annually (max.)**	**Lethal Take (no.)**		**Harassment Take w/CMs (no.)**	**Total Take (no.)**
				No CMs	**With CMs**		
Eliza Spring							
Drawdown	Exposed	No. Stranded +1 SD					
Full	0	0	4	0	**0**	**0**	**0**
Partial	0	0	8	0	**0**	**0**	**0**
Algae Control	0	0	6	0	**0**	**0**	**0**
Habitat Cleaning	Affected	Mean Density + 1 SD					
All Habitat	800	0.004	1	3	**1**	**2**	**3**
Total Eliza Spring					**1**	**2**	**3**
Old Mill Spring							
Drawdown	Exposed	No. Stranded +1 SD					
Full	0	0	4	0	**0**	**0**	**0**
Partial	0	0	8	0	**0**	**0**	**0**
Algae Control	0	0	6	0	**0**	**0**	**0**
Habitat Cleaning	Affected	Mean Density + 1 SD					
All Habitat	1800	0.009	1	16	**1**	**15**	**16**
Total Old Mill Spring					**1**	**15**	**16**

Table 21. Presented below are estimates of *E. waterlooensis* incidental take from finite habitat restoration projects in this Plan in Old Mill and Eliza springs. Salamander density in each habitat section is the mean density plus one standard deviation (SD). Take is estimated as the product of density and affected habitat area; Conservation Measures are assumed to be 90% effective in reducing lethal take. Total take values are greater than the sum of lethal harassment take due to rounding up of values less than 1.

Eurycea waterlooensis						
Activity	**Area** ($ft.^2$)	**Density + 1 SD** ($no./ft.^2$)	**Lethal Take** (no.)		**Harassment Take w/ CMs** (no.)	**Total Take** (no.)
			No CMs	**With CMs**		
Eliza Spring						
Daylight Stream						
Quads III & IV	350	0.008	**3**	**1**	**2**	**3**
Concrete Removal						
Phase I (Quad I)	75	0.004	0.3	0.1	0.2	1
Phase I (Quad II)	75	0.005	0.4	0.1	0.3	1
Phase II (Quad I)	150	0.004	0.6	0.1	0.5	1
Phase II (Quad IV)	25	0.004	0.1	0.1	0.1	1
Phase III (Quad II)	150	0.005	0.8	0.1	0.7	1
Phase III (Quad III)	25	0.012	0.3	0.1	0.2	1
Phase IV (Quad IV)	150	0.004	0.6	0.1	0.5	1
Phase V (Quad III)	150	0.012	1.8	0.1	1.7	1
Project Subtotal			**5**	**1**	**4**	**5**
Total Eliza Spring			**8**	**2**	**6**	**8**
Old Mill Spring						
Habitat Reconstruction						
All Habitat Areas	1800	0.009	16	**1**	**15**	**16**
Total Old Mill Spring				**1**	**15**	**16**
Parthenia Spring						
Concrete Removal						
Fissures	1000	0.0012	1	**0**	**1**	**1**
Total Parthenia Spring				**1**	**1**	**1**

5.3 Cumulative Effects on Covered Species

Over time, all species experience dynamic variation in the environment that is not driven by human activities. Natural environmental variation over long periods of time can result in evolution of characteristics that allow individuals of a given species to adapt to the changing environment. However, human activities can alter this natural process of evolution and adaptation by detrimentally changing the environment over time periods that are too short for species to adapt. The temporal extent of this HCP is 20 years, roughly equivalent to 20 - 100 generations of these salamanders. The proposed 20-year HCP duration is too short to expect the species to adapt to a changed environment, particularly since Barton Springs' *Eurycea* populations are small.

The primary threats to the covered species include degradation of water quality from urbanization and increased withdrawal of groundwater (USFWS 2005, see Section 4). Urban development is projected to increase over time in the Barton Springs Zone (see section 2.7), and development outside of the City's jurisdiction is regulated by other municipal and county authorities. Regulation of wastewater disposal is conducted by the Texas Commission on Environmental Quality. Withdrawal of groundwater from the Barton Springs Segment of the Edwards Aquifer is regulated by the Barton Springs Edwards Aquifer Conservation District.

Actions conducted by others outside the geographical and jurisdictional scope of this HCP that affect water quantity and quality influence the cumulative impacts on the covered species. This section describes the expected cumulative effects on *E. sosorum* or *E. waterlooensis* of the anthropogenic actions described in this HCP in combination with actions by others that may occur in the foreseeable future. Although the City has no legal authority or direct control over such actions, the City's actions described in this HCP help mitigate and minimize some of the detrimental cumulative effects. The determination of whether cumulative impacts the covered species in jeopardy can only be made by the Service. However, the City finds that this HCP that will not adversely affect the continued viability of Barton Springs' endemic *Eurycea* species over the proposed duration.

5.3.1 Cumulative Effects of Water Quality Degradation

Water quality degradation can occur in many ways, and as such, can affect salamanders and their habitat differently depending on the type of pollution (see section 4.3.1). Urban development over the Barton Springs Zone is expected to continue over time as the human population increases (Figures 6, 7), and the quality of water discharging from Barton Springs may be decreasing over time (Herrington *et al*. 2005, Herrington and Hiers 2010, Mahler *et al*. 2011) although the Edwards Aquifer continues to maintain high quality water (Mabe 2007). Water quality of Barton Springs is not currently harmful to salamanders (see section 3.2.3), and future degradation is not expected to exceed levels that would be toxic to salamanders over the proposed 20-year duration of this HCP under current water quality regulations and at current rates of change (Herrington *et al*. 2005).

Urban development in the Barton Springs Zone is regulated by multiple municipal and county authorities other than the City including the City of Dripping Springs, the Village of Bee Caves, Travis County, and Hays County. Urban development oversight of these entities, with the exception of Travis County, is not currently regulated under the Act through approved Habitat Conservation Plans. Travis County and the City of Austin jointly hold a separate 10(a)(1)(B) permit from the Service, referred to as the Balcones Canyonlands Conservation Plan (BCCP), which requires mitigation for public infrastructure development projects that affect several endangered bird and karst invertebrate species habitat in western Travis County. However, the City has included conservation measures in this HCP to participate in regional planning efforts to continue to protect the water quality of Barton Springs. Additionally, the City has included conservation measures in this HCP to minimize the entry of pollutants directly into salamander habitat from adjacent land areas as well as measures to minimize the deposition of silt into habitat areas through specific preventive and maintenance activities (see section 6). Separate from this Plan, the City strictly limits the increase of impervious cover within its jurisdiction over the Barton Springs Zone and requires that new development not degrade water quality by requiring the use of constructed water quality structural controls. The City also continues to pursue reductions in the loads of suspended sediments, metals, and hydrocarbons to the Edwards Aquifer through the Texas Pollutant Discharge Elimination System permit program and maintains programs to minimize or mitigate the impacts of any catastrophic contaminant spill. These beneficial water quality protection activities, in combination with the planned habitat restoration projects included in this HCP are projected to outweigh the potential detrimental impacts of water quality degradation on Barton Springs' *Eurycea* from continued urban expansion in the Barton Springs Zone over the proposed 20-year duration of the permit.

5.3.2 Drought Groundwater Depletion

Decreased water quantity flowing from Barton Springs can negatively affect endemic salamanders by decreasing dissolved oxygen concentrations (Turner 2009, Woods et al. 2010), altering the spring ecology or imposing unknown effects on behavior and reproduction (see section 3.3.2). Depletion of groundwater discharging from Barton Springs can result from both natural (drought) and anthropogenic (pumping) causes (see Section 2.3). Severe droughts have not been an uncommon occurrence in central Texas over the past several hundred years (Cleaveland *et al*. 2011), and central Texas *Eurycea* have evolved over the course of millennia (Chippindale *et al*. 2000) enduring many extreme climactic events. However, the combined effect of groundwater withdrawal and decreased aquifer recharge may result in droughts having an even more severe impact on discharge from Barton Springs. Daily discharge from Barton Springs has been recorded as low as 9.6 ft^3/s in the 1950s (USGS 1990), designated as drought-of-record conditions. The current desired future condition during extreme drought established by the Texas Water Development Board is at least 6.5 ft^3/s of discharge from Barton Springs. Currently, the total authorized groundwater withdrawal from the Barton Springs Zone of the Edwards Aquifer is 6.7 ft^3/s. Using the lowest recorded average monthly Barton Springs' discharge of 11.7 ft^3/s as the low baseline, the current authorized withdrawal would result in an average monthly Barton Springs' discharge of 5 ft^3/s (Dupnik 2011). At these historically unprecedented discharges, a large proportion of protected salamander habitat would become severely degraded. In addition to Upper Barton Springs, surface habitats in both Eliza Spring and Old Mill Spring would become dry. In the remaining wetted habitat of Parthenia Spring, dissolved oxygen concentrations would fall to levels that would adversely affect the covered species (Turner 2009, Woods et al. 2010, Johns 2006).

The Barton Springs Edwards Aquifer Conservation District does not yet have a Habitat Conservation Plan for Barton Springs' *Eurycea* approved by the Service although one is in development. Included in this HCP is a conservation measure requiring the City to work directly with the Barton Springs Edwards Aquifer Conservation District to ensure sufficient water quantity to maintain viable salamander populations. Also included in this HCP are specific habitat restoration projects and controls on City maintenance activities that may reduce the negative impacts of drought on habitat viability (see sections 6.1, 6.2).

If an unprecedented drought occurred for an extended period of time, it is unknown if the conservation measures of this HCP alone would be sufficient to maintain viable wild salamander populations. However, this HCP includes actions that are intended to help counteract detrimental effects of a future extreme drought driven by actions outside the City's jurisdictional control. It is the scientific opinion of the City that in the event of such an extreme drought it is unlikely that the actions proposed here would impose detrimental effects that would appreciably reduce the likelihood of survival of the covered species.

6.0 Conservation Program

The overarching goal of this conservation program is to protect and restore the ecological integrity and resilience of the springs in the Barton Springs complex. Some of the goals of this amended habitat conservation plan include:

- Improve habitat for *Eurycea sosorum* and *Eurycea waterlooensis* by maintaining or restoring natural ecosystem characteristics, native aquatic species community, and an ecologically-healthy, native riparian community to the greatest extent feasible.
- Reduce and mitigate the impacts of detrimental anthropogenic pollutants that may enter Barton Springs Pool and Eliza, Old Mill, and Upper Barton springs.
- Change operation and management procedures to restore and/or maintain as much as is feasible the natural flow regime of a central Texas spring-fed stream system for *Eurycea sosorum* and *Eurycea waterlooensis*. The natural flow regime includes variation in water depth, velocity and turbulence within the channel associated with variation in aquifer discharge, surface water floods and base flows. This will help maintain natural and artificial selection on these species favoring adaptive responses to current and future variation in surface water flows and disturbance.
- Restore and/or maintain more natural flow regimes in Barton Springs Pool, Eliza Spring, and Old Mill Spring to the maximum extent feasible by modifying, replacing, or removing existing infrastructure. Restoration of free-flowing spring pools and overland streams at Eliza and Old Mill springs will improve and enlarge surface salamander habitat and improve habitat quality.
- Protect the evolutionary potential of wild and captive populations of *Eurycea sosorum* and *Eurycea waterlooensis.* This effort will include maintenance and/or enhancement of genetic variation and gene flow among populations of each species, and maintenance of natural selection characteristic of wild environments. Maintenance of evolutionary potential includes consideration of artificial selection for adaptations to future environmental conditions.
- Adopt benign cleaning methods for the maintenance of Barton Springs Pool to reduce the harassment and/or harm of *Eurycea sosorum* and *Eurycea waterlooensis*.
- Continue to obtain and manage data on *Eurycea sosorum* and *Eurycea waterlooensis* and their habitats. These data and other pertinent information will be shared with the Service, Texas Parks and Wildlife, City employees working within salamander habitat, the scientific community, and the general public.

The focus of conservation measures in the 1998 HCP was on actions that directly threatened survival of protected salamanders and implementation of some of those measures significantly reduced these short-term detrimental effects. Many harmful maintenance practices were eliminated (prohibition of toxic chemical use to control algae) or minimized (reduction in rapid, short-term drawdowns of water level). Other measures proved unsuccessful in mitigating or minimizing effects on salamanders or their habitat. Still other measures were one-time tasks that have been completed. Successful conservation measures are included in this amended HCP along with several additional measures. A comparison of measures in this HCP with the 1998 HCP is presented in Table 22. Discussion of rationale and evidence supporting removal or amendment of measures in the previous HCP is presented in Appendix B.

Table 22. Comparison of Conservation Measures from the 1998 Habitat Conservation Plan with those in the 2012 amended HCP. A summary of 1998 measure is provided along with a description of amended actions (in bold).

Measure # from 1998 HCP	Measure # from 2012 Major Amendment	Summary of Measure or Change in Measure from 1998 HCP to 2012 Amendment
1	6.1.1.3 (see also sections 1.5, 6.4)	The City will manage salamander habitat areas, maintain data on the salamander, and submittal annual permit reports for specified permit duration. **The 2012 amendment renews the permit for an additional 20 years.**
2	6.1.1.5	The City will frequently inspect habitat. **Inspection frequency is reduced from daily to at least 4 days per week**.
3	6.1.3.7, 6.1.3.8	The City will search for stranded salamanders during drawdowns. **The number of biologists present during drawdowns is reduced from 4 to 2.**
4	Deleted - measure completed.	Gates in downstream dam of Barton Springs Pool will be modified to control drawdown rate. **Dam gates have been modified to control water level. This measure is no longer necessary.**
5	6.1.1.7b, 6.1.1.10, 6.1.6.4	Spring water will be used for maintenance, and to provide water over fissures during drawdown.
6	6.1.6.3	The City will clean the shallow end of Barton Springs Pool without full drawdown of water.
7a	Deleted	The City may clean walkway on the Beach. **Minor amendment in 1999 eliminated construction of walkway. The measure is not necessary.**
7b	6.1.1.7a, 6.1.1.7b	**Salamander habitat will be cleaned using low-pressure spring water to keep at least 2 inches of habitat from becoming embedded with sediment.**
7c	6.1.1.2	The City previously maintained 11,000 ft^2 of habitat in the Beach area of Barton Springs Pool. **Protected salamander habitat areas in Barton Springs Pool were redrawn to include more habitat that is, or can be, maintained as suitable habitat and exclude unsuitable habitat areas of Beach.** There is no reduction in total area of protected habitat.
7d	6.1.3.3	The City will develop a plan for routine silt and gravel removal from the deep end of Barton Springs Pool.
8	6.1.3.4, 6.1.3.5	The City will not conduct full drawdowns if Barton Spring discharge is less than 54 ft^3/s. **The City will maintain a written plan with protocols for conducting Barton Springs Pool drawdowns.**

Table 22 (continued)

Measure # from 1998 HCP	Measure # from 2012 Major Amendment	Summary of Measure or Change in Measure from 1998 HCP to 2012 Amendment
9	Deleted	Limestone slabs to be placed over fissures of Parthenia Spring. These slabs proved to be detrimental to salamander habitat quality and were frequently dislodged. Their use has been eliminated (see 6.1.4.3).
10	6.1.3.4, 6.1.3.5, 6.1.3.9, 6.1.3.10	The City may conduct a full drawdown for cleaning only if it would not cause Eliza Spring surface habitat to go dry. No more than 4 full drawdowns will be conducted per year. **The City is adding the option to conduct 8 partial drawdowns per year.**
11	6.1.3.9	The City will maintain water over the fissures area during Pool drawdowns to reduce the likelihood of stranding salamanders.
12	6.1.2.2	The City will control adjacent surface water runoff to salamander habitats.
13	6.1.3.1, 6.1.4.2	The City will modify Old Mill Spring to restore water flow to surface stream. **The natural flow regime will be restored; natural substrate in spring Pool will be restored.**
14	Deleted	**The bypass grate changes have been completed. The measure is no longer necessary.**
15	6.3.2	The City will provide educational programs including the SPLASH Exhibit to enhance public awareness of salamander conservation. **At least $45,000 will be committed annually to salamander education efforts.**
16	6.1.7.2, 6.2.1	Access to Eliza and Old Mill Spring will be restricted.
17	6.3.2	Educational signs will be installed to enhance public awareness of the salamander and the aquifer.
18	6.3.1	The City will provide money to a conservation fund. **The money donated is increased from $45,000 to $53,000.**
19	Deleted	One time provision of $10,000 to the Conservation Fund for mitigation of activities completed prior to 1998 was completed. Measure is no longer necessary. **The 2012 HCP includes additional, on-going financial provisions from the City.**
20	6.1.1.7b	The City will clean salamander habitat with low-pressure spring water.
21	6.1.1.8	The City may remove woody debris as necessary. Debris will be inspected for salamanders prior to removal.

Table 22 (continued)

Measure # from 1998 HCP	Measure # from 2012 Major Amendment	Summary of Measure or Change in Measure from 1998 HCP to 2012 Amendment
22	6.1.3.2	Barton Springs Pool may be lowered in advance of a flood with approval of City biologist and if Barton Springs' discharge is above 54 ft^3/s.
23	6.1.1.7b	The City may clean sediment and debris from habitat as necessary with low-pressure spring water.
24	6.1.1.6c	The City will not allow introduction of exotic plants or animals in any spring in the Barton Springs Complex.
25	6.1.5.1	Translocation of salamanders among sites was prohibited. This is detrimental to genetic integrity of species. **Measure amended. The City will move salamanders between sites or reintroduce captive salamanders to the wild only according to a Service-approved plan.**
26	6.1.6.1	The City may manually trim submerged vegetation.
27	6.1.1.6d	The City will not allow unauthorized SCUBA in Barton Springs.
28	6.1.1.6a	The City will prohibit unauthorized, deliberate disturbance of salamander habitat.
29	6.1.1.9	Material removed during routine cleaning will not be disposed of in salamander habitat.
30	6.1.7.3	Professional supervisors will direct and document Pool cleaning procedures.
31	6.1.7.3	Staff of Barton Springs Pool will be knowledgeable about the protected aquatic salamander species.
32	6.1.7.4	All people conducting salamander surveys will be properly trained and supervised by City biologists on the 10(a)(1)(A) permit.
33	6.1.7.3	The City will provide yearly spill response training and maintain an inventory of necessary containment and remediation equipment.
34	6.1.6.2	Specific areas will be designated for fueling and maintenance of equipment and vehicles away from habitat.
35	6.1.3.3	The City will develop a plan for removal of silt and gravel from the deep end of the Pool.
36	6.2.2	The City will maintain a catastrophic spill response plan.
37	6.1.4.1, 6.1.4.2	The City will restore habitat in Eliza and Old Mill springs.
38	6.1.7.1, 6.1.7.4	The City will continue to regularly monitor salamander populations. **Monitoring frequency may be reduced from monthly to other approved interval.**

Table 22 (continued)

Measure # from 1998 HCP	Measure # from 2012 Major Amendment	Summary of Measure or Change in Measure from 1998 HCP to 2012 Amendment
39	6.1.7.5	The City will form a Scientific Advisory Committee.
40	6.1.2.1	The City will reduce contaminant loadings to Barton Springs through a Texas Pollutant Discharge Elimination System Municipal Separate Storm Sewer System Discharge Permit.
41	6.2.3	The City will maintain a captive refugium population of salamanders and develop a captive-breeding program.
Did not exist in 1998 HCP	6.1.1.1	**The City will develop habitat management plans for each spring site and submit then to FWS.**
Did not exist in 1998 HCP	6.1.1.4	**The City will improve and maintain suitable substrate in habitat areas and will only use limestone gravel or cobble if substrate is added.**
Did not exist in 1998 HCP	6.1.1.6b	**The City will not allow unauthorized deliberate alteration of flow regime.**
Did not exist in 1998 HCP	6.1.1.10	**The City may withdraw water from Barton Springs Pool to irrigate Pool grounds and to use for cleaning of habitat areas.**
Did not exist in 1998 HCP	6.1.3.6	**Approval from a City salamander biologist is necessary before water level in Barton Springs Pool may be lowered.**
Did not exist in 1998 HCP	6.1.3.10	**The City may conduct 8 partial drawdowns of Barton Springs Pool if Barton Spring discharge is above 54 ft^3/s.**
Did not exist in 1998 HCP	6.1.4.3	**The City will restore and maintain groundwater flow and light penetration to salamander habitat in Barton Spring Pool. This includes gradual removal of concrete from the fissures.**
Did not exist in 1998 HCP	6.1.6.5	**The City will prohibit use of toxic chemicals for cleaning Barton Springs Pool.**
Did not exist in 1998 HCP	6.2.4	**The City may add oxygen to water of salamander habitat when necessary.**
Did not exist in 1998 HCP	6.3.2	**The City will continue to support research projects designed to gather and evaluate data applicable to wild or captive populations of the Barton Springs Salamander, *E. sosorum*, and the Austin Blind Salamander, *E. waterlooensis* and their habitats.**

Table 22 (continued)

Measure # from 1998 HCP	Measure # from 2012 Major Amendment	Summary of Measure or Change in Measure from 1998 HCP to 2012 Amendment
Did not exist in 1998 HCP	6.3.4	**The City will cooperatively develop a memorandum of understanding with the Barton Springs Edwards Aquifer Conservation District to formalize collaborative efforts to protect the covered species and the Barton Springs Segment of the Edwards Aquifer.**
Did not exist in 1998 HCP	6.3.5	**The City will participate in regional water resource planning that may affect the Barton Springs Segment of the Edwards Aquifer and advocate for protection of water quality and quantity adequate to protect the covered species.**

6.1 Measures to Minimize Impacts

The City will implement the following conservation measures to achieve the stated biological and community goals of this plan and minimize the impacts of City activities on the covered species. Justification in support of the proposed conservation measures is provided where necessary (see Appendix B).

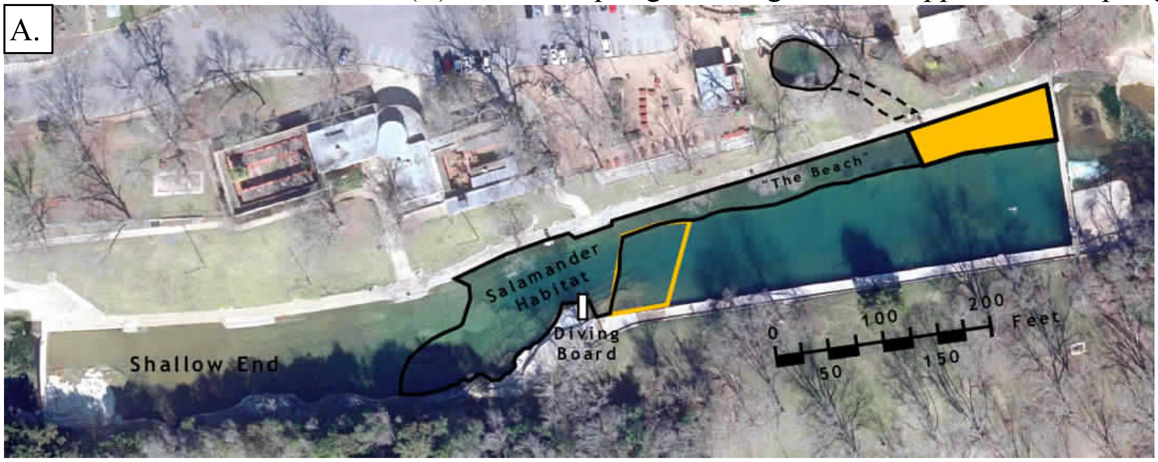
6.1.1 The City will maintain habitat for *Eurycea sosorum* and *Eurycea waterlooensis* by maintaining or restoring natural ecosystem characteristics, the native aquatic species community, and an ecologically-healthy, native riparian community to the greatest extent feasible.

6.1.1.1 The City will develop written habitat management plans for each spring site. These plans will include ongoing activities to improve the quality of aquatic habitat and ecosystem health. This includes but is not limited to introduction of native aquatic plants and maintenance of adequate tree canopy cover. Habitat management plans will be provided to the Service for review within one year of permit issue. The City will revise these plans with the written or verbal approval of the Service as necessary.

6.1.1.2 With the verbal or written approval of the Service, the City will redraw the footprint of protected salamander habitat in Barton Springs Pool (Figure 16) to include more habitat that is and can be maintained as suitable for salamander residence and exclude unsuitable habitat based on monitoring data and habitat condition. The total square footage of protected habitat in Barton Springs Pool will not be less than that delineated in the 1998 Habitat Conservation Plan.

Figure 16. Salamander habitat in the Barton Springs Complex. Current boundaries of salamander habitat in each spring are outlined in black. (A) Barton Springs Pool and Eliza Spring. Area to be added to salamander habitat in Barton Springs Pool is outlined in yellow;

area to be removed is shaded yellow. Dashed line from Eliza spring indicates general area of future restored outflow stream. (B) Old Mill Spring. See Figure 1 for Upper Barton Spring.



6.1.1.3 The City will be responsible for the management of aquatic and riparian habitats of:

a. Barton Springs Pool and Parthenia Spring (fissures, springs, and Beach habitat; Figure 1),
b. Eliza Spring (spring pool, outflow pipe and/or stream; Figure 1),
c. Old Mill Spring (spring pool and outflow stream; Figure 1),
d. Upper Barton Spring (spring and outflow streams; Figure 1).

6.1.1.4 The City will continue improvement and maintenance of suitable substrates in salamander habitat. If replacement of rocky substrate of salamander habitat is necessary, the City may use only limestone gravel or cobble in order to maintain the natural groundwater buffering of karst aquifers.

6.1.1.5 The City will make visual inspections of all protected habitat areas (spring sites when flowing) at least four days a week. City Parks and Recreation Department staff will be present at Barton Springs Pool when it is open and will visually inspect Parthenia Spring daily. Inspections will note any problem conditions such as vandalism, trash, debris, introduction of exotic fish or animals or disturbance of habitat. If problems are discovered, the City will take appropriate action to protect salamanders and their habitat. Appropriate actions may include but are not limited to repairing damage from vandalism, removal of trash, and removal of introduced exotic fish or animals.

6.1.1.6 The City will prohibit the following activities to reduce harassment of *Eurycea sosorum* and *Eurycea waterlooensis* and protect associated habitat:

a. unauthorized, deliberate disturbance of salamander habitat, including substrate, aquatic vegetation, algae, and leaf litter or woody material from terrestrial vegetation,
b. unauthorized, deliberate disturbance or alteration of flow regime,
c. introduction of non-native flora or fauna into any salamander habitat or Barton Springs Pool,
d. unauthorized SCUBA in salamander habitat or Barton Springs Pool.

6.1.1.7 **a. The City will clean salamander habitat as necessary** to keep at least the upper 2-3 inches of habitat from becoming embedded with sediment. Easily observable or measurable characteristics of physical habitat (*e.g*., embeddedness, sediment depth or percent sediment cover) will be used as benchmarks for determining when to clean.

b. All salamander habitats will be cleaned with the spring water of Barton Springs at pressures not to exceed 30 lb/in^2 at the substrate and/or suspend rocks larger than 4 inches in diameter. Water for cleaning may be obtained by recirculation through submersible pumps, or other methods acceptable to the Service.

6.1.1.8 The City may remove woody debris from aquatic habitat if necessary by hand or any methods approved by the Service through verbal or written correspondence. All debris removed from salamander habitat will be visually inspected for salamanders and their prey before and after removal. Live salamanders will be noted and returned to the water. Live prey will be returned to the water as much as is feasible.

6.1.1.9 Sediment, algae and debris disturbed or collected during routine cleaning of the Pool will not be disposed of in, allowed to settle in, or otherwise adversely affect aquatic habitat.

6.1.1.10 The City will minimize the detrimental impacts of withdrawal of spring water from Barton Springs Pool for irrigation and aquatic habitat cleaning by taking the following actions. The City will locate the intake for the pump inside Barton Springs Pool against the downstream dam but outside of habitat areas. The intake will be sufficiently baffled to reduce velocities and the likelihood of entrapment of salamanders on intake screens. Water withdrawn from Barton Springs Pool for irrigation will be used in a manner consistent with the other conservation measures of this plan, and irrigation water will not be allowed to runoff from the grounds back into the Pool. Withdrawal of water for irrigation will be limited to no more than 100 gallons/minute (0.2 ft^3/s) and no more than 6,006,000 gallons will be withdrawn annually. This amount is equivalent to 0.2% of the total annual discharge from Barton Springs calculated using the lowest ever recorded instantaneous discharge value of 9.6 ft^3/s applied for an entire year. Water withdrawn from Barton Springs Pool will be used for irrigation of only areas inside the fence surrounding Barton Springs Pool. The City will observe all watering restrictions applicable under City of Austin regulations when irrigating with water withdrawn from Barton Springs Pool.

6.1.2 The City will minimize the entry of anthropogenic pollutants detrimental to salamanders or their habitat into Barton Springs Pool and Eliza, Old Mill and Upper Barton Spring.

6.1.2.1 The City will reduce loadings of petroleum hydrocarbons, heavy metals and sediments to Barton Springs from current development and other activities located within the Barton Springs Zone in areas subject to the City's jurisdiction. This reduction in loadings will be achieved through the measures set out in the City's Stormwater Management Plan as required by the City's Texas Pollutant Discharge Elimination System (TPDES) storm water permit. The City's TPDES Stormwater Management Plan includes specific monitoring and protection measures for the Barton Springs Zone to protect the water quality of Barton Springs.

6.1.2.2 The City will control local surface water runoff around Barton Springs Pool, Eliza Spring, Old Mill Spring, and Upper Barton Spring to the maximum extent practical. Runoff of storm water can carry sediment and potential pollutants directly into Barton Springs Pool and adjacent springs, which could adversely affect aquatic life. Stormwater may be diverted away from Barton Springs Pool or treated using structural best management practices prior to entering Barton Springs Pool. Runoff protection improvement projects will not have adverse effects on salamanders or their habitat. These controls do not include storm water runoff collecting in Barton Creek that causes basin-wide flooding that can inundate the springs.

6.1.3 The City will change operation and management procedures at Barton Springs Pool to restore and/or maintain as much as is feasible the natural flow regime of a central Texas spring-fed stream system for *Eurycea sosorum* and *Eurycea waterlooensis*. This will help maintain natural and artificial selection on these species favoring adaptive responses to current and future variation in surface water flows and disturbance. The natural flow regime includes variation in water depth, velocity, and turbulence within the channel associated with variation in aquifer discharge, surface water flood and base flows.

6.1.3.1 The City will restore and maintain more natural flow regimes in Barton Springs Pool, Eliza Spring, and Old Mill Spring by modifying, replacing or removing existing infrastructure. Restoration of free-flowing spring pools and overland streams at Eliza and Old Mill springs will improve and enlarge surface salamander habitat and improve habitat quality (see section 3.3.3). Restoration of a more natural flow regime in Barton Springs Pool by modification and/or replacement of dams, modification of the bypass culvert infrastructure, and suitable changes in management activities will improve aquatic habitat quality and ecosystem stability, as well as provide maximum operational flexibility. The City will develop plans for these restoration projects and, with concurrence of the Service, implement restoration. Flow regime improvements will not compromise water quality during baseflow.

6.1.3.2 The City will allow floodwater to pass through Barton Springs Pool as unimpeded as is feasible to restore or maintain a more natural disturbance regime, which includes increased water velocities that inhibit excess settling of sediment and debris within the Pool confines. This will also reduce the need for dredging or other removal of accumulated flood debris from the Pool, thereby reducing potentially detrimental impacts of such projects on salamanders or their habitat. Some floodwater may continue to enter the bypass culvert and pass around the Pool. Prior to opening the gates in the downstream dam in preparation for potential flooding, Pool staff will confirm with City biologists that Eliza Spring is properly prepared according to the Drawdown Plan. In the event of a flash flood or potential flash flood, Pool staff will prepare the Pool grounds for flooding and coordinate with City salamander biologists in conducting flood-related drawdowns. The City may open dam gates for all floods according to procedures described in the Drawdown Plan.

6.1.3.3 The City, with concurrence of the Service, will develop and implement a plan for routine silt and gravel removal from the deep channel of the Pool downstream of Parthenia Spring that does not compromise the continued survival of covered species. The Pool is bounded by upstream (southwest) and downstream (northeast) dams across Barton Creek. These dams cause accumulation of aquifer-borne silt as well as flood-borne silt and gravel within the Pool confines, altering flow regime and natural geomorphic processes. Removal of this material from the deep channel of the Pool has been and will continue to be necessary until the dams are modified, replaced, or removed. The plan will describe when the removal of material will occur and focus on vacuum dredging or other minimally invasive methods approved by the Service. The plan will be submitted to the Service within one year of the issuance of this permit and may be revised as necessary with the verbal or written approval of the Service.

6.1.3.4 The City will maintain a Drawdown Plan, which will provide standard operating procedures for use when Pool water elevation is drawn down. This plan requires the approval of the Service and will be submitted to the Service prior to issuance of this permit. The Drawdown Plan will be updated as needed with concurrence of the Service.

6.1.3.5 The City will not conduct a full drawdown of the water level in Barton Springs Pool if the combined discharge of the Barton Springs complex is less than 54 ft^3/s without consultation and verbal or written concurrence of the Service. This measure is intended to prevent dewatering of surface habitat of Eliza Spring. When discharge is equal to or greater than 54 ft^3/s, water can be maintained in surface habitat of Eliza

Spring during a full drawdown, based on current substrate elevation. The 54 ft^3/s threshold can be revised with the verbal or written approval of the Service if habitat restoration or changes in substrate elevation allow maintenance of wetted surface habitat at lower discharges.

6.1.3.6 Approval from a City Salamander Conservation Program salamander biologist is necessary before the water level in Barton Springs Pool may be drawn down under any flow conditions.

6.1.3.7 When water level in Barton Springs Pool is drawn down for cleaning and maintenance, trained and permitted City salamander biologists and staff under their direct supervision **will visually inspect all exposed habitat for stranded salamanders** before cleaning and maintenance activities in those areas begin. Any stranded salamanders will be moved to permanent water. Water level in Eliza Spring will be inspected to ensure that water is retained in surface habitat of the spring pool.

6.1.3.8 A minimum of two City salamander biologists will be present when a full drawdown is conducted for cleaning and maintenance, and a minimum of one City salamander biologist will be present when a partial drawdown is conducted for cleaning and maintenance.

6.1.3.9 The City may conduct 4 full drawdowns per year exclusive of floods, when the combined Barton Springs complex discharge is at least 54 ft^3/s at the time of drawdown. Exposed habitat will be kept wetted with spring water or creek water while staff searches for stranded salamanders. The City will maintain water over the fissures area during drawdown for cleaning in order to minimize the stranding of salamanders. After the fissures area has been searched for stranded salamanders, the area may be allowed to dry and be cleaned.

6.1.3.10 The City may conduct eight partial drawdowns per year exclusive of floods when the combined Barton Springs complex discharge is equal to or greater than 54 ft^3/s. If the discharge is less than 54 ft^3/s, partial drawdowns will only be conducted in consultation with the Service. The water depth over the beach will be maintained at greater than or equal to 12 inches and surface habitat in the adjacent perennial springs (Eliza and Old Mill) would not be allowed to go dry. This measure will minimize the impact of low aquifer levels at the adjacent perennial spring sites. (Refer to Appendix B for measure justification.)

6.1.4 The City will restore and/or maintain more natural flow regimes in Barton Springs Pool, Eliza Spring, and Old Mill Spring to the maximum extent feasible by modifying, replacing or removing existing infrastructure. Restoration of free-flowing spring pools and overland streams at Eliza and Old Mill springs will improve and enlarge surface salamander habitat and improve habitat quality. The City will develop plans for these restoration projects with the verbal or written approval of the Service prior to implementing restoration. Flow regime improvements will not compromise water quality during baseflow (City of Austin 2011b).

6.1.4.1 Eliza Spring flow regime improvement will be implemented to the maximum extent feasible to recreate historical salamander habitat by restoring the surface outflow stream. Presently, the outflow from the spring is routed through an underground pipe into the Barton Springs Pool bypass culvert and ultimately into Barton Creek downstream of Barton Springs Pool; there is no surface stream. The underground pipe is proposed to be "daylighted" and a natural surface stream created in its place. The new stream will be protected salamander habitat and access will be restricted. To fully recreate a free-flowing spring-fed stream system, the natural elevation and composition of the substrate in the spring pool will be restored to the maximum extent feasible. This will eliminate hindrance of aquifer flow to surface habitat, and provide wetted surface habitat during low aquifer discharge conditions and drawdowns without hindering outflow from the spring pool. A natural substrate will also provide abundant avenues for movement to and from subterranean habitat, reducing the potential for stranding salamanders during drawdowns. The current outflow pipe may be repaired as necessary until the stream is restored. All restoration activities will be submitted to the Service and receive verbal or written approval before implementation. The City will determine the feasibility of this restoration activity and submit an estimate of when construction activities may occur, if feasible, to the Service within 3 years of permit issuance.

6.1.4.2 Old Mill Spring habitat restoration will be implemented to the maximum extent feasible to eliminate permanent, immovable obstructions and hindrances to free outflow from the spring pool to its stream. Infrastructure associated with the plugged outflow pipe on the Tier 1 stone wall (immediately surrounding the spring pool) will be removed within 3 years of permit issuance if feasible. The elevation of the outflow streambed may be lowered to ensure free water flow from the spring pool to its stream. A community of native aquatic vegetation will be established, which will help mitigate effects of low spring discharge by releasing oxygen into the water. Canopy cover vegetation will be maintained or increased to provide shade over the spring pool and stream, which will help mitigate increased surface water temperature during seasonal periods of high air temperature. Remaining stone walls of the amphitheater outside of aquatic salamander habitat and the supporting riparian habitat (Tiers 2 – 4) may be rehabilitated or stabilized as necessary to ensure safety in publicly accessible areas. Plans will be submitted to the Service and receive verbal or written approval before implementation.

6.1.4.3 The City will restore and permanently maintain groundwater flow and light penetration to the maximum extent feasible in salamander habitat of the fissures of Parthenia Spring. The City will not artificially obstruct groundwater flow or artificially inhibit light penetration in the fissures habitat area. Restoration will include permanent removal of concrete in the natural fissures transmitting groundwater to the surface in Parthenia Spring. Small areas of concrete may be removed gradually using underwater hand tools. Large areas may be removed at one time during drawdown, which would allow use of larger construction tools and foster retreat of salamanders from work area. Removal methods will be chosen to minimize harassment of resident salamanders and subject to verbal or written approval of the Service.

6.1.5 The City will protect the evolutionary potential of wild and captive populations of *Eurycea sosorum* and *Eurycea waterlooensis*. This effort will include maintenance and/or enhancement of genetic variation and gene flow among populations of each species, and maintenance of natural selection characteristic of wild environments. Maintenance of evolutionary potential may include artificial selection for adaptations to future environmental conditions in the wild.

6.1.5.1 The City may move salamanders among spring sites or release salamanders born in captivity according to a Service-approved plan to maintain genetic diversity of the species. The four spring sites do not harbor genetically unique populations based on current genetic information. Transfer of individuals between sites will not adversely affect the genetic integrity of those populations and will maintain the genetic integrity of the species.

6.1.6 The City will adopt benign cleaning practices for the maintenance of Barton Springs Pool to reduce the harassment and/or harm of *Eurycea sosorum* and *Eurycea waterlooensis*.

6.1.6.1 The City may manually trim and remove aquatic vegetation (macrophytes, bryophytes and algae) as necessary. Vegetation management will not adversely affect habitat or compromise ecosystem health. Only City biologists listed under current federal Endangered Species Act 10(a)(1)(A) and state scientific permits are authorized to manage vegetation in salamander habitat areas.

6.1.6.2 Specific areas will be designated for the fueling and maintenance of equipment and vehicles used in maintaining the springs and surrounding areas. Fueling and maintenance areas will be at least 25 feet away from the water to avoid the chance of detrimental impacts on the spring habitats or aquatic life. Absorbent pads will be used underneath or around all equipment, supplies, and vehicles containing toxic components during all operations, fueling and maintenance activities.

6.1.6.3 The City will clean the shallow end of Barton Springs Pool without full drawdown of water level in the entire Pool. Adjustable gates in dams or similar water control devices may be used to conduct partial drawdowns that expose only the shallow end for cleaning.

6.1.6.4 The City will use spring water for cleaning in Barton Springs Pool to the maximum extent feasible. The City will install an electrically powered pump system that provides spring water from Barton Springs Pool for cleaning of the Pool. The pump system may also be used to provide spring water for the fissures areas during Pool drawdown.

6.1.6.5 The City will prohibit use of toxic chemicals for cleaning of the Pool.

6.1.7 The City will continue to obtain and manage data on *Eurycea sosorum* and *Eurycea waterlooensis* and their habitats. These data and other pertinent information will be shared with the Service, Texas Parks and Wildlife, City employees working within salamander habitat, the scientific community and the general public.

6.1.7.1 The City will monitor salamander populations and habitat. Salamander population surveys will be conducted at perennial Parthenia, Eliza, and Old Mill springs and at intermittent Upper Barton Spring when flowing at least bimonthly throughout the year or other interval sufficient to determine the status of the species and population dynamics as deemed appropriate by a City salamander biologist and approved by the Service. The City will develop and maintain a written monitoring plan. The City will ensure that all people surveying for salamanders are properly trained. Surveys can include methods to elucidate life history characteristics of both species. Methods will be evaluated by the Service and conducted under the terms and conditions of a valid federal Endangered Species Act 10(a)(1)(A) scientific permit issued to the City.

6.1.7.2 Eliza Spring and Old Mill Spring will be used as outdoor educational facilities for the study of the biology and ecology of Central Texas springs.

6.1.7.3 The City will ensure that Barton Springs Pool lifeguards and maintenance staff including seasonal employees are knowledgeable about the protected salamander species. At a minimum, staff will be trained yearly about the protected salamanders, resident aquatic wildlife and flora and the ecology of Edwards Aquifer springs. Training will include contaminant spill and response protocols, proper containment techniques, and remediation. An inventory of necessary containment and remediation equipment will be conducted by Pool staff annually and after the use of equipment in response to any spill. City Parks and Recreation Department Aquatics supervisors will direct and document all cleaning procedures at the Pool.

6.1.7.4 The City will ensure that all people conducting salamander and habitat monitoring are properly trained. All monitoring and surveys will be conducted under the terms and conditions of a current federal Endangered Species Act 10(a)(1)(A) scientific permit issued to the City of Austin.

6.1.7.5 The City of Austin will form the Barton Springs Scientific Advisory Committee, which will include local and regional experts. The committee may be divided into subcommittees that focus on specific areas of expertise and will meet at least annually to discuss and refine Barton Springs' maintenance and environmental management activities. A variety of interests including swimming, biology, hydrogeology, and captive breeding may be represented on this committee. In addition, this committee will periodically review this Plan and make suggestions for needed amendments as deemed necessary. The Advisory Committee will also be responsible for helping identify potential revisions to the Plan and suggest adaptive management strategies. The City will be responsible for implementation of adaptive management strategies with verbal or written approval of the Service.

6.2 Measures to Mitigate Impacts

The City will implement the following conservation measures to achieve the stated biological and community goals of this plan and mitigate the impacts of City activities on the covered species. Justification in support of the proposed conservation measures is provided where necessary (see Appendix B).

6.2.1 Access to Eliza Spring and Old Mill Spring will be restricted to ensure no unauthorized disturbance of salamander habitat and/or its supporting riparian habitat. Unsupervised access to these sites is limited to individuals holding valid federal Endangered Species Act 10(a)(1)(A) and state scientific permits. Recreational access to Barton Springs Pool will continue to be permitted. Public access to Upper Barton Spring is not prohibited. Upper Barton Spring lies within the Barton Creek Greenbelt, and because of its location within the floodplain of Barton Creek it cannot be feasibly isolated from public access.

6.2.2 The City will maintain a plan and necessary equipment and training for responding to, and mitigating the effects of catastrophic contaminant spills that threaten protected salamanders or their habitat.

a. Should a catastrophic spill threaten to extirpate *E. sosorum* or *E. waterlooensis* in the wild, the City may conduct a full or partial drawdown as necessary to rescue salamanders. The City will notify the Service in the event of a catastrophic spill. Trained and permitted City staff will search all exposed habitat area for salamanders.

6.2.3 The City will maintain viable, evolutionarily fit captive breeding populations of *Eurycea sosorum* and *Eurycea waterlooensis*. The City will designate a staff biologist and dedicate a minimum of $28,000 annually to the development and maintenance of this program. This program may provide captive salamanders suitable for reintroduction into the wild if catastrophic events that compromise or cause extirpation of wild populations were to occur. This program may provide a refugium facility for salamanders collected in response to contaminant spills or other immediate threat that could cause extirpation of the species in the wild. The program will develop and maintain a captive population of each species that represents the genetic diversity of wild populations without compromising their size or fate by permanently removing individuals from the wild. This program is also intended to support research that contributes to elucidation of biology, life history and natural history of both species. The City will develop and maintain written plans for population management, reintroduction, and husbandry. These plans will be updated as necessary (See Appendix E).

6.2.4 Under conditions when decreased dissolved oxygen concentrations may be harmful to salamanders, the City may supplement dissolved oxygen in Eliza, Old Mill, and Parthenia springs using air pumps, water recirculation, or other method approved by the Service.

6.3 Additional Conservation Measures

In addition to the proposed minimization and mitigation activities, the City will conduct additional research and education activities to further the stated conservation goals.

6.3.1 The City of Austin will set up a fund for conservation and research efforts for *Eurycea sosorum* and *E. waterlooensis*. The City will deposit $53,000 annually (for the term of the permit) into this fund from the revenues generated by Barton Springs Pool. This fund will also be open to donations from any group or private individual. A committee of technical representatives will determine the allocation of money from this fund. At a minimum, the committee will consist of one technical representative from the City and one technical representative from the Service. These technical representatives must be knowledgeable and experienced in salamander biology. Other committee members could include state, county, university representative or other qualified biologists and karst aquifer hydrogeologists, and swimmer/stakeholder representatives. The City and the Service would both retain "veto" power in deciding how the money is allocated. The funds would be used for study of salamander biology, captive breeding, refugium development, reintroduction, watershed related research, improved cleaning techniques for natural water bodies, education and/or land acquisition.

6.3.2 The City will continue to support research projects designed to gather and evaluate data applicable to wild or captive populations of the Barton Springs Salamander, *E. sosorum*, and the Austin Blind Salamander, *E. waterlooensis*. These projects would be in addition to the regular monitoring already conducted under the permit and would be approved by the Service when applicable.

6.3.3 The City will continue to provide educational programs to enhance public awareness and community support for *Eurycea sosorum*, *Eurycea waterlooensis*, Barton Springs, and the Edwards Aquifer. The SPLASH! Into the Edwards Aquifer Exhibit at Barton Springs Pool will continue to be a major focus of this effort. The mission of the SPLASH! Exhibit is to foster stewardship of the Barton Springs Segment of the Edwards Aquifer and Barton Springs through public education. The City of Austin Parks and Recreation Department will dedicate a minimum of $10,000 annually from the revenues generated by Barton Springs Pool to the development and maintenance of this exhibit. The City of Austin Watershed Protection Department will make available at least $35,000 annually for the support of exhibits and events, and maintaining museum operating hours at the SPLASH exhibit. Outdoor educational displays will emphasize the biology and ecology of Barton Springs and the Edwards Aquifer with an emphasis on the Barton Springs Salamander, *Eurycea sosorum*, and the Austin Blind Salamander, *Eurycea waterlooensis*.

6.3.4 The City will cooperatively develop a memorandum of understanding with the Barton Springs Edwards Aquifer Conservation District to formalize collaborative efforts to protect the Barton Springs Salamander, *Eurycea sosorum*, the Austin Blind Salamander, *Eurycea waterlooensis,* and the Barton Springs Segment of the Edwards

Aquifer. The memorandum of understanding will be adopted by the City within one year of permit issuance.

6.3.5 The City will participate in regional water resource planning that may affect the Barton Springs Segment of the Edwards Aquifer and advocate for protection of water quality and quantity adequate to protect the Barton Springs Salamander, *Eurycea sosorum*, and the Austin Blind Salamander, *Eurycea waterlooensis*.

6.4 Reporting

The City will be responsible for compliance with all measures in this Plan. All management measures will be implemented upon issue of the permit unless otherwise stated and the timely transmittal of information and data to the Service will be the City's responsibility.

The City will submit an annual report on February 1 of each calendar year, or other agreed to date, to the US Fish and Wildlife Service Austin Ecological Field Services Office, the City Manager and City Council. The annual report will include assessments of the status of the protected salamander species, analysis of biological data and review of Barton Springs Pool maintenance and management activities during the year. In the annual report, each point of this amended habitat conservation plan will be addressed.

6.5 Adaptive Management

Adaptive management is a framework for changing the conservation plan based on data gathered during implementation of the plan (USFWS and NMFS 1998). Adaptive management is also an approach for responding to both foreseeable and unforeseeable changes in circumstances. Typically, steps for adaptive management in conservation programs follow these steps:

1. Considering various actions to meet management objectives
2. Predicting the outcomes of these management actions based on what is currently known
3. Implementing management actions
4. Monitoring to observe the results of those actions
5. Using the results to update knowledge and adjust future management actions accordingly.

There are several opportunities in this Plan for adaptive management response to foreseeable changes in circumstances. Explicit descriptions in this Plan of goals and activities intended to meet those goals (section 6) provide the general framework for revision based on acquisition of data and information. While the expected benefits of the proposed mitigation and management activities are supported by abundant scientific evidence from other ecosystems, a clear understanding of their effects in the Barton Springs system is necessary to determine the realized benefits to *E. sosorum* and *E. waterlooensis*. This requires rigorous scientific evaluation throughout the term of this Plan.

Therefore, the City will develop detailed sampling quality assurance project plans (QAPP) to evaluate effectiveness of management activities throughout the term of this Plan. Plans will be developed for evaluation of ecosystem and population monitoring, habitat management and restoration, captive population management and husbandry, drawdowns, flood debris removal (dredging), and recreational operations. These plans will include descriptions of the management activity and its intended effect and will include where applicable testable hypotheses relevant to the intended effect, data collection protocols, methods of statistical analysis, and criteria for revision of target activity. Implementation of these plans will provide the tools for identifying adaptive management activities in response to changed conditions. They also provide the opportunity to adjust scientific evaluation of population and habitat management as new data are collected. Provided below are strategies for evaluating the success of relevant conservation measures. In general, the hypotheses to be tested, data collection, and analysis methods will examine whether the management action of interest has had a statistically significant beneficial impact on salamander populations or their habitat. Baseline data are those collected before implementation of this Plan whenever possible, or other data appropriate for the hypotheses to be tested. Frequency of evaluation of management depends on the frequency of a particular action (routine, ongoing, or discrete) and the associated hypotheses. For example, examination of the effects on the fate of salamander populations requires analysis of many years of data, while immediate effects of drawdowns on take of salamanders can be examined annually.

6.5.1 Operations

Ongoing operation of Barton Springs Pool involves cleaning and flood management, as well as special operations necessary during contaminant spills. In addition, changes in normal operational activities have the potential to increase take of protected salamanders. Therefore, effectiveness of operations must be evaluated and management practices changed accordingly if unanticipated effects occur.

6.5.1.1 Drawdowns

An important part of the management of Barton Springs Pool is the ability to draw down the level in the Pool for routine cleaning, flood management, and contaminant spill response. Drawdowns are attained by opening gates in the downstream dam, allowing more water to pass through and lowering the elevation of the water. Rapid drawdowns of water can impose direct detrimental effects on salamanders by stranding them in suddenly dry habitat. However, drawdowns also reduce some of the short- and long-term detrimental effects of dams and contaminants. Since drawdowns can have a beneficial effect on protected salamanders and their habitat, evaluation of their effects is an important aspect of adaptive management.

6.5.1.1.1. Cleaning Drawdowns

The City proposes to conduct a maximum of 12 drawdowns annually (8 partial, 4 full; one per month) when Barton Springs' discharge is at least 54 ft^3/s for routine cleaning of Barton Springs Pool and salamander habitat of Parthenia Spring. Based on data collected during experimental partial drawdowns in 2004, these additional drawdowns are expected to gradually improve the quality of salamander habitat and aquatic environment, while minimizing short-term take. Expected improvements include reductions in sediment depth, sediment cover, and abundance of nuisance algae. Each event will include collection of relevant data from Parthenia and Eliza Spring to evaluate the effectiveness of these drawdowns. Short-term effects can be examined using data on Barton Springs' discharge, number of salamanders affected, rate of water recession, and amount of habitat exposed.

Long-term effects on habitat can be examined with data collected during routine salamander population monitoring and periodic studies of rate of sediment accumulation. Statistically significant improvements in habitat quality can be used to revise number, frequency, or extent of drawdown, as well as the Barton Springs' discharge threshold of 54 ft^3/s.

Hypotheses:

Parthenia and Eliza Spring

H1: Is there a difference in observed take of protected salamanders before and after implementation of new drawdown regime?

H2: Do percent sediment cover and sediment depth in salamander habitat differ before and after implementation of new drawdown regime?

H3: Does rate of sediment accumulation differ before and after implementation of new drawdown regime?

H4: Is there a difference in salamander abundance before and after implementation of new drawdown regime?

Criteria for evaluating success of management:

The plan will include analysis of hypothesis 1 annually and analysis of hypotheses 2 – 4 every 5 years. Statistically significant changes in sediment cover and depth, and rate of accumulation or change in observed Take warrant consideration of a change in habitat management.

6.5.1.1.2. Flood Drawdowns

The City proposes to conduct flood-related drawdowns to reduce deposition of gravel, sediment, and debris during floods by allowing flood water to pass through Barton Springs Pool as unimpeded as possible. Additionally, flood-related drawdowns remove excess debris deposited by the flood after waters recede. Opening dam gates for impending flooding partially restores the natural flow regime, and generally reduces deposition of flood-borne sediment and debris upstream of the dams. Open dam gates also prevent floodwater from backing up overland and entering the Eliza Spring pool, inhibiting sediment deposition. After floodwater has receded, Barton Springs Pool continues to be closed to recreation for several days to remove flood-borne debris and sediment, which is accomplished more efficiently and thoroughly if water level is fully drawn down. Preliminary data indicate this approach results in less deposition of sediment in salamander habitat. Continued success of conducting these drawdowns will be examined by measuring sediment depth and sediment cover in both Parthenia Spring and Eliza Spring, and measuring gravel depth in front of Parthenia Spring mouths immediately after flood waters have receded. Significant reduction in the magnitude of these characteristics would indicate that the drawdowns are successful in meeting the goals. A reduction in average number of post-flood closure days would also indicate that this drawdown strategy is meeting the desired goals. Future restoration of gated openings in the upstream dam will allow for similar testing of their effects on material deposited within Barton Springs Pool by floods. In addition, openings in the upstream dam may have an effect on flood-related deposition of sediment in Upper Barton Springs upstream of Barton Springs Pool. This can be examined by determining if average sediment depth and cover post-flood is reduced when gates are open. Statistical comparisons and methods for evaluation would depend on the amount and frequency of collected data that will be determined in the QAPP.

Hypotheses:

Parthenia Spring

H1: Are there differences in depth of sediment and percent sediment cover in fissures habitat after floods when dam gates are open?

H2: Are there differences in depth of debris in front of spring mouths after floods when dam gates are open?

H3: Is there a difference in observed Take during post-flood drawdown when dam gates are open?

Eliza Spring:

H1: Are there differences in depth of sediment and percent sediment cover in fissures habitat after floods when dam gates are open?

H3: Is there a difference in observed Take during post-flood drawdown when dam gates are open?

Criteria for evaluating success of management:

Statistically significant changes in sediment cover and depth or change in observed Take

6.5.1.1.3. Drawdown Discharge Threshold

The proposed threshold for conducting drawdowns is intended to ensure that water does not recede from surface habitat in the Eliza spring pool. At the time of this Plan, the floor of Eliza Spring is concrete overlying natural substrate, which raises the elevation of surface habitat approximately one foot. During drawdowns of Barton Springs Pool when discharge is below 54 ft^3/s, water recedes from Eliza's concrete floor deeper into the aquifer, leaving dry surface habitat. Restoration of the natural substrate elevation and composition by removing this concrete floor is a management activity proposed in this Plan. Lower elevation of surface substrate in Eliza Spring should result in wetted surface habitat during drawdowns at lower discharge values. Conducting drawdowns at lower discharges would allow for restoration of more natural flow regimes during a wider range of aquifer conditions. To determine if drawdown threshold can be revised, a series of experiment drawdowns could be conducted after removal of the concrete floor and at discharges lower than 54 ft^3/s. Data on changes in water depth, rate of water recession, amount of wetted surface habitat, and stranded salamanders in Eliza Spring can be collected and compared with existing baseline data for drawdowns with the concrete floor in place. No significant increase in water recession rate or number of stranded salamanders, coupled with maintenance of wetted surface habitat in Eliza Spring would indicate that drawdown threshold could be revised.

Hypotheses:

H1: Is there a difference in Take of protected salamanders during drawdowns below 54 ft^3/s and above 54 ft^3/s?

H2: Does surface habitat of Eliza Spring remain wet during drawdowns at < 54 ft^3/s after concrete floor is removed?

H3: Does average water depth differ during drawdowns drawdowns below 54 ft^3/s and above 54 ft^3/s?

H4: Does rate of water recession differ during drawdowns drawdowns below 54 ft^3/s and above 54 ft^3/s?

Criteria for evaluating success of management:
Maintenance of wet surface habitat during all drawdowns
Statistically significant increase in Take of protected salamanders during drawdowns below 54 ft^3/s *versus* above 54 ft^3/s

6.5.1.2 Flood Debris Dredging

Frequency of flood debris removal is dependent on the scale of dredging method, the configuration of the dams, and amount of material that is deposited within the confines of Barton Springs, which is dependent on activities and conditions in the upstream watershed. Prior to 1998, removal had been frequent (roughly bi-annually) and conducted using large-scale, environmentally destructive methods. With the listing of *E. sosorum* as endangered in 1998, these methods were abandoned and alternatives were investigated. Flood-borne material accumulated for 15 years until the first alternative was used, vacuum dredging. This method is sufficient for removal of material up to 5 inches in diameter and is the method proposed here because it is environmentally unobtrusive and small scale. It provides the best protection of salamanders and least perturbation of the supporting aquatic ecosystem. Adoption of this method requires continuing analysis of the optimal removal frequency.

The City proposes to remove flood debris using vacuum dredging when its accumulation within 200 ft upstream of the downstream dam reaches or exceeds ≥ 1000 cubic yards. This is expected to translate into removal no more frequently than every 3 years. However, the exact frequency will be determined by the actual rate of accumulation, which is not consistent year to year. The hydrology of Central Texas is characterized by irregular alternation between periods of floods and droughts. Months of frequent flooding can deposit large amounts of material, but these are typically followed by months or years of base flow and drought when no material is deposited. Therefore, necessity for dredging will not occur at some regular, predictable frequency. In addition, the frequency proposed here is based on use of vacuum dredging, the least intrusive method feasible for this site at this time. Less intrusive dredging methods may be developed in the future and should be considered if they reduce impact on protected salamanders and their habitat. Use of a different method may affect the frequency of dredging. Each project will be accompanied by collection and analysis of data to evaluate efficiency of project and potential detrimental effects. This information will be used to revise and refine dredging frequency and method.

Hypotheses:
Parthenia Spring
H1: Salamander take does not differ among dredging events?
H2: Salamander abundance in habitat adjacent to dredging does not differ?
H3: Debris accumulation between vacuum dredging events does not differ?

Criteria for evaluating success of management:
Statistically significant difference in salamander take or abundance. Statistically significant different in debris accumulation.

6.5.1.3 Catastrophic Spill Response

The Barton Springs Catastrophic Spill Response Plan is activated whenever a contaminant is spilled in the Barton Springs recharge or contributing zone of the Edwards Aquifer. The plan delineates clear steps for responding to spills of contaminants that could detrimentally affect water quality of the Barton Springs complex. Activation of the plan mobilizes City hydrogeologists, biologists, and spill response specialists to the spill site and Barton Springs to assess conditions and implement actions to minimize impacts on the salamanders and their habitat. Major tasks of responding to a spill are:

1. Identify whether spill is in Barton Springs Recharge or Contributing Zone
2. Identify if spill is material of concern
3. Identify potential to contaminate springs
4. Predict potential detrimental effects of spills entering aquifer or surface creeks
5. Determine appropriate response to protect salamander populations (no response, increase monitoring, partial rescue, full-scale rescue).

Since spills are unplanned and their occurrence is unpredictable, each event (real or simulated) is an opportunity to evaluate and revise the response plan. Formal evaluation and revision of the plan will be conducted every 5 years. Although statistical tests are not always applicable, the collection of data on number of salamanders affected, mortality of salamanders, number of salamander rescued, number of salamanders returned to the wild, and ongoing monitoring of wild salamander abundance is useful. In addition, concentrations of contaminants that enter salamander habitat and their persistence over time can be correlated with monitoring data.

<u>Hypotheses</u>
H1: Was spill detrimental to salamanders?
H2: Was spill detrimental to salamander habitat?
H3: Was response beneficial or detrimental to salamanders?
H4: Was actual threat worse than perceived threat?
H5: Was response the appropriate scale for actual threat?
H6: Was speed of response adequate to protect salamanders and their habitat?

<u>Criteria for evaluating success of management:</u>
H1-H2: If yes, determine if and how effects can be minimized
H3: high mortality of rescued salamanders indicates detrimental
H4-H6: If yes, adjust threat evaluation and revise response category thresholds

6.5.2 Recreation

In this Plan, lethal Take from recreation is assessed by number of salamanders or incidents, while non-lethal Take is assessed by area. These potential detrimental effects have been inferred from evidence of alteration observed during daily checks of spring sites and incidents reported by Barton Springs' staff. There are no data demonstrating direct or indirect effects on salamanders of habitat disturbance by recreational users, so the adequacy of Take allotted to recreation at this time may not be sufficient if recreational use increases substantially in the future. Therefore, Take should be re-evaluated after appropriate data have been collected. In order to achieve this goal a written record of all observed Take and reported incidents with the potential to impose Take would be created and maintained. This record will include date, type of disturbance, observed effects on protected salamanders and/or their prey, number of people in the water during month of high recreational use. These data can be used to revise management and operations to reduce impacts of recreation.

6.5.3 Habitat Restoration

Success of proposed habitat restoration can be evaluated using survey data of salamander abundance, recruitment, population growth trajectory, prey abundance, and habitat condition. Statistically significant increases in salamander abundance, evidence of recruitment, positive or stable population growth rate, improvement in habitat quality (biotic and abiotic), and improvement in prey availability are criteria that would demonstrate the success of the projects. Analyses of restoration success must be considered in biologically and evolutionarily relevant time scales because benefits of habitat restoration may not be immediately apparent.

6.5.3.1 Modification of Dams

This Plan includes projects to study modifying both upstream and downstream dams of Barton Springs Pool to provide the mechanisms by which a more natural flow regime can be restored. Dams affects flow regime, which in turn, influences aquatic habitat of streams by driving the composition and abundance of aquatic flora and fauna. Adding gates in both dams could reduce impediments to flow through the Pool, decreasing deposition of sediment, gravel, and debris. The potential effects of addition of gated openings or reconfiguration of existing openings is the subject of a hydrodynamic modeling study that is in progress. The study focuses on describing patterns of flow velocity and turbulence in the Pool with dams in their present configuration, and creating a computer model that can be used to test the effects of various placements, shapes, and numbers of gates in both dams on flow regime during flood and base flow. Ultimately, the results will be used to guide engineering design of modifications and construction to be implemented in the future when funding is available.

After the dams are modified, the effectiveness of the new configurations can be evaluated by comparing existing baseline and post-modification data. Restoration of a more natural flow regime would be indicated by a shift in physical and biological characteristics from those typical of lentic waters to those typical of lotic waters (e.g., decrease in abundance and composition of lentic-water algae, increases in tightly-attached periphytic algae, reductions in sediment deposition and cover).

Hypotheses:

Parthenia Spring (evaluate effects of new or modified gates in dams)

- H1: Is the composition of the algal and macroinvertebrate communities in salamander habitat different after dam modifications?
- H2: Is there a difference in long-term average salamander abundance before and after dam modification?
- H3: Does the rate of deposition of flood-borne material differ?

Upper Barton Spring (evaluate effects of construction of gates in upstream dam)

- H4: Are there differences in depth of sediment and percent sediment cover in after floods when upstream dam gates are open?

H5: Is there a difference in long-term average salamander abundance before and after implementation of dam modifications?

Criteria for evaluating success of management:

H1 and H2: Statistically significant differences

H3: Statistically significant decrease in long-term average salamander abundance

H4: Statistically significant increase in Take

H5: Statistically significant increases in sediment

H6: Statistically significant decrease in long-term average salamander abundance before and after implementation of dam modifications

6.5.4 Wild Population Monitoring

The overall goal of population monitoring is to collect data from which the status of the species can be inferred. Measurement of salamander abundance in each spring site is one method for inferring population size and long-term trends in population growth. The Plan proposes to conduct bi-monthly census surveys of salamander populations and use time-series statistical methods to evaluate trends in population size and factors that covary with salamander abundance. Additional data collected on salamander size and age category are used to test for recruitment using common parametric and non-parametric statistical methods. Additional research that contributes to an understanding of factors influencing survival, reproduction, and recruitment in wild populations of *E. sosorum* and *E. waterlooensis* would be positive contributions to predicting the fate of populations. A better understanding of genetic variation in protected species and mean evolutionary fitness of populations as well as of individuals, phenotypes, and genotypes would provide baselines upon which to assess probabilities of species persistence. Assessments of population response to natural and artificial selection would provide a basis for evaluating the long-term fate of protected species in the wild. All of these research avenues may require experimental designs other than the bi-monthly abundance estimates proposed. Therefore, the proposed survey frequency should be modified based on monitoring plans approved by the Service.

Hypotheses

H1: Changes in sample size proposed in this Plan result in no reduction in statistical power for population growth, salamander abundance and recruitment, and habitat quality analyses.

Criteria for evaluating success of management:

No statistically significant reduction in statistical power.

6.5.4 Ecosystem Resilience

Ecosystems are dynamic; multidimensional variation is the norm. Natural variation occurs on time scales ranging from minutes to millions of years. Conserving resilience requires some understanding of the difference between natural and anthropogenic variation and the potential time period in which they exert their effects. A fundamental characteristic of stream ecosystems in arid climates is the range of variation in hydrology over relatively short time periods (e.g., months); discharge moves from flood to drought and back, often with only short periods of constant conditions. Species and communities that evolved in these systems are adapted to variation; when that variation is dampened by anthropogenic activities, these species can suffer and the community destabilized by their loss. The hydrological variation in Parthenia, Eliza, and

Old Mill Springs has been dampened by the construction of dams and other impoundments; the simplest example is the lack of variation in water depth in Barton Springs Pool with hydrological conditions. Water depth variation is necessarily accompanied by variation in other characteristics of the ecosystem, from flow velocity, to sediment transport, to distribution and abundance of microhabitats, to presence of absence of aquatic macrophytes and algae. Riparian habitat complexity and variation affect aquatic habitats in many ways, from regulating allochthonous organic inputs to altering sunlight penetration, which in turn affect water temperature and ecosystem productivity. Management of aquatic and terrestrial habitat in this Plan is intended to help protect or foster ecosystem resilience to both natural and anthropogenic perturbations. The overall goal is to restore as much as possible the biological communities native to Edwards Plateau springs, streams, and riparian areas. Aquatic and riparian biological community management in this Plan focuses on creating a physical environment that supports healthy communities of native species. It also includes protection of resident species, repatriation of native species, removal of non-native species. The City proposes to evaluate whether this strategy is effective by continuing to collect data on the physical and biotic characteristics of each spring (e.g., flow velocity, algal community abundance and composition, invertebrate abundance and diversity, DO, water temperature, canopy cover). The data can be used to examine the range of variation at short (months) and long (years) time scales, to detect significant changes. Moreover, the data can be used to evaluate whether methods of mitigation for long-term alteration in hydrology are sufficient.

Hypotheses - Aquatic Habitat Management:

H1: Do aquatic habitat characteristics before and after implementation of new management strategies differ?

H2: Are habitat characteristics of Barton Springs similar to those of healthy creeks and rivers?

Criteria for evaluating success of management:

H1: Statistically significant differences in relevant characteristics (e.g., flow velocity, algal community composition and relative abundances, invertebrate abundance).

H2: Statistically significant differences between Barton Springs and healthy creeks and rivers

Hypotheses - Riparian Habitat Management

H1: Do aquatic habitat characteristics before and after implementation of new management differ?

H2: Are habitat characteristics of Barton Springs similar to those of healthy creeks and rivers?

Criteria for evaluating success of management:

H1: Statistically significant differences in relevant characteristics (leaf litter, canopy cover, water temperature, ecosystem productivity, etc.).

H2: Statistically significant differences between Barton Springs and healthy creeks and rivers.

6.5.5 Scientific Research

As an additional conservation measure the City proposes to support (funding and staff) research projects designed to gather and evaluate data applicable to wild populations of *E. sosorum* and *E. waterlooensis*. These projects would be in addition to the regular monitoring already conducted under the permit. A number of research projects have already been conducted through the Barton Springs Salamander Conservation Fund and in association the Barton Springs Edwards Aquifer Conservation District's development of a Habitat Conservation Plan. Result of such projects will be used to adjust population management, as occurred with the study of Woods et al. (2010). Their laboratory work on response of *E. sosorum* and *E. nana* to low concentration of dissolved oxygen was used to determine when to begin efforts to mitigate the effects of drought. Adaptive management under this Plan will include use of new scientific information to improve conservation measures.

6.5.6 Captive Salamander Program

In accordance with the initial permit, the City has developed a captive salamander program. The facility housing the program is located in Zilker Park and is referred to as the Austin Salamander Conservation Center (ASCC) (See Appendix E for summary of existing program). The primary goal of the program is to serve as a refugium for populations of *E. sosorum*, and *E. waterlooensis* suitable for return to the wild, without compromising or harming wild populations. To meet this goal, the captive populations should contain the genetic diversity of the species in wild and maintain evolutionary fitness of captive salamanders. The captive population should provide salamanders that are fit for survival and reproduction after repatriation or reintroduction into wild populations. Life history and morphological characteristics typical of wild salamanders must be maintained in captive salamanders in order to retain capacity for evolution in response to changing environments. Meeting these program goals while at the same time minimizing collections of wild salamanders requires management strategies that incorporate complexity and can be revised as conditions and available information change. Adaptive management plays an important role in choosing management strategies for captive populations. The projects at the ASCC appropriate for adaptive management are scientific research on captive animals, captive breeding scenarios, reintroduction/repatriation, and husbandry conditions.

6.5.6.1 Captive Population Demographic Management

A captive population management plan (PMP) has been developed for *E. sosorum* and *E. waterlooensis* at the ASCC (Chamberlain 2012). This plan is updated and revised continually as new information becomes available. The Plan relies on a detailed database and model-fitting analytical tools designed for management of captive populations (Pollak *et al*. 2000). The planning tools include a framework for collecting life history data from captive individuals and analytical methods for examining demographic characteristics of captive populations. Life history characteristics include captive salamander longevity, lifetime reproductive success, and age-specific fecundity, survivorship, and mortality. Captive population characteristics include growth rate, fitness, and genetic diversity. Demographic analyses allow for examination of how the population changes over time as well as how it is expected to change in the future, based on life history data from the target species. These tools can be used to understand how the species responds to the captive environment over time, to evaluate management practices, and estimate captive population growth rate.

Hypotheses

H1: Life history characteristics of captive salamanders are similar to wild salamanders

H2: Age-specific survival and fecundity are similar to wild salamanders

H3: Age at first reproduction is similar to wild salamanders

H4: Longevity is similar to wild salamanders

H5: Captive population fitness is similar to wild populations

H6: Captive salamanders behavior (feeding, breeding, anti-predator) is similar to wild salamanders

H7: Captive population growth rate does not exceed size necessary for genetic diversity

H8: Captive salamanders reproduce successfully.

H9: Captive salamander mortality rate does not increase over time.

Criteria for evaluating success of management:

H1-H6: Statistically significant differences warrant re-evaluation

H7: Number of captive animals exceeds necessary size

H8: Reproduction ceases in captivity

H9: Mortality in captivity does not increase or exceed rates in natural populations

6.5.6.2 Captive Population Genetic Diversity Management

Captive populations are small populations, and therefore can lose genetic diversity due to inbreeding, genetic drift, and random changes over multiple generations. Detrimental genetic mutations or combinations can persist in captivity when animals are protected from natural selection. Small, captive populations may also adapt to the environment in captivity. Management strategies to maximize the overall genetic diversity of the captive population is one of the most productive methods of maintaining animals fit for survival and reproduction in the wild. Therefore, active management is essential to reach the goal of maintaining captive populations suitable for reintroduction into the wild.

Determining the minimum and optimal population sizes necessary to maintain or increase genetic diversity can be investigated using standard pedigree and life table analyses of salamanders currently in captivity. Potential breeding scenarios can be tested with computer model fitting to determine the resultant genetic diversity of the captive population (see Appendix E). A common goal for captive breeding programs is to manage the population such that it would be possible to maintain 90% genetic diversity over 100 years (Foose *et al*. 1995). A shorter time period could be chosen, but the goal is always to maintain genetic diversity over generations while minimizing collection of wild individuals. Adaptive management would be to measure genetic diversity in the Austin Salamander Conservation Center populations, compare that diversity with theoretical potential diversity in captive population, and with wild populations. Evaluation of management of genetic diversity of captive populations would include the following.

Hypotheses

H1: What is the projected maximum genetic diversity theoretically obtainable with salamanders currently in captivity?

H2: What is the theoretical time frame or maximum number of captive-bred generations before the projected genetic diversity would drop below target levels?
H3: How many new, wild-caught founders are necessary to meet genetic diversity goals? Are additional wild-caught founders necessary to meet genetic diversity goals, and, if so, how many? Have other strategies (such as maximizing the reproductive success of individual wild-caught salamanders already in the program) been considered prior to additional collections?
H4: Are life history parameter values (age-specific birth and death rates, fecundity, longevity, etc.) used in theoretical breeding scenarios that maximize genetic diversity similar to life history in wild populations?

Criteria for evaluation of management success
H1: Maximum genetic diversity obtainable is not sufficient to avoid detrimental inbreeding and loss of fitness and evolutionary potential
H2: Theoretical maximum number of generations of projected genetic diversity will not meet program goals.
H3: Number of actual founders differs from requisite founders
H4: Life history parameter values necessary to maximize genetic diversity in captive populations differ from those of wild populations such that potential for reintroduction to wild populations is compromised.

6.5.6.3 Reintroduction/Repatriation

Under some circumstances, repatriation of wild-caught or reintroduction of captive-bred salamanders may be necessary to supplement or restore wild populations. For example, if there were to be a contaminant spill that extirpated a protected species from the wild, continued existence of the species would require reintroduction of captive animals. In addition, if wild population sizes become extremely small due to unforeseen circumstances, reintroduction may be necessary to ensure persistence of the species in the wild. Success of reintroduction or repatriation programs is dependent on both short-term fate of individuals and long-term effects on the population, including evidence of evolutionary fitness. Short-term success can be measured at the level of the individual by tracking the survival, fecundity, and lifetime reproductive success of individuals. Evaluation of long-term success requires measurement at the level of the population and would include evidence of positive or stable population growth and sufficient mean fitness of the population. Founder individuals should be as genetically distant as possible, maximizing the genetic variation introduced into the existing population and the population's ability to respond to selection.

To prepare for possible reintroduction/repatriation, preliminary studies need to be conducted to determine if captive-raised individuals would survive in the wild. The Information gained from these studies would be used to evaluate the effectiveness of the captive breeding program and management would be modified as necessary. For example, the most effective strategy may be to release wild-caught salamanders after they have reproduced in captivity; in this way, the genes of those individuals may contribute to both the wild and the captive populations. Ultimately, the fitness and evolutionary potential of captive salamanders must be evaluated to determine if their reintroduction would benefit wild populations. In general, the adaptive management associated with reintroduction/repatriation can be evaluated as follows.

<u>Hypotheses</u>

H1: Physical health of captive salamanders to be reintroduced does not differ from physical health of wild salamanders.

H2: Life history characteristics of captive salamanders do not differ from wild animals.

H3: Expected fecundity and reproductive success of captive salamanders is sufficient to maintain or enhance wild population fitness and evolutionary potential.

<u>Criteria for evaluation of management success</u>

H1: Captive salamanders die after reintroduction

H2: Age and breeding history in captivity differs from that of wild salamanders

H3: Fecundity and reproduction success in captivity differs from that in the wild.

7.0 Alternatives Considered

As part of the development of this HCP, the City considered four potential strategies for balancing the needs of resident endangered species and the use of Barton Springs Pool as a recreational facility. The preferred alternative is the issuance of a 10(a)(1)(B) incidental take permit based on the conservation measures described in this HCP to allow for continued operation of Barton Springs Pool by the City with minimal impact on endangered salamander populations. The alternative "No Action" scenario is not to obtain an incidental take permit for the Barton Springs Salamander, *E. sosorum*, and the Austin Blind Salamander, *E. waterlooensis*, resulting in the closure of Barton Springs Pool to recreation. The "Maintenance Prior to Listing Alternative" would be to re-instate the Pool maintenance practices that were in place prior to the listing of *E. sosorum* as an endangered species in 1997, resulting in increased take of salamanders over the preferred alternative. An additional alternative evaluated involved the purchase of all remaining undeveloped land and retirement of groundwater pumping rights.

These strategies are described below and include the rationale for rejecting them in favor of the preferred alternative as described by this HCP. Presentation of this information is intended to enhance the transparency of the decision-making process of the City in development of this plan. The alternatives presented in this HCP were evaluated by the City only, and were not suggested or officially evaluated by the Service. They are completely separate from any alternatives evaluated in the associated Environmental Assessment prepared for the Service in compliance with the National Environmental Policy Act.

7.1 No Action Alternative

Under the No Action alternative, Barton Springs Pool would not be cleaned or lowered for cleaning. As a result of the lack of maintenance, the Pool would be closed to swimming for safety reasons. Habitat areas within the pool would become embedded with excessive sediment. To minimize the possibility of incidental take at Upper Barton Springs, the spring area would need to be restricted from public access, and wading would be prohibited. Maintenance activities at Old Mill and Eliza springs would be severely limited. Habitat restoration activities at all sites would be discontinued. Education and outreach activities, funded in part by pool entry fee revenues which would no longer be available, would decrease or be discontinued. Monitoring at all sites not covered under a separate 10(a)(1)(A) permit would end.

Under the No Action alternative, Barton Springs Pool would not be used for public recreation activities. The loss of revenue from Pool entry fees to the Parks and Recreation Department would adversely affect the City General Fund. Human interaction with Barton Springs has occurred over the last 10,000 years. The loss of the iconic gathering space for the community would be personally detrimental to the many regular users of the Pool and represent a significant loss to the cultural sense of place of the City. Public and political support for increased water quality protections and restrictive development ordinances within the Barton Springs Zone would be significantly diminished, and could lead to relaxation of some water quality protections resulting in further degradation of the Edwards Aquifer.

7.2 Maintenance Prior to Listing Alternative

The "Maintenance Procedures Prior to Listing" alternative would operate Barton Springs Pool with the level of maintenance used prior to the listing of the Barton Springs Salamander (*Eurycea sosorum*) as endangered (May 1997). Adverse impacts of this alternative are the stranding of salamanders during the drawdowns for the cleaning of the deep and shallow ends of the Pool, increased potential for take from maintenance for public recreation. Additionally, public access and recreation at Old Mill Spring would no longer be restricted.

Under this alternative, routine maintenance of Barton Springs Pool would require the periodic lowering of the water level and the removal of silt and organic debris. During the swimming season (March through September), the Pool would be lowered twice a week and only once a week during the remaining months of the year. The total number of cleanings would be 60 times per year. Maintenance at Eliza and Old Mill springs would be minimal with weekly litter removal and periodic habitat restoration. Potable water would be used to conduct cleaning. Maintenance activities would not include the additional conservation measures described in this Plan (see Section 6) including use of low-pressure water in salamander habitat areas.

Drawing down the water level in the Pool for cleaning would result in incidental take in Parthenia and Eliza springs. Under this alternative, the entire Pool must be drawn down 4 to 5 feet for at least one day to remove algae and sediment. Cleaning methods would include high-pressure hosing and mechanical scrubbing of substrate with a small tractor equipped with a hydraulic rotary brush. The Beach would be dragged with a chain-link drag (or similar device) pulled by a small tractor to dislodge the algae and sediment; then the silt and organic debris would be moved into the deep end with fire hoses and very high water pressure.

During the off-season (October through February), the Pool water elevation would be drawn down once a week for routine maintenance of the shallow and deep ends. This weekly maintenance would include algae and sediment removal using the methods described in the previous paragraph. In March, before the main swimming season begins, the Pool water would be lowered for two weeks for annual maintenance and cleaning. To ensure minimal impact to the endangered salamanders at all of the spring habitat areas, City staff would closely coordinate this major maintenance effort. A City staff biologist would be present to monitor salamander populations before and during Pool drawdowns.

Swimmers would be prohibited from searching for and capturing salamanders or otherwise disturbing the gravel substrate within the salamander habitat. Signs that discourage harassment of the wildlife in the Pool would be posted. SCUBA diving or the use of any other equipment other than the usual recreational swimming gear (such as snorkels and underwater cameras) by anyone other than authorized City staff would not be allowed. No non-native animals (other than humans), plants, fungi, or other organisms could be purposely introduced into Barton Springs Pool without the approval of City and Service biological staff. The City would provide spill and response training for staff performing maintenance activities. The intrusive cleaning procedures, reduced habitat maintenance and restoration activities and removal of the public access restrictions at Old Mill Spring would result in increased take over the Preferred Alternative.

7.3 Preferred Alternative

The Preferred Alternative is described by this HCP. The conservation program described here balances recreational use with protection of the Barton Springs Salamander (*E. sosorum*) and the Austin Blind Salamander (*E. waterlooensis*). The continued use of Barton Springs Pool as a recreational facility fosters public support and commitment to protection of the rich natural resource of the Barton Springs complex. It also provides abundant opportunities for the public to better understand the relationship between a healthy aquatic environment and human activities within the Barton Springs Zone. Public education and public support are vital for the long-term protection of the aquifer, the Barton Springs complex, and the biological resources that depend on this spring system.

Measures in this alternative are designed to minimize and mitigate the impacts of maintenance and operation of Barton Springs Pool and Zilker Park on protected salamander species, enhance salamander habitat, and provide a safe recreational environment for swimmers. The Preferred Alternative would allow the continued use of Barton Springs Pool as an aquatic recreational facility operated by the City. Structural and procedural changes would be initiated or continued which would minimize or eliminate negative impacts of the cleaning of the Pool to the salamander. The City would implement the measures of this habitat conservation plan to minimize and mitigate for any impacts caused by pool maintenance and recreational use.

7.4 Acquisition of Land, Retirement of Pumping and Extension of Utility Service

A potential strategy to attempt control of water quality and quantity at Barton Springs and meet the requirements of the Act would involve City purchase of all remaining undeveloped land in the City's jurisdiction in the Barton Springs Zone. These lands once acquired would be protected by conservation easement or otherwise permanently protected to ensure no new development on these lands. There are approximately 16,000 acres of undeveloped land with the City's jurisdiction in the Barton Springs Zone. The majority of this land (83%) would be developed currently under the provisions of the SOS ordinance, which requires no degradation of water quality.

Average cost per acre of land in western Travis County may be generally approximated from recent appraisals performed for the City by an independent appraiser. Actual land acquisition costs vary greatly based on parcel size, location, and existing infrastructure. Based on several recent fee simple and conservation easement acquisitions of land in western Travis County, costs range from approximately $7,000/acre to $408,000/acre (Marsha Schultz, City of Austin Real Estate Services, personal communication). The cost of acquiring all remaining undeveloped land in the Barton Springs Zone within the City's jurisdiction might range from $112,000,000 to $6,528,000,000 assuming all landowners were willing to sell. The entire capital project budget for the Watershed Protection Department was approximately $15,000,000 in fiscal year 2012. If the entire capital budget of the Watershed Protection Department were dedicated to acquiring the remaining undeveloped land in the Barton Springs Zone it could take up to 435 years to accrue the necessary funds. This assumes that all landowners would participate, and that no other flood control, erosion control or other water quality protection capital projects would be completed in this time period. The purchase of land already protected by the non-degradation conditions of the SOS ordinance would not be an efficient use of the City's revenues. The City's jurisdiction only represents 28% of the total area of the Barton Springs Zone. Even if the City purchased and permanently protected all remaining undeveloped land in the Barton Springs Zone within jurisdictional limits, the majority of land in the Barton Springs Zone would remain available to development.

City wastewater utility services would be extended to all facilities using on-site sewage disposal (OSSF, *e.g.*, septic tanks) over the recharge zone to discontinue use OSSF and reduce nutrient loading to the aquifer. City wastewater utility service would be extended to all subdivisions or facilities relying on land application or direct discharge of wastewater effluent in the Barton Springs Zone as permitted by the Texas Land Application Permit system to discontinue these facilities and reduce nutrient loading to the aquifer. Once all existing facilities in the Barton Springs Zone have been connected to the City wastewater utilities, the City would not allow new connections consistent with the previously described land acquisitions to limit all further development in the Barton Springs Zone within the City's jurisdiction. The estimated cost of City utility service extensions cannot be directly estimated without a detailed systems planning analysis. The pressure planes are not known, and thus pipe sizes, storage tank locations, need for pump stations and interceptors cannot be used to derive a cost. The utility extensions would likely cost in the billions of dollars.

By extension of City utilities to the majority of areas within the City's jurisdiction in the Barton Springs Zone, the City could also allow land owners to convert drinking water supply sources from groundwater withdrawal from the Edwards Aquifer to City supplied water from the Colorado River. City utilities could additionally be extended to residential wells that are exempted from regulation by the Barton Springs Edwards Aquifer Conservation District and their restrictions on pumping during drought conditions. There are an estimated 558 exempt groundwater withdrawal wells regulated by the Barton Springs Edwards Aquifer Conservation District that are within the City's jurisdiction. These wells are permitted to withdraw an estimated 779,581,930 gallons per year during non-drought conditions (Barton Springs Edwards Aquifer Conservation District, R. Gary personal communication). Conversion of these water users from groundwater to Colorado River water supplied by the City will reduce the City's available allocation from the Colorado River as permitted by the Lower Colorado River Authority. Once converted the groundwater withdrawal permits could be permanently retired providing additional spring flow during extreme drought periods to habitat in the plan area. The cost of the retirement of these pumping permits is unknown, as a legal framework to retire groundwater withdrawal permits under these conditions has not yet been created in Texas (Dupnik 2011). Some regulatory or financial incentive may have to be provided to landowners to encourage switching from use of land application for wastewater disposal and use of groundwater for drinking water supply to City services since City utilities would cost more.

All of the surface management measures described in the preferred alternative would also need to be implemented in addition to the land acquisitions and utility extensions described. These surface management measures are critical to maintaining sufficient habitat to ensure survival of the covered species.

The total estimated cost of these land acquisitions and utility extensions cannot be accurately quantified, but is estimated to be in the billions of dollars, not including the cost of retirement of groundwater withdrawal permits or financial incentives for groundwater right retirement. This cost surpasses the ability of the City to implement while still maintaining all other necessary City functions, and would represent an extremely disproportionate amount of the City's total annual budget. This action would be unprecedented and could face significant legal challenges from individual homeowners or from the Texas Legislature. Despite the exorbitant costs, the majority of land in the Barton Springs Zone would remain unprotected from urbanization. This alternative would not completely control threats to water quality of the aquifer from urbanization, or ensure adequate spring flows to ensure salamander survival during future extreme droughts as not all groundwater rights would be retired for conservation purposes. This measure is not financially feasible for the City and would not guarantee sufficient control of water quality or quantity to ensure survival of the covered species.

8.0 Implementation

This section describes who will administer this habitat conservation plan and how much the plan actions may cost in fiscal year 2011 dollars. This section also describes actions to be taken if circumstances change.

8.1 Program Administration

The City will be solely responsible for implementing this habitat conservation plan and complying with the terms and conditions of the associated 10(a)(1)(B) incidental take permit. The City's Watershed Protection Department maintains 4 staff positions dedicated to the Salamander Conservation program. These staff members work on permit implementation, compliance and reporting, salamander population monitoring, operation of the captive breeding facility, and other projects that may affect protected salamander populations.

An annual report to the Service documenting the progress towards achieving the conservation objectives of this Plan and detailing the current status of the species based on monitoring data will be submitted to the local Service office. The Service will review the annual reports to determine City compliance with terms of the amended habitat conservation plan and associated 10(a)(1)(B) permit. The Service may request additional information from the City to determine if the City is in compliance with the terms of the permit if necessary.

Major or minor amendments to this habitat conservation plan or associated Incidental Take permit may be necessary over the term. All amendments will be made in accordance with applicable federal laws and regulations. Amendments to this habitat conservation plan must not jeopardize the Barton Springs Salamander, *E. sosorum*, or the Austin Blind Salamander, *E. waterlooensis*. The Service must be consulted and concur on all proposed amendments.

Minor amendments involve routine administrative revisions or changes to the operation and management program and that do not diminish the level or means of mitigation. Such minor amendments do not alter the terms of the section 10 (a)(1)(B) permit. Upon the written request of the City, the Service is authorized to approve minor amendments to the habitat conservation plan if the amendment does not conflict with the conservation goals of the Plan.

All other amendments will be considered a major amendment to the section 10(a)(1)(B) permit, subject to any other procedural requirement of federal law or regulation that may be applicable to amendment of such a permit.

8.2 Cost Estimates and Funding

The City of Austin will fund the conservation measures and hire the staff needed to implement this plan. Since the issuance of the first incidental take permit for the Barton Springs Salamander, *E. sosorum*, to the City in 1998, the City has demonstrated that sufficient funding is available to implement the required conservation measures and supply the necessary staff. The directors of the Watershed Protection Department and the Parks and Recreation Department have the full, pre-existing authority to implement the conservation measures described in this plan and commit to upholding the terms of this plan as specified for the duration of the permit. The City has allocated the necessary funds to fully implement this plan from the City of Austin General Fund and the capital improvement and operating funds of the Watershed Protection Department, a fee-funded utility. The City guarantees that sufficient funding will continue to be provided throughout the duration of the permit.

At least $28,000 annually is dedicated by this habitat conservation plan to be allocated to the operation of the captive breeding facility. At least $45,000 annually is dedicated by this plan to the operation of the SPLASH educational exhibit. At least $10,000 of the SPLASH funding is derived from Barton Springs Pool entry fee revenues, and at least $35,000 is derived from Watershed Protection Department funds. At least $53,000 annually from Barton Springs Pool entry fee revenues is dedicated by this plan to a conservation fund.

The conservation measures described in Section 6 include dedication of a full-time staff member to operate the Austin Salamander Conservation Center (refugium and captive breeding facility), and a minimum of two salamander biologists to conduct wild population monitoring and Barton Springs' operation and oversight. These salamander biologists are employees of the Watershed Protection Department, a fee-funded utility of the City of Austin.

Based on fiscal year 2011 estimates, the Austin Salamander Conservation Center and associated staff costs were approximately $120,000 annually. The remaining Watershed Protection Department staff activities and materials relating to implementing the conservation measures for *E. sosorum* and *E. waterlooensis* were approximately $230,000.

Individual restoration projects proposed in this Plan will be funded from the Capital Improvement Process funds of the City. The cost of each project will vary and depends on preliminary engineering assessments, evaluation of the feasibility of design options, engineering and construction costs, and inflation. Therefore, the costs of restoration projects in this habitat conservation plan have not been estimated.

8.3 Changed Circumstances

Changed circumstances are defined as "circumstances affecting a species or geographic area covered by a conservation plan that can be reasonably anticipated by plan developers and the Service and that can be planned for…" (63 CFR 8859). This habitat conservation plan identifies provisions to compensate for negative impacts to the covered species from changed circumstances.

Climatic, water quality or water quantity conditions outside of the control of the City could change over the proposed 20-year term of the permit. Changed circumstances that can be reasonably anticipated include:

- catastrophic events leading to temporary loss of habitat (hazardous material spills, temporary dewatering)
- permanent loss of habitat or habitat degradation from global climate change
- covered species become de-listed
- covered species become extinct
- unintentional introduction of invasive plants that modify salamander habitat or conditions in the Pool
- unintentional introduction or increase in population of non-native predators in habitat areas
- unintentional failure of dams or floodwater bypass altering water levels of Barton Springs Pool
- new information published in scientific literature establishes detrimental effect levels for *Eurycea* salamanders or appropriate surrogate amphibians resulting from exposure to sunscreen products or other personal care products introduced to Barton Springs Pool from recreational activities

In the event of a catastrophic event such as a hazardous material spill leading to temporary loss of habitat, the City will notify the Service verbally or in writing. The City will implement the measures detailed in the Spill Response Plan to limit or remediate the impacts of the spill and rescue as many salamanders as possible. Rescued salamanders may be temporarily housed in the captive breeding facility or other suitable aquarium facilities. The City will determine when conditions are appropriate for salamanders to return to wild habitats. Salamanders will be returned to wild habitat areas subject to the genetics plan created by the City and approved by the Service as described in Section 6.

A structural failure of the downstream dam impounding Barton Creek and forming the Pool or failure of the Barton Creek bypass culvert may lead to unintentional rapid lowering of the water level in the Pool. The City will notify the Service verbally or in writing if this event occurs and discuss any potential changes to this habitat conservation plan or associated incidental take permit that may be appropriate. City biologists will ensure that salamanders are not stranded by following Service-approved draw down protocols. Swimmers in the Pool will be restricted from entering habitat areas near the main spring and fissures area until the problem is resolved and water level returns to normal elevation.

The City is committed to permanent protection of endangered salamander habitat and compliance with the requirements of the Act. It is possible that global climate change may lead to changed precipitation patterns in the Barton Springs Zone and resulting groundwater flow patterns in the Barton Springs Segment of the Edwards Aquifer. Global climate change has the potential to alter regional distribution of vegetative and macroinvertebrate communities within salamander habitat. Climate change could result in permanent loss of suitable habitat. Unlike temporary dewatering of habitat areas, these changes may be irrevocable and are completely outside of the control of the City. There is currently insufficient information available to predict the potential for habitat in the Plan Area to be affected by global climate change over the proposed 20-year term of this Plan.

The effects of climate change on central Texas water resources are uncertain, in part because of the difficulty in incorporating climate models into hydrological studies (Mace and Wade 2008). Loáiciga *et al*. (2000) predicted that under a doubling of atmospheric carbon dioxide, water resources of the Edwards Balcones Fault Zone Aquifer would diminish even if pumping did not increase above its current level. The Edwards Aquifer is one of the most vulnerable watersheds to climate change impacts in part due to anthropogenic water demands, a strong relationship between precipitation and recharge, and high variability of precipitation and the occurrence of multi-year droughts (Loáiciga *et al*. 2000).

Even if climate change does not affect Texas within the next 20 years, the threat of multi-year droughts is still significant, as historical records based on tree-ring data indicate that droughts more severe than the drought of the 1950's have occurred many times in the past several hundred years (Cleaveland *et al*. 2011). Thus, an extreme drought would not be out of the ordinary in the context of prehistoric environmental conditions, yet current anthropogenic activities (groundwater withdrawal, reduced recharge from impervious cover, increased contaminants) could significantly alter the frequency and severity of droughts. The ultimate effects of such a drought on the Barton Springs Salamander, *E. sosorum*, and the Austin Blind Salamander, *E. waterlooensis*, are partially dependent on whether these changes differ from climatic variation under which these species evolved.

There is insufficient information to plan for alternative conservation measures to mitigate for any adverse effects of climate change. If climate change results in decrease in quality and quantity of suitable habitat for the covered species, the City will consult with the Service to determine what modifications of the conservation measures are necessary to mitigate the adverse effects. As information on the effects of climate change on the Central Texas environment becomes available, the City will periodically review monitoring procedures and research needs over the proposed term. The City may propose adjustment or addition of monitoring and research projects to the Service to evaluate the effect of climate change on salamanders and habitat. Knowledge obtained through these research efforts may be used to determine suitable mitigation measures or alternative conservation measures. The City may pursue modifications to this habitat conservation plan in consultation with the Service if warranted by global climate change impacts and supported by scientific evidence. The adaptive management framework described in this document (section 6.4) provides guidance for evaluation of changes in environmental conditions that are unforeseeable or unpredictable at this time.

The objective of this habitat conservation plan is to ensure the persistence of the covered species (*E. sosorum* and *E. waterlooensis*) in the wild over the proposed 20-year term. If either species recovers during the proposed 20-year term such that protection under the Act is no longer necessary, the species could be de-listed by the Service. To de-list a species, the Service is required to determine that the identified threats have been eliminated or controlled. The Endangered Species Act requires the Service to monitor the species for at least five years after recovery to assess the long-term sustainability without federal protection. If either species becomes de-listed due to recovery over the proposed 20 year term, the City will notify the Service and discuss any potential changes to this habitat conservation plan or associated incidental take permit that may be appropriate.

Unintentional introduction and colonization of the habitat areas by invasive non-native plants may occur that could negatively impact habitat suitability for the covered species. The City will notify the Service verbally or in writing if this occurs. The City will remove the nuisance vegetation using Service-approved methods, or will consult the Service if addition methods are necessary to maintain habitat areas.

Changed conditions in habitat areas could lead to an overabundance of existing native predator populations or introduction and colonization of a new non-native predator in the Pool. The City will notify the Service verbally or in writing if this occurs. The City will manage the predator populations such that the predators would have no unnatural detrimental effect on the covered species, if appropriate. Predator management methods would be consistent with the conservation measures of this plan. The City will assess conditions leading to the change in predator populations, and consult with Service if modifications to this habitat conservation plan are necessary.

Despite the existence of this habitat conservation plan and the best efforts of the City to preserve the species in perpetuity, either *E. sosorum* or *E. waterlooensis* may become extinct over the proposed 20-year term due to uncontrollable changes in environmental conditions. The City will remain in regular contact with the Service to ensure that all necessary permit obligations are satisfied to conserve the covered species. Should either *E. sosorum* or *E. waterlooensis* become extinct in the wild, the City will notify the Service and discuss any potential changes to this habitat conservation plan or associated Incidental Take permit that may be appropriate.

There is currently insufficient information to establish adverse effect levels for sunscreen and other personal care products for *Eurycea* salamanders to enable quantitative risk assessment. Sunscreen and personal care products may be introduced to Barton Springs Pool through human recreational activities. It is unlikely that sunscreen and personal care products would be introduced from recreational use of Eliza Spring or Old Mill Spring as public access to these locations is prohibited by this Plan. Effects of sunscreen and personal care products on the covered species at Upper Barton Spring may be moderated by the ephemeral wetted surface condition of this site depending on aquifer water levels. Take of the covered species from known recreation activities in Barton Springs or Upper Barton Spring is explicitly included in this Plan. It is foreseeable that within the 20-year term of this Plan, new toxicity studies published in scientific literature could establish quantitative adverse effect levels for sunscreen or personal care products on *Eurycea* salamanders, appropriate surrogate amphibians, known salamander prey or salamander habitat. Should this circumstance arise, the City will undertake a risk assessment to evaluate the likelihood of exposure and potential effects on the covered species from identified harmful components of sunscreen or personal care products. The risk assessment will evaluate at a minimum the following factors associated with the identified harmful contaminants:

- the potential amount introduced to Barton Springs
- dilution, transport and fate within salamander habitat
- magnitude and time-variability of salamander exposure
- bioaccumulation effects
- contaminant mode of action relative to salamander life history
- exposure relative to adverse effect levels

Results of the risk analysis will be presented to the Service for review. If the risk analysis assessment determines that sunscreen or personal care products may affect the covered species, the City will consult with the Service to determine if changes to the habitat conservation plan or incidental take permit are necessary. The City in consultation with the Service may add avoidance management measures to prevent additional take of the covered species from sunscreen or personal care products.

8.4 Unforeseen Circumstances

If unforeseen circumstances should occur and are not provided for in this habitat conservation plan, under the No Surprises Rule the Service will not require any additional conservation measures without the consent of the City provided that this habitat conservation plan is otherwise properly implemented. In the event of an unforeseen circumstance, the Service shall provide written notification to the City of a proposed finding of unforeseen circumstances. The Service will work with the City to develop an appropriate response to the new conditions. The City shall have the opportunity to rebut the proposed finding if necessary. The Service may request that the City alter this habitat conservation plan to address the unforeseen circumstance, provided that the new measures maintain the terms of the original habitat conservation plan to the maximum extent possible pursuant to the No Surprises Rule.

8.5 Assessment of Issuance Criteria

Upon receiving a permit application and conservation plan, the Service must evaluate the issuance criteria described by 50 CFR 13.21 and in section 10(a)(2)(B) of the Endangered Species Act in determining whether to issue a permit. The criteria specify that in order for the Service to issue a permit, the following must apply to the applicant:

1. The applicant may not have been assessed a civil penalty or been convicted of a criminal offense relating to the activity for which the application is filed.

2. The applicant may not fail to disclose material information or make false statements in connection with the application.
3. The applicant must demonstrate a valid justification for the permit and a showing of responsibility.
4. The authorization may not threaten the continued existence of wildlife populations.
5. The applicant is qualified to conduct the proposed activities.

The City believes it has satisfactorily met all of the applicable general permit issuance criteria described at 50 CFR 13.21. The covered activities described in this habitat conservation plan are otherwise lawful, and within the authority of the City to regulate. The City continues to foster open communication with the Service and has fully disclosed all material information to the Service. The City has not made any intentionally false statements in connection with this habitat conservation plan to the Service. The City has a valid justification for the permit in maintaining Barton Springs as a historic, recreational, and cultural resource. The City has demonstrated that since issuance of the first Incidental Take permit, it is a responsible permit holder. The requested incidental take authorization does not threaten the continued existence of either the Barton Springs Salamander, *E. sosorum*, or the Austin Blind Salamander, *E. waterlooensis*, and is intended to promote the recovery of the species.

Additional criteria specific to issuance of 10(a)(1)(B) Incidental Take permits is described at 50 CFR 17.22(b)(2) and 50 CFR 17.32(b)(2). and section 10(a)(2)(B) of the Endangered Species Act. The additional criteria that must be satisfied in order for the Service to issue the permit are:

1. The taking must be incidental to otherwise lawful activity or must be associated with mitigation activities.
2. The applicant will, to the maximum extent practicable, minimize and mitigate the impacts of such takings.
3. The applicant will ensure adequate funding for the Plan.
4. The taking will not appreciably reduce the likelihood of survival and recovery of the species in the wild.
5. The applicant will ensure that other measures as required by the Service will be provided.
6. The Service has received assurances that the Plan will be implemented.

The City believes it has satisfied the issuance criteria specified by section 10(a)(2)(B) of the Act. Although some of the otherwise lawful covered activities conducted by the City may harm or harass the covered species, the take associated with these activities is incidental. Actions covered under this habitat conservation plan are not conducted with the singular intent to harm or harassment the covered species. Although some actions, such as capture of salamanders, may constitute a deliberate take of endangered species, these actions are only conducted by the City to minimize more serious forms of take (e.g., rescue from catastrophic toxic spill into habitat) or to further scientific knowledge of the species for the enhancement of beneficial management measures.

The City has, to the maximum extent practicable, minimized and mitigated the impacts of the covered actions on the covered species. The mitigation measures are adequate to ensure the continued persistence of the covered species over the proposed term of this habitat conservation plan, and the City has demonstrated the ability to successfully implement these management measures in the past. The City is committed to providing sufficient funding to continue to implement the necessary conservation measures described in this plan over the proposed term.

City actions over the term of the prior habitat conservation plan issued in 1998 have significantly increased the overall abundance of salamanders in Eliza and Parthenia springs, with strong evidence of reproduction and recruitment during favorable environmental conditions (Dries 2012). In addition, since 2004, adult salamander populations in these two springs do not show an overall decline in size (Bendik and Turner 2011). The successful conservation measures from the prior habitat conservation plan are carried forward to this amended plan, and additional improvements based on new scientific evidence are included. Based on the track record of success and proposed improvements, the City believes that the covered actions will not appreciably reduce the likelihood of survival and recovery of either the Barton Springs Salamander, *E. sosorum*, or the Austin Blind Salamander, *E. waterlooensis*, in the wild. Should the Service propose other conservation measures, the City will to the maximum extent practicable implement these additional conservation measures. The City is fully committed to implementing this plan as described throughout the proposed term.

Appendix A. Status of the Species

Title: Variation in abundances of *Eurycea sosorum* and *Eurycea waterlooensis* (Plethodontidae: Hemidactyliini: *Eurycea*: Notiomolge), with examination of influences of flow regime and drought

Laurie A. Dries

Abstract

Eurycea sosorum and *Eurycea waterlooensis* are federally recognized as imperiled; *E. sosorum* is listed as endangered; *E. waterlooensis* is a candidate for endangered status. Both are perennibranchiate salamander species endemic to the habitats within and beneath a cluster of springs along the Balcones Fault Zone with the Barton Springs segment of the Edwards Aquifer, collectively known as Barton Springs. Threats to these species include habitat loss and fragmentation due to modification of natural flow regimes of these springs (*e.g.*, dams, impoundment) for commercial and recreational uses. Additionally, increasing withdrawal of groundwater from this segment of the Edwards Aquifer threatens the quantity and quality of water emanating from Barton Springs. Evaluating effects of anthropogenic threats on these salamanders requires an understanding of the relationship between habitat variation arising from threats and salamander abundance. In this paper, I use salamander census and surface habitat composition data collected over the past 8 – 17 years to examine variation in salamander abundance in surface habitat within and among springs sites. I specifically focus on relationships of abundance with habitat characteristics related to flow regime modification and drought. Abundance of *E. sosorum* and *E. waterlooensis* varied within and among spring sites, as did habitat characteristics. There were more salamanders during periods when discharge from the Barton Springs complex exceeded 25 $ft.^3$/sec. and in sites with the least flow regime modification. *Eurycea sosorum* is found in significantly higher abundances, with increased reproduction and recruitment, in sites with habitat consisting of clean, rocky substrate in flowing water (mean 0.57 ft./sec.), with low sediment depth (< 0.7 in.) and cover. Abundance of subterranean *E. waterlooensis* in surface habitats is low, but is positively correlated with abundance of *E. sosorum*, suggesting general similarity of surface habitat requirements. Periods of drought (< 25 $ft.^3$/sec.) are accompanied by decreases in flow velocity, but also biologically significant decreases in dissolved oxygen and increases in water temperature. *Eurycea sosorum* experiences steep reductions in abundance and curtailment of reproduction and recruitment; *E. waterlooensis* largely disappears from surface habitat. Flow regime alteration and groundwater withdrawal magnify the severity of droughts that threaten both species, continued efforts to fully restore natural flow regimes could potentially help mitigate detrimental effects of drought.

Introduction

Eurycea sosorum and *Eurycea waterlooensis* are perennibranchiate salamander species whose known habitats are within and beneath a cluster of springs along the Balcones Fault of the Edwards Aquifer, collectively known as Barton Springs (Sweet 1982, Chippindale *et al*. 1993, Hillis *et al*. 2001). Both species are federally recognized as imperiled; *E. sosorum* is listed as endangered (U.S. Dept. of the Interior 1997); *E. waterlooensis* is a candidate for endangered status (U.S. Dept. of the Interior 2002). Typically, endangered species have small population sizes or small ranges (Munton 1987, Mace and Kunin 1994, Mace and Kershaw 1997, Manne *et al*. 1999, Abrams 2002), both of which are true for Barton Springs' *Eurycea*. Maximum observed abundances are small enough (1900 for *E. sosorum* and 43 for *E. waterlooensis*) for both species to be considered at risk of extinction by several rules-of-thumb (Muller 1950, Bell 1983, Lynch and Gabriel 1990, Lynch 1996, Maynard Smith 1998). *Eurycea sosorum* and *E. waterlooensis* also have very small ranges (Chippindale *et al*. 1993, Hillis *et al*. 2001); the four springs in which they are found are located within 1200 feet (350 meters) of one another, adjacent to or within Barton Creek, in Zilker Park, Austin, Texas (Fig. 1). The species are sympatric (Chippindale *et al*. 1993, Hillis *et al*. 2001) in that they occupy the same cluster of springs, and are syntopic in that their ranges can overlap within spring sites. This partial segregation among epigean and subterranean habitat within spring sites has been documented in other Edwards Aquifer *Eurycea* (Sweet 1984: *E. tridentifera* and "*E. neotenes*" *sensu lato*/ *E. latitans* of Chippindale *et al*. 2000; Bishop 1941, Russell 1976, Longley 1978, Chippindale 1995: *E. nana* and *E. rathbuni*). Epigean *E. sosorum* is found in abundance in surface habitat and utilizes subterranean habitat for reproduction and retreat (Chippindale *et al*. 1993, Hillis *et al*. 2001, City of Austin 2010), while subterranean *E. waterlooensis* is rarely found at the surface, and when found, in very small numbers (Hillis *et al*. 2001, City of Austin 2010). Each species has morphological characteristics reflecting adaptation to either epigean (image-forming lenses in the eye of *E. sosorum*, Chippindale *et al*. 1993) or subterranean habitat (lack of eyes in subterranean *E. waterlooensis*, Hillis *et al*. 2001). *Eurycea* found in Barton Springs have been recognized for decades as distinct from perennibranchiate *E. nana* found 30 miles to south (Bryce and Flury specimens collected in 1946, Sweet 1982, Chippindale *et al*. 2000, Hillis *et al*. 2001, Bendik 2006).

Thus, the entire ranges of both species lies within a city with a rapidly growing human population (790,390 U.S. Census data 2011), leading to increasing urban development of the Edwards Aquifer and consequent degradation in quality and quantity of groundwater feeding Barton Springs (citations). In addition, Barton Springs has been used for site of commercial and recreational purposes since the 19^{th} century (Pipkin 1995, reviewed in Limbacher and Godfrey 2007, Austin History Center archive photographs). The springs have been modified to facilitate those uses, resulting in loss and fragmentation of habitat. While these factors have been recognized as major threats to the persistence of both species, (U.S. Fish and Wildlife Service 1997, 2001), an complete understanding of how these threats affect Barton Springs' *Eurycea* is hampered by lack of scientific information on natural history of both species. Strategies for protection and management of these species have been based on inferences drawn from other *Eurycea* species.

All *Eurycea* species are members of Plethodontidae, an evolutionary clade of lungless brook salamanders. All of the species of brook salamanders (~240) are associated with streams and surrounding riparian habitats (Petranka 1998). Most *Eurycea* have biphasic life cycles where aquatic juveniles metamorphose into semi-aquatic or terrestrial adults (Duellman and

Trueb 1994; Petranka 1998), utilizing aquatic habitat for at least some portion of their life. This is in contrast with several other closely related salamander groups that inhabit ponds, swamps, sloughs, and lakes (Fig. 2).

The Edwards Aquifer of the Edwards Plateau region of central Texas contains a monophyletic group (*Paedomolge*, Hillis *et al*. 2001) of solely aquatic, perennibranchiate ("always gilled") *Eurycea* species (Chippindale *et al*. 2000). There are numerous intermittent and perennial springs throughout the Edwards Aquifer that harbor endemic epigean and subterranean *Eurycea* species (Sweet 1978; Chippindale *et al*. 1993; Chippindale *et al*. 2000; Hillis *et al*. 2001; Bendik 2006). Since the regional climate is generally arid, these springs and spring-fed streams are the only sites where presence of flowing water is reliable. Barton Springs is one cluster of the few perennial springs in the Edwards Aquifer (Brune 1975, 1981).

Edwards Aquifer spring-fed surface streams ebb and flow with climatically driven variation in amount and distribution of recharge to ground waters (Brune 1981). Thus, resident perennibranchiate *Eurycea* experience natural contractions and expansions of surface habitat (Sweet 1982, Hubbs 1995), and occasional inundation by floods. These conditions are thought to have favored the evolutionary loss of metamorphosis and consequent dependence on epigean and/or subterranean spring-fed streams throughout the life span of central Texas *Eurycea* (Bruce 1976, Sweet 1977, 1982; Chippindale *et al*. 2000). Natural variation in amount of water flowing into the surface of springs is thought to play a role in the evolution of life histories of Edwards Aquifer *Eurycea* species (Bruce 1976, Sweet 1982). Reliable patterns of flow variation may provide signals of impending habitat contractions and expansions, and could influence a variety of characteristics in perennibranchiate and metamorphic *Eurycea* species, from timing of reproduction to movement between epigean and subterranean habitat (Levins 1968, Schmidt-Nielsen 1975, Sweet 1982, Pianka 1983, Tumlison and Cline 1997, Bonett and Chippindale 2006).

Existing knowledge of life history, and evolutionary ecology of Barton Springs' *Eurycea* is limited; much of information about life history and behavior comes from salamanders in captivity and two experiments conducted by Gillespie (2011) on wild-caught salamanders. Gillespie's work (2011) included examination of sensory modalities of response to potential predators and temporal variation in diet. She demonstrated that wild-caught *E*. *sosorum* reduce activity in response to visual and bioelectric cues of predatory largemouth bass (*Micropterus salmoides*) and red crayfish (*Procambarus clarkii*), but did not respond to olfactory cues. Gillespie (2011) also expanded the suite of known prey items of *E*. *sosorum* (predominantly *Hyalella azteca* amphipods, chironomid larvae, ostracods and isopods; Bogart 1967, Chippindale *et al*. 1993, Chamberlain and O'Donnell 2001) to include planarians (*Dugesia* sp.) and mayfly larvae (Baetidae). This study also showed that planarians form the largest proportion of the diet of wild *E*. *sosorum*, followed by amphipods and chironomid larvae, but diet varies temporally with relative abundances of potential prey items. Data collected from captive populations of both species maintained by the City of Austin have identified courtship behavior, size at sexual maturity, duration of embryonic development and juvenile growth, fecundity, and life span (Chamberlain and O'Donnell 2001). Captive *E*. *sosorum* engage in courtship that includes the tail-straddling walk, chin rubbing, and chin slapping (Chamberlain and O'Donnell 2001), as described by Arnold (1977) for other plethodontids. Median fecundity of captive *E*. *sosorum* females is ~ 20 eggs, with hatching success of ~ 40%, which is similar to captive *E*. *nana* (Navar *et al*. 2007). Eggs are a few millimeters in diameter and deposited singly on substrate to which they adhere, which is also seen in other *Eurycea* species (Duellman and Trueb 1986, Nelson

1993). In captivity, such substrate is mostly moss and plastic plants, although rocks are not available in every aquarium. All eggs of captive Barton Springs' *Eurycea* were deposited in flowing water because all aquaria have some degree of constant water flow (D. Chamberlain personal communication). Many other *Eurycea* species also deposit eggs in flowing water (Fries 2002, Petranka 1998), which presumably maximizes diffusion of oxygen through the egg capsules (citation). Less than 10 eggs have been seen in the wild. Those found in surface habitat were loose in leaf litter, moss, or on exposed substrate, and they did not have developing embryos (City of Austin staff personal observations). The rarity of eggs in surface habitats suggests egg deposition occurs predominantly underground, which is consistent with other perennibranchiate *Eurycea* (Nelson 1993, Tumlison *et al*. 1990, Fries 2002, Roberts *et al*. 1995). Embryonic development takes 3-4 weeks, hatchlings are small (~ 10mm) and often with incomplete development of limbs and yolk sacs. Survival of captivity juvenile *E. sosorum* is roughly 0.60 of hatched eggs, conferring average female reproductive success of 0.7 offspring per clutch, which is considerable higher than juvenile survivorship of wild *E. neotenes* of 0.10 (Bruce 1976). Captive-bred *E. sosorum* reach sexual maturity in about 11 months at 1.7- 2 inches (43-50 mm) total length (0.9-1.0 inches, 24 - 27 mm SVL). Captive-bred *Eurycea waterlooensis* grow to sexual maturity in about 18 - 23 months at 1.9 - 2.1 inches (48-55 mm) total length. Adults of both species continue to grow after sexual maturity but much more slowly, reaching ~ 3 inches (76 mm) total length. Longevity data from captive-reared and wild-caught juvenile *E. sosorum* and *E. waterlooensis* indicate that these salamanders can live at least 15 years. Longevity in the wild is unknown.

Eurycea sosorum salamanders are found in epigean habitat at the four springs of Barton Springs, Parthenia Spring in Barton Springs Pool (hereafter "Parthenia"), Eliza Spring, Old Mill/Sunken Garden Spring (hereafter “Old Mill”), and Upper Barton Spring (Chippindale *et al*. 1993; City of Austin 2004, 2005, 2006, 2007). *Eurycea waterlooensis* is predominantly a subterranean species, spending most of its life in the aquifer (Hillis *et al*. 2001). These salamanders are found in small numbers in the surface habitats of Parthenia, Old Mill, and Eliza Spring where *E. sosorum* is found. It has not been found at intermittent Upper Barton Spring. The four springs of Barton Springs are hydrologically connected via the subterranean conduits of the underlying karst aquifer (Brune 1981, Slade *et al*. 1986, Hauwert *et al*. 2004, Hauwert 2009). In the past, there were surface connections among springs via outflow streams that converged with Barton Creek. While subterranean connections remain, surface habitats have been isolated by construction of dams, amphitheaters, and a floodwater diversion culvert, and the interment of outflow streams. No surface migration routes from Parthenia to other springs exist today; marginal migration routes exist between Eliza, Old Mill, and Upper Barton springs (Fig. 1). Water flow from Parthenia and Eliza Spring is perennial; surface habitats have not gone dry, according to recorded human history (Brune 1975, 1981).

Barton Springs Pool contains the largest area of potential habitat (~15,000 sq. ft.). The natural habitat of Parthenia Spring is composed of crevices, fissures, and small natural caves (< 5-foot diameter) in the limestone rock (~6,000 sq. ft.) where groundwater issues from the aquifer. An additional 11,000-square-foot area along the northern margin of Barton Springs Pool was designated as salamander habitat (USFWS 1998) and is a manmade shelf of compacted caliche, gravel, and cobble known as the “beach”. The beach was originally cut out of the creek bank and flattened to create a wading area for recreation in the 1930s. Area in which the majority of salamanders are found are at and immediately downstream of the caves. Parthenia

Spring is submerged under unnaturally deep water (3-17 feet) by the upstream and downstream dams across Barton Creek creating Barton Springs Pool.

Eliza Spring is a small spring pool of roughly 800 square feet, surrounded by a concrete amphitheater. The floor of the spring pool is a layer of concrete overlying natural habitat and artificially raising the elevation of surface habitat ~ 1 foot. Groundwater exits the aquifer beneath the concrete and reaches surface habitat through 15, 1-foot openings around the perimeter of the spring pool, and 7, 10-inch diameter holes through the concrete. In the early 1930s, the outflow stream was confined to a buried pipe that carried water into Barton Springs Pool, but that connection was eliminated with the construction of a floodwater bypass culvert in 1974. Presently, outflow from the spring pool is carried through the buried pipe into the culvert and on to Barton Creek downstream of Barton Springs Pool. Groundwater flow into Eliza Spring varies with aquifer conditions and apparently does not cease, as water was present in natural surface habitat during the drought of the 1900s. Since 1998, water flow in unnatural surface habitat on top of the concrete has been managed by obstructing outflow to maintain wetted habitat under all natural aquifer conditions. Consequently, surface habitat has been submerged under 2 to 7 feet of water periodically until 2003, when target managed water depth was decreased to approximately one foot.

Salamander habitat in Old Mill Spring ranges from approximately 1300 to 1700 square feet composed of a spring pool and outflow stream. Wetted surface habitat contracts with decreasing discharge and, based on anecdotal accounts, the spring pool may have gone dry in the 1800s. The first permanent alterations to this spring occurred in the 1800s with the construction of Paggi's Mill, which partially obstructed outflow to the natural stream. In 1937, under the auspices of the National Youth Administration, an amphitheater was built on top of the Old Mill walls, which replaced the gates with a wall and eliminated the stream by diverting outflow into a buried pipe, which connects to Barton Creek downstream of all three of the other spring sites. Elevation of surface habitat was raised 5 to ten feet with the addition of deep layer of rock sometime in the last few decades. All of these changes resulted in unnaturally deep water in salamander habitat under non-drought conditions. The elevated substrate resulted in apparent loss of wetted surface habitat in the last decade (D.A. Chamberlain pers. communication 2004). Currently, removal of some of the excess rock has lowered substrate roughly 5 feet, allowing for continuously wetted habitat in the spring pool since 2003. A stream has been partially reconstructed, creating additional wetted habitat in all aquifer conditions except extreme drought. Construction of this stream also restored the surface connection between the spring and Barton Creek.

Upper Barton Spring is the smallest site. The average size of the surface habitat is 493 square feet, and can be as large as 880 square feet under high aquifer conditions. Water flow at the surface is intermittent; it disappears when Barton Springs' discharge drops below 40 ft^3/s. The site lies in the flood plain on the southeast bank of Barton Creek and has no artificial impoundments or permanent structures around it. Only *E. sosorum* has been found at this site; the first sighting occurred on April 1, 1997.

Evaluating potential effects of anthropogenic threats to these species requires basic ecological and population dynamic information on these species, which is lacking. Gillespie (2011) presented evidence of climatic environmental features correlated with salamander abundance. She demonstrated that much of the variability in abundance of young adult and adult *E. sosorum* could be explained by patterns of rainfall over the recharge zone of Barton Springs 7 to 12 months earlier. Rainfall recharging the aquifer influences a suite of interconnected characteristics of groundwater in Barton Springs, *i.e*., discharge, flow velocity, water temperature, dissolved oxygen, turbidity (Mahler *et al*. 2006). The identification of rainfall and other climatic factors correlated with subsequent variation in Barton Springs' *Eurycea* populations increases our understanding of indirect, longer-term influences of watershed-scale factors. But, we still lack a clear understanding of which aspects of habitat within Barton Springs directly affect resident salamander populations.

In general, suitable habitat for *E. waterlooensis* and *E. sosorum* appears to be areas of flowing groundwater associated with subterranean and epigean habitats, respectively. Habitats with flowing water and rocky substrates have networks of clean interstitial spaces, which are typical of habitats occupied by other karst-associated perennibranchiate *Eurycea* species (Randolph 1978; Tumlinson *et al*. 1990; Petranka 1998, Barr and Babbitt 2002; Bonett and Chippindale 2006, Bowles *et al*. 2006, Pierce *et al*. 2010). It has been posited that this type of habitat also provides protection from predators, abundant invertebrate prey, and constantly renewing dissolved oxygen. In the past, *E. sosorum* has been reported as abundant in submerged leaves (J. R. Reddell personal communication to P. Chippindale reported in Chippindale et al. 1993), moss (Dee Ann Chamberlain personal communication 2002), and plants (Andrew H. Price, personal communication 2005). *Eurycea nana*, sister species to *E. sosorum*, is reported to be found in rocks, logs, and vegetation (Tupa and Davis 1976, Thaker *et al*. 2006, Epp and Gabor 2008), and *Spyrogyra* sp. algal mats (Najvar 2001, personal communication 2011). This suggests that there is variation in optimal microhabitat among Notiomolge *Eurycea*, or optimal microhabitat is unavailable to species in sites modified by human activities.

There are no published studies of the microhabitats in which in *E. sosorum* is found, or the relationship between water chemistry, flow velocity, spring discharge and salamander abundance. Identification and description of microhabitats in which Barton Springs' *Eurycea* are found when all types are available would be a significant advance in understanding precisely what constitutes good habitat. Furthermore, examination of variation in microhabitat among spring sites and with aquifer conditions would contribute to a more integrated understanding of how we expect natural and anthropogenic environmental variation to affect Barton Springs' *Eurycea* and over what time frames. Yet, no studies to date have described variation in average annual abundance of juveniles, young adults, and adults, or examined recruitment in wild populations of either species in all spring sites for entire periods of record.

My objective in this paper is to begin to address this lack of scientific information. I use data from 8 to 17 years of monitoring to ask several questions about salamander populations and habitat. Specifically, I ask 1) do salamander abundance and density vary among and within spring sites, 2) is there evidence of reproduction and recruitment within spring sites, 3) which microhabitat characteristics are correlated with salamander abundance, and 4) does salamander abundance vary with aquifer discharge and water chemistry? I also ask if habitat management since federal listing of *E. sosorum* is correlated with salamander abundance. I use the information to discuss variation in populations of *E. sosorum* and *E. waterlooensis*, and how surface habitat quality may affect both species.

Materials and Methods

Barton Springs' *Eurycea* abundance data have been collected in all spring sites by City of Austin staff roughly 12 times per year from 1993 through 2011 for *E. sosorum*, and from 1998 through 2011 for *E. waterlooensis*. Initial year of data collection varies among spring sites, with

Parthenia Spring surveys initiated in 1993, Eliza and Old Mill springs in 1995, and Upper Barton Spring in 1997.

Annual survey number and frequency have varied over time. Target frequency of each site was one each month, but, actual number of surveys varied and intervals were irregular prior to 2003. Average number of surveys per year is 9.8 for Parthenia Spring (1993 – 2002), 8.3 for Eliza Spring (1995 – 2002), 6.3 for Old Mill Spring (1996 – 2002), and 8.7 for Upper Barton Spring. From 2003 through 2011, surveys were conducted every thirty to thirty-seven days or multiple thereof to facilitate use of times series statistical analyses. Since Upper Barton Spring flows intermittently, there are gaps in survey data corresponding with dry surface habitat. All surveys were conducted during daylight hours of a single day except two surveys of Parthenia Spring (1994 and 1996), which were conducted at night. Surveys of Parthenia Spring require SCUBA to search substrate because the spring has been submerged under several feet of water since the construction of permanent dams in 1929. Eliza and Old Mill springs have variable water depths; some surveys required SCUBA while others only required snorkeling; since 2003 all but four surveys were conducted by snorkeling. Upper Barton Spring water depth was always shallow enough to searched substrate by wading except during floods. Surveys of Parthenia and Upper Barton springs are not conducted when it is inundated by floodwater from Barton Creek because underwater visibility is typically nil and current velocity is too fast to ensure safety of surveyors. Generally, floodwater does not inundate Eliza and Old Mill Spring, although floodwater can reach Eliza Spring if the gates in the downstream dam of Barton Springs Pool are closed.

Surveys conducted from 1993 to July 2003 consisted of searches of some or all of surface habitat in all spring sites. Prior to July 2003, more than one spring site may have been surveyed in a single day; since 200x, only one spring site was surveyed per day to allow for more exhaustive searching of habitat. From 1993 through 1998, surveys of Parthenia Spring were of 1 x 1 meter squares every 10 feet along six transects across fissures and caves where groundwater exits the aquifer. From 1999 through 2001, survey method in Parthenia Spring was changed to searches of contiguous areas at the caves and sporadic searches of fissures. From 2002 through June 2003, salamander abundance was estimated by rapid scan of disjunct areas at the spring mouths. From 1995 to June 2003, surveys of Old Mill and Eliza springs generally consisted of searches of the entire wetted habitat in the spring pool or targeted smaller areas. When a surface outflow stream was present at Old Mill Spring, it was also searched for salamanders. Total wetted area in Eliza Spring varied with water depth, which was not recorded for some surveys in 2001 and 2002. Consequently, total survey area is unknown for some dates.

In 2003, survey design and method were changed. From July 2003 through 2010 salamander abundance was estimated in all spring sites using a modification of the drive survey method (Rasmussen and Doman 1943, Gilbert and Grieb 1957) of all of wetted surface habitat in Eliza, Old Mill, and Upper Barton springs, and large, contiguous areas of Parthenia Spring. In Parthenia Spring, areas associated with caves were always surveyed, while fissures were surveyed as time and staffing permitted. Only the upstream most section of the "beach" (Beach 1) has been included in salamander monitoring. It was surveyed regularly from 1993 to 2001, and in 2010. The modified drive method consisted of observers oriented in a line perpendicular to the current, moving in concert from downstream to upstream, removing all loose substrate and replacing it behind the line. This creates a moving, 6 to 10-inch strip of coverless habitat that these salamanders are reticent to cross. Each salamander crossing coverless habitat from upstream to downstream was added to the cumulative number; any salamander returning to upstream habitat from behind the line was subtracted. When observers were in close proximity to aquifer openings, salamanders observed moving forward and retreating into the aquifer were added to the total.

Data collected before 1998 classify all perennibranchiate salamanders found as *E. sosorum* because Eurycea *waterlooensis* was not discovered until 1998 (subsequently described in Hillis *et al*. 2001). Since 1998, each *Eurycea* salamander found was identified to species and assigned a size category based on total body length (TL). From 1998 through June 2003, two categories were used, < 1 inch (25.4 mm) and ≥ 1 inch (25.4 mm). From 2003 through 2010, three categories were used, < 1 inch, 1-2 inches (25.4-50.0 mm), and ≥ 2 inches (50 mm). Total length categories were converted to snout-vent length (SVL) according the following equation:

SVL (mm) = 3.171 + 0.476*TL (mm).

This equation is based on linear regression ($p<0.0001$, $r^2=0.91$) of unpublished City of Austin data collected in 2003 from 208 wild *E. sosorum*. The snout-vent length categories were then compared to SVLs reported for juvenile and sexually mature *E. sosorum* museum specimens (Chippindale *et al*. 1993), and size at first reproduction and approximate growth of captive-bred salamanders (Chamberlain and O'Donnell 2001, 2002). This resulted in three categories of life stage, juvenile (<15.3 mm SVL), young adult (15.3-27.0 mm SVL), and adult (≥ 27.0 mm SVL). These categories are consistent with life-stage/size relationships for *E. nana* (Najvar 2001), sister species to *E. sosorum* (Hillis *et al*. 2001, Chippindale et al. 1993, Bendik 2006), and *E.* "*neotenes*" of Lamb and Turtle Creek springs (Bruce 1976), now recognized as *E. latitans* (Chippindale *et al*. 2000). I applied the same procedure to assign life stage to *E. waterlooensis* because the size/age relationship is similar to *E. sosorum* (Hillis *et al*. 2001, City of Austin unpublished. Lastly, type of microhabitat in which each salamander was found was noted (under rock, in plants, moss, algae, or leaf litter, or no cover).

Each spring site was divided into sections, within which substrate habitat characteristics were measured. Percent of habitat area composed of rocks, plants, moss, algae, and leaf letter was estimated visually and verified using a grid overlaid on photographs. In each section in each spring, we collected five measurements of sediment depth to the nearest millimeter and visually estimated percent of substrate with overlying layer of sediment. We also estimated percent by volume of sediment composed of sand. We measured water depth to the nearest millimeter in five haphazardly chosen locations in each section of each spring, except Parthenia Spring. Water in Parthenia Spring is unnaturally deep (5–20 feet) because the downstream dam is used to keep it relatively constant for recreational users. So, water depth was not measured during these surveys. Since 2003, total dissolved gas pressure, partial pressure of dissolved oxygen, water temperature, and barometric pressure measured near a spring mouth in each site using a saturometer (Common Sensing, Model TBO-F). Dissolved carbon dioxide concentration was measured using Winkler titration. During low discharge conditions, dissolved oxygen concentrations (DO) decreased to levels of concern for *E. sosorum* (Woods *et al*. 2010) in Eliza Spring in 2008 and in Old Mill Spring in 2006 and 2008. Consequently, DO was artificially increased in these sites by water recirculation and/or aeration. Hence, the data collected during these periods are higher than natural concentrations. Prior to 2003, measurements of dissolved oxygen in Parthenia, Eliza, Old Mill, and Upper Barton springs, were sporadic and obtained using Hydrolab datasonde (model 4a). I also used U.S. Geological Survey estimates of aquifer discharge from Barton Springs (all flowing springs combined) to categorize climate condition as drought or non-drought and examine potential correlations with salamander abundance. Finally, from 2008 through 2011, site-specific discharge and flow velocity at the substrate were measured in Eliza, Old Mill, and Upper Barton springs during each survey using a Marsh-McBirney flow meter. Flow velocity at the substrate in Eliza Spring was measured with a Marsh-McBirney meter at fifteen locations where groundwater entered the spring pool and flowed roughly parallel to the substrate. Similar measurements were taken in five locations in the Old Mill Spring pool and in the outflow stream, and five locations in each of the outflows of Upper Barton Spring. Flow velocity was not measured in Parthenia Spring.

I generated descriptive statistics for salamander abundance and density of *E. sosorum* and *E. waterlooensis* for each year of record for each site. *Eurycea waterlooensis* are seen in very small numbers and infrequently in the surface spring, which limited most statistical analysis to simple, descriptive methods. Since, the *Eurycea sosorum* data sets are larger and generally more salamanders are found, it was feasible to use statistical tests to compare variables among and within sites. I used all of the data for Parthenia Spring (1993 – present) to compare numbers of salamanders among survey sections because of obvious, large differences in habitat characteristics, e.g., water depth, flow velocity, anthropogenic disturbance from recreation. Because data collection methods and inter-survey interval changed in 2003, I chose to exclude earlier data from many analyses to avoid misinterpretation of the results. Since the nature of drive surveys alters distribution of animals within the surveyed, measurements of density can vary if total area surveyed varies, and thus not necessarily reflect intraspecific competition. This potential problem was mitigated in Eliza and Old Mill springs by surveying all of wetted surface habitat. This problem could not be avoided in Parthenia Spring because exhaustive searches of all of surface habitat were not possible with the resources available. Densities calculated for this study are not meant to indicate actual spatial distribution of salamanders.

I examined potential differences in habitat characteristics and salamander abundance within sites and among drought ($\leq 25\ ft^3/s$ total Barton Springs' discharge) *versus* non-drought ($> 25\ ft^3/s$) conditions. I used this discharge threshold rather than a geological or climatic threshold because it is biologically relevant for *E. sosorum*. When the discharge of the Barton Springs complex is below 40 ft^3/s, surface habitat of Upper Barton Spring and adjacent Barton Creek are dry. This represents loss of surface connection of this site with the perennial springs, and signals when retreat underground may begin to affect interspecific interaction between *E. sosorum* and *E. waterlooensis*. In addition, the surface habitat in old Mill Spring contracts and the outflow stream ceases to flow, and habitat in Eliza Spring would be dry if water depth were not managed. At $\leq 25\ ft^3/s$, dissolved oxygen in Parthenia declines to below 5 mg/L (Mahler *et al*. 2010). Because Barton Springs' discharge measured and reported by the U. S. Geological Survey is that of all flowing springs sites combined, it is directly correlated with site-specific discharges. I used the combined spring discharge data as a proxy for site-specific discharge in statistical analyses except where noted because combined discharge is used to guide various conservation management activities, from onsite maintenance of Barton Springs Pool to regulation of groundwater removal from the aquifer.

All data were tested for statistical assumptions of typical parametric *t*-tests, ANOVA, and linear regression (Sokal and Rohlf 1995, Zar 1984). Most of the data did not meet requisite assumptions of normality and homogeneity of variances. In addition, salamander abundance and some habitat data within sites are also serially auto-correlated. Therefore, I did not test for deterministic trends in salamander abundance or water chemistry here. Time series analyses of *E. sosorum* data from Eliza and Parthenia Spring are presented elsewhere (Gillespie 2011, Bendik and Turner 2011). I used non-parametric tests because although the probability of Type II error is increased (accepting the null when it is false), their power and reliability are not as compromised when assumptions are violated as in parametric tests (Tukey 1962, Seaman and Jaeger 1990, Potvin and Roff 1993). I used non-parametric Mann-Whitney *U* and Kruskal-Wallis tests to detect differences in salamander abundance and density within and among sites. I used non-parametric Pearson Rank correlations to test for variation in habitat variables and relationships with salamander abundance and density within sites. I also used Pearson Rank Correlation to test for recruitment within sites by asking if abundance of younger salamanders is correlated with older salamanders 2, 3, and 4 months in the future. These time lags are consistent with development and growth observed in captive *E. sosorum*. Metric measurements were converted to inches after statistical analyses. I used StatView software (SAS Institute 1992-1998) for analysis of all data. Significance thresholds used were at $\alpha = 0.05$, unless otherwise noted.

Results

Variation in salamander abundance among and within spring sites

Abundance and density of both species of salamander vary over time among sites (Figs. 4-8, Tables 1). Total abundances and densities of both species differ significantly among sites (*E. sosorum* abundance: $H=141.8$, $p<0.0001$, density: $H=182.3$, $p<0.0001$; *E. waterlooensis* abundance: $H = 34.7$, $p<0.0001$, density: $H=70.2$, $p<0.0001$). Highest to lowest average abundances of *E. sosorum* were found in Eliza, Parthenia, Old Mill, and Upper Barton Spring, in descending order. *Eurycea sosorum* abundance and density in Old Mill Spring is significantly lower than in Eliza and Parthenia Springs (abundance: Kruskal-Wallis $H = 37.53$, $p < 0.0001$; density: $H = 133.02$, $p < 0.0001$; Fig. 5, Tables 2,3). While salamander abundance is lowest in Upper Barton Spring (Fig. 6), density is not significantly different than in Old Mill Spring ($U = 4811$, $z = -1.629$, $p < 0.0001$; Table 3). Average annual abundances range across several orders of magnitude for *E. sosorum* and reached record highs in all sites in 2008.

Eurycea waterlooensis abundance is significantly positively correlated with *E. sosorum* abundance ($\rho = 0.505$ $z = 4.628$, $p < 0.0001$). Abundance and density of *E. waterlooensis* are significantly higher in Old Mill Spring relative to Eliza and Parthenia springs (abundance: $H = 36.10$, $p < 0.0001$; density: $H = 32.96$, $p < 0.0001$; Fig. 7, Tables 4, 5). Ranges of *E. waterlooensis* abundance in all sites are small relative to *E. sosorum* (Tables 2 and 3). Salamanders of this species were found frequently in Old Mill Spring (Table 5) over the period of record, while they were not found regularly in Eliza or Parthenia Spring until 2003 (Table 4). There is no significant difference in abundance of these salamanders in Old Mill Spring before and after 2003 ($U = 1536$, $z = -0.082$, $p = 0.935$). Abundances in Eliza and Parthenia Spring are significantly higher since 2004 (Eliza abundance: $U = 1332.5$, $z = -3.950$, $p < 0.0001$; Parthenia abundance: $U = 2207$, $z = -1.855$, $p = 0.0005$).

Abundance of *E. sosorum* varied within sites over the period of record. Eliza Spring abundance is significantly lower from 1995 - 2002 than from 2003 - 2010 ($U = 150.5$, $z = -9.667$, $p < 0.0001$), which corresponds with before and after reconstruction of some natural features of aquatic habitat (City of Austin 2005, 2006; Fig. 4a), but also with the change in survey method. A comparison of periods immediately before and after habitat reconstruction using only data collected under the same survey method revealed significantly lower abundance in 2003 than from 2004 to 2005 ($U = 0.0$, $z = -4.268$, $p < 0.0001$). Abundance in Parthenia Spring increased significantly after changes in management of Barton Springs Pool associated with federal listing of *E. sosorum* (U.S. Fish and Wildlife Service 1998) ($U = 1{,}765.5$, $z = -3.281$, $p = 0.001$). Abundance is significantly higher from 2006 - 2010, relative to 1998 - 2005 ($U = 2158.5$, $z = -2.871$, $p_{\alpha=0.025} = 0.004$; Fig. 5a). These periods correspond with before and after habitat reconstruction in Parthenia Spring in 2004 to 2005. There is no significant difference in *E. sosorum* abundance in Old Mill Spring for any these time periods (abundance: $U = 388.5$, $z = -0.310$, $p_{\alpha=0.05} = 0.756$).

Reproduction and recruitment within spring sites

There is evidence of sporadic reproduction of *E. sosorum* in all spring sites for the periods of record (Fig. 8). Timing and amount of reproduction are not constant and do not follow terrestrial seasons (Fig. 8). In Parthenia and Eliza springs, juvenile abundance is positively correlated with adult abundance 3 months earlier (Parthenia: $\rho = 0.534$, $z = 3.291$, $p = 0.001$; Eliza: $\rho = 0.381$, $z = 2.771$, $p < 0.0056$). In Old Mill Spring, adult abundance is negatively correlated with juvenile abundance 3 months later ($\rho = -0.686$, $z = 4.394$, $p < 0.0001$). Few juveniles had been found in Upper Barton Spring until 2008, but there is no statistical evidence of a consistent pattern of reproduction. The number of adults is not correlated with number of juveniles three months later ($\rho = 0.053$, $z = 0.268$, $p = 0.79$).

There is evidence of recruitment in Parthenia, Eliza, and Old Mill springs during some time periods (Fig. 8). From 2003 -2010, juvenile abundance is significantly positively correlated with young adult abundance three months later in these three springs (Eliza: $\rho = 0.721$, $z = 5.395$, $p<0.000$, Fig. 8a; Parthenia: $\rho = 0.509$ $z = 3.135$, $p_{\alpha=0.05} = 0.0017$, Fig. 8b; Old Mill: $\rho = 0.663$ $z = 2.901$, $p_{\alpha=0.05} = 0.005$, Fig. 8c). In Parthenia Spring, there is no significant relationship among juvenile abundance and "adult" (> 1 inch TL) abundance 3 months later from 1993 – 1997, ($\rho = -0.085$, $z = -0.583$, $p_{\alpha=0.05} = 0.5596$), but this relationship is statistically significant after 1997 ($\rho = 0.467$, $z = 2.723$, $p_{\alpha=0.05} = 0.0065$). Young adult abundance is positively correlated with adult abundance two months later in Eliza ($\rho=0.342$, $z=2.512$, $p=0.012$) and Parthenia ($\rho = 0.507$ $z = 2.999$, $p_{\alpha=0.05} = 0.0027$); and three months later in Old Mill ($\rho = 0.669$ $z = 3.068$, $p_{\alpha=0.05} = 0.003$). There are no statistically significant correlations among size classes of salamanders in Upper Barton Spring for the period of record (Fig. 8d). Number of juveniles is not correlated with young adults three months later ($\rho=0.255$, $z=1.145$, $p_{\alpha=0.05}=0.25$), neither is number of young adults correlated with adults three months later ($\rho=-0.061$, $z=-0.311$, $p_{\alpha=0.05}=0.76$). There are no statistically significant correlations at 4-month lags.

Reproduction and recruitment of *E. waterlooensis* are difficult to discern based on abundance of salamanders observed in surface habitat (Fig. 9). Reproduction does occur because juveniles are seen in surface habitat of all three perennial spring sites, typically when there are higher numbers of juvenile *E. sosorum* ($\rho = 0.633$, $z = 7.443$, $p < 0.0001$). Based on visual examination of graphs of abundance (Fig. 9) there does not appear to be recruitment in the *E. waterlooensis* populations of any site. There are no statistically significant correlations among size classes in any site.

Microhabitat, flow regime, and salamander abundance

Abundance of *E. sosorum* varies significantly among potential cover microhabitat within sites. The vast majority of salamanders have been found in the interstitial spaces of clean, rocky substrate (98% in rock, 1.7% in moss + plants + algae, 0.2% leaf litter, 0.1% no cover). Salamander abundance and density in Eliza Spring are significantly positively correlated with flow velocity, and negatively correlated with percent sediment cover and water depth (Table 6). Significantly larger numbers of salamanders were found after a more natural flow regime was restored in 2003 (*U* = 152, z = -7.348, p < 0.0001), relative to 1998 to 2002. Percent sediment cover is positively correlated with water depth; as water depth decreases, percent sediment cover also decreases.

In Parthenia Spring, mean sediment depth was significantly less in two sections of deeper habitat in front of the caves after habitat reconstruction (2006-2010) than before (2003-2005)(Little Main: *U* = 153.0, z = -2.730, p = 0.006; Side Spring: *U* = 158, z = -2.192, p = 0.03). From 1993 to the present in Parthenia Spring, more *E. sosorum* were found in habitat in deeper water in front of the caves than in fissures in shallower water (H = 213.18, $p_{\alpha=0.05} < 0.0001$).

In Old Mill Spring, *E. sosorum* abundance is also significantly positively correlated with flow velocity (ρ = 0.787, z = 5.944, p < 0.0001) and water depth (ρ = 0.528, z = 5.944, p < 0.0001), and negatively correlated with sediment depth (ρ= -0.366, z = -2.761, p = 0.0058) and percent sediment cover (ρ = -0.413, z = -2.802, p = 0.0051). These variables are correlated with one another; flow velocity is negatively correlated with sediment depth (ρ = -0.486, z = -2.477, $p_{\alpha=0.01} = 0.013$), percent sediment cover (ρ = -0.529, z = -2.181, $p_{\alpha=0.01} = 0.03$), and water depth (ρ = -0.340, z = -2.095, $p_{\alpha=0.01} = 0.036$). In Upper Barton Spring, salamander abundance is not significantly correlated with flow velocity, water depth, sediment depth, or percent sediment cover, and none of the habitat characteristics are significantly correlated with one another

Discharge, water chemistry, and drought

In general, *E. sosorum* and *E. waterlooensis* abundances vary with discharge from Barton Springs; total from all springs ranges from ~ 10 - 120 cubic feet per second (cfs). Discharge differs among spring sites; the largest volumes of water issue from Parthenia Spring (75-90%). Site-specific discharges from Eliza and Old Mill springs vary from 1 - 12 cfs and 0 - 12 cfs, respectively. Upper Barton Spring discharge ranges from 0 – 3 cfs.

From 1993 to the present, total abundance of salamanders in Parthenia Spring is significantly negatively correlated with Barton Springs' discharge (ρ = -0.262, z = -2.048, p = 0.04), but is significantly *positively* correlated with discharge 6 months earlier (ρ = 0.500, z = 3.042, p < 0.0023). The relationship between discharge and abundance is statistically significant for juveniles (ρ = 0.484, z = 2.947, $p_{\alpha=0.0125} < 0.0032$) and all adults combined (≥ 1")(ρ = 0.504, z = 3.067, $p_{\alpha=0.0125} < 0.0022$). From 2003 to the present, young adult and adult abundances are significantly correlated with a six-month lag in discharge (young adult: ρ = 0.467, z = 2.838, $p_{\alpha=0.0125} = 0.0045$; adult: ρ = 0.422, z = 2.568, $p_{\alpha=0.0125} = 0.012$). There are no similar significant correlations for any of the other spring sites.

While there have been several periods of low discharge since 1993, there was only one period of severe drought during which total Barton Springs' discharge was ≤ 25 cfs: from June 2008 to October 2009. Parthenia and Eliza Spring remained wet with detectable water flow for the entire period. Mean water flow velocity in Eliza Spring was significantly lower (*U* = 36.50, z = -2.960, p = 0.0031) during the drought (0.29 ±0.05 s.e.) than before (0.85 ft/sec. ± 0.17 s.e.). There was water in surface habitat in the spring pool of Old Mill Spring, but there was no detectable discharge and the stream was dry. Upper Barton Spring had gone dry 30 days earlier.

The drought's effects on surface habitat were evident in the reduction of dissolved oxygen in all sites, increases in water temperature in Eliza and Old Mill Springs (Tables 7,8,9). Dissolved oxygen was significantly lower in Eliza and Parthenia Spring during the 2008 - 2009 drought than in the previous 5 years (2003 - 2008) (Eliza: 2003-2008: $U = 28.0$, $z = -4.733$, $p < 0.0001$; Parthenia: $U = 13.0$, $z = -4.556$, $p < 0.0001$; Table 7), and the previous twelve months (May 2007- May 2008) (Eliza: $U = 0.0$, $z = -3.766$, $p = 0.0002$; Parthenia: $U = 0.0$, $z = -3.554$, $p = 0.0004$). There is no significant difference in DO in Old Mill Spring for either of those comparisons (pervious 5 years: $U = 20.0$, $z = -0.485$, $p = 0.6274$; preceding 12 months: $U = 175$, $z = -0.139$, $p = 0.889$)(Table 9). However, dissolved oxygen was augmented in Old Mill Spring during the majority of the 2008-2009 drought to protect salamanders, effectively reducing sample size of natural concentrations to 3 measurements. In addition, a less severe drought in 2006 also required augmentation of DO because its concentration dropped to below 2.0 mg/L while Barton Springs' discharge remained above 25 cfs. When data from the 2006 and 2008 droughts are combined, there is a significant difference in DO concentration ($U = 447.5$, $z = -4.674$, $p < 0.0001$). Approximately 1 month before Barton Springs' discharge dropped to 25 cfs, Upper Barton Spring surface habitat had contracted down to a 1-foot square puddle with a dissolved oxygen concentration of 1.6 mg/L.

Mean water temperature was significantly higher during the drought in Eliza ($U = 328.0$, $z = -3.225$, $p = 0.00$), Old Mill ($U = 802$, $z = -2.141$, $p < 0.0001$), and Parthenia ($U = 230.5$, $z = -3.715$, $p = 0.0002$). Mean flow velocity in Eliza Spring during drought (0.32 ft./s. ± 0.19 S.D., 0.06 s.e.) was significantly lower than during non-drought (0.85 ft./s. ± 0.58 S.D, 0.12 s.e.; $U = 46.5$, $z = -3.038$, $p = 0.002$).

There were significantly fewer *E. sosorum* salamanders in Eliza and Old Mill springs during the drought than in the preceding twelve months (Eliza: $U = 46.0$, $z = -2.147$, $p = 0.032$, Fig. 10a; Old Mill: $U = 5.0$, $z = -3.444$, $p = 0.0006$, Fig. 11). In Eliza Spring, juvenile and adult abundances were significantly lower during the drought (juvenile: $U = 172.0$, z =z –2.662, $p = 0.0078$; Adult: $U = 131.5$, $z = -3.286$, $p = 0.001$; Fig. 10a), while young adult abundance was not ($U = 268.5$, $z = -0.960$, $p = 0.337$). Abundances of young adults and adults in the year following the drought did not differ significantly from during the drought (young adult: $U = 46.0$, $z = -1.609$, $p = 0.11$; adult: $U = 49.0$, $z = -1.442$, $p = 0.15$), but juvenile abundance was significantly *lower after* the drought than before ($U = 31.5$, $z = -2.413$, $p = 0.016$).

In Parthenia Spring, there was no significant difference between abundances during the drought and the previous year ($U = 40.0$, $z = 0.0$, $p > 0.99$), nor was there a difference among abundances before, during, and after the drought (abundance: $H = 0.825$, $p = 0.66$; Fig. 10b).

Discussion

There is significant variation in abundances of *E. sosorum* and *E. waterlooensis* among and within spring sites. In general, abundance of *E. sosorum* has increased significantly since 2003 in all spring sites except Old Mill, where it has not increased but also has not decreased. *Eurycea sosorum* abundance in Upper Barton is low on average, with densities similar to those in Old Mill Spring. Abundance varies directly with discharge from this spring as lower discharge causes surface habitat contraction and disappearance. The fate of salamanders in Upper Barton Spring during periods when surface habitat is dry is unknown and the origin of salamanders found after groundwater returns to surface habitat is likewise unknown. Of 48 salamanders in Upper Barton Spring that were marked (Visible Implant Elastomer) in 2007, none were found in any other spring while Upper Barton Spring was dry in 2008; and only four (8%) were seen again in Upper Barton Spring when flow returned in 2009 (City of Austin 2010, 2011). Apparently healthy adult and young adult salamanders have been found in this spring within a couple of weeks of the return of wetted surface habitat (City of Austin data L. Dries pers. obs.), but their site of origin is unknown. It is unclear whether salamanders are migrating among sites in response to habitat contractions and expansions. There is no evidence of recruitment in Upper Barton Spring, but, juveniles have been found, and in record high abundance in 2008. *Eurycea waterlooensis* has been seen more frequently and in higher numbers in Eliza and Parthenia Spring since 2003, and continues to been seen regularly in Old Mill Spring. It has yet to been observed in Upper Barton Spring, although whether its subterranean range extends to this spring site is unknown.

There is evidence of reproduction and recruitment of E. *sosorum* in the three perennial spring sites. Presence of juveniles indicates that reproduction does occur and varies over time. Evidence that juveniles grow and are recruited into the adult population is provided by the positive correlation of juvenile abundance with subsequent young adult and adult abundances at time lags are consistent with growth rates in captivity. In addition, the positive correlations of adult abundance with juvenile abundance 3 months later in Eliza and Parthenia Spring suggest that increases in adult abundance may be useful indication of the onset of a period of reproduction. In general, periods of reproduction and recruitment are not seasonal *per se*, but vary with aquifer discharge; reproduction and recruitment decrease or disappear during severe drought.

Factors other than increases in population size could have contributed to observed increases in *E. sosorum* abundance within sites. Migration of salamanders among sites or between epigean and/or subterranean microhabitats within sites or the change in survey method could underlie the increases in abundance within each site. Migration among sites would produce a pattern of decrease in one site concurrent with an increase in another site; this is not the pattern observed. Salamander abundances in all sites increase during the same periods. Variation in detection probability associated with a change in survey method is unlikely to produce multiple obvious periods of reproduction and recruitment of juveniles into the adult populations of Eliza and Parthenia Spring that are correlated with environmental conditions. Moreover, the consistent pattern of variation in abundance, reproduction, and recruitment with environmental conditions based on data collected under the same survey method further rejects the hypothesis that variable detection probability underlies the observed increases in abundance. The results reported here are consistent with real biological processes driving increases in population sizes, rather than changes in survey method or effort producing spurious increases in abundance.

The vast majority of Barton Springs' *Eurycea* salamanders (98%) were found in rocky substrate in all springs. Although, common use of other microhabitat has been reported by others, the results presented here suggest that these salamanders prefer clean, rocky substrate if it is available, rather than moss, plants, algae, or leaf litter. This is consistent with microhabitats where many other perennibranchiate *Eurycea* are found (Tupa and Davis 1976, Randolph 1978, Sweet 1982, Tumlison *et al*. 1990; Petranka 1998, Barr and Babbitt 2002; Bonett and Chippindale 2006, Bowles *et al*. 2006, Pierce *et al*. 2010). Interestingly, *E. sosorum* is not commonly found in abundance in green filamentous algae, as has been reported for closely related *E. nana* (Najvar 2001, 2007). However, the dominant green, filamentous algae in Barton Springs are *Cladophora* sp., and the algae in which *E. nana* is typically found in abundance are *Spyrogyra* sp. or *Lyngbya* sp. (P. Najvar personal communication). During the recent drought, the predominant filamentous algae have been *Spyrogyra* sp. and more *E. sosorum* has been found in there than in the past, but this is still a very small proportion of salamanders.

In Eliza Spring, there were dramatic changes in habitat associated with reconstruction of more natural flow regime in surface habitat in 2003 and 2004 (City of Austin 2004, 2005). Large obstructions to outflow from the spring pool were permanently removed, resulting in generally shallower water, and faster water flow. Increased flow velocity under all discharge conditions was accompanied by decreases in sediment depth and the extent of substrate covered with a thick layer of sediment. In 2004 and 2005, there were similar efforts to enhance water flow in Parthenia Spring by removing accumulated sediment and rock from fissures and cave mouths. Sediment suspended in the groundwater and surface water settles in Parthenia Spring during periods of high aquifer discharge (Mahler and Lynch 1999, Mahler *et al*. 1999) and floods; large amounts of gravel and rock are also deposited with Barton Springs Pool during floods.

Since habitat reconstruction in Eliza Spring, salamander density is positively correlated with flow velocity, and negatively correlated with water depth and sediment cover. In Parthenia Spring, fewer salamanders are found in fissures compared with sections in front of the spring mouths, which is consistent with the sediment depth results; sediment depth has not changed in the fissures, while it has decreased in two areas in front of spring mouths.

The negative correlations between salamander density and percent sediment cover suggests that one of the benefits of flowing water is less of substrate area is covered in sediment. The pattern of correlations among flow velocity, sediment cover, water depth, and sediment depth in Eliza Spring are consistent with typical interactions in stream systems. Shallower water flows faster, faster water flow flushes out excess sediment and helps prevent its deposition (Leopold *et al*. 1992), all of which help create clean interstitial spaces in rocky substrate that can be inhabited by aquatic flora and fauna (Hynes 1972, Nowell and Jumars 1984, Giller and Malmqvist, Poff and Ward 1989, Poff *et al*. 1990, Vogel 1994). Mean values of sediment and water depth became more typical of shallow, flowing streams in which the majority of *Eurycea* species are found (Wells 2007, Petranka 1998).

Eurycea sosorum abundance varies among the deeper and shallower habitat locations within Parthenia Spring. Within the natural habitat, more salamanders were found in sections in front of the small caves where the majority groundwater issues from the aquifer. This isn't simply an artifact of the drive survey method because of the architecture of the fault system in and the direction of the drive. The shallower survey sections are located on the upstream part of the system, on top of a rimrock ledge littered with small fissures. These fissures carry groundwater toward an abrupt drop off that leads to the relatively larger cave openings at the bottom of a rimrock ledge. These deeper sections are surveyed before or at the same time as shallow habitat, and salamanders counted are those that move from upstream to downstream, away from caves and fissures. Greater abundance of salamanders in deeper water near the caves in Parthenia is a real phenomenon.

The occurrence of more salamanders in deeper water (10-17 feet) in Parthenia Spring may seem contradictory to results from Eliza Spring. However, the water current issuing from the caves is readily detectable by humans as stronger than water flowing in fissures, suggesting the relationship may be driven by flow velocity and the resulting effects on substrate condition rather than water depth. Since *E. sosorum* and *E. waterlooensis* are stream-adapted salamanders, water velocity is likely to be the more critical proximate factor. Flow velocity varies with water depth, but the degree to which that affects salamander abundance is also driven by volume and rate of water discharge from a particular spring. Parthenia Spring is much, much larger than Eliza Spring, emitting up to 10 times the water flow. Water velocity at the spring mouths in

Parthenia Spring is likely similar to or higher than in Eliza Spring, even when submerged under several feet of water. In addition, occupation of habitat closer to the surface of the water in Parthenia Spring puts salamanders in closer proximity to swimmers and other recreational users, and may experience more harassment from unnatural habitat disturbance.

As would be expected for a stream-adapted species, *E. sosorum* abundance is correlated with these factors. Higher abundances occur when flow velocity is faster, and sediment cover, and sediment and water depths are lower. After habitat reconstruction, *E. sosorum* abundance and density increased by several orders of magnitude, and have remained significantly higher to date, despite the recent severe drought. Although no flow velocity data were collected in Parthenia Spring, sediment depth was significantly less after these efforts in some areas, and *E. sosorum* abundance increased significantly by 2006. *Eurycea waterlooensis* has been seen more frequently after the temporary or permanent flow regime reconstructions in Parthenia and Eliza Spring, respectively.

All of the results of examinations of microhabitat indicate that *E. sosorum* fares better in habitats with briskly flowing water (~ 0.5 – 1 ft./s.) and less sediment-laden, rocky substrate. This is consistent with a preference for flowing water (Thaker *et al*. 2006) of 0.39 ft/sec in *E. nana* (Fries 2002). The benefits of flowing water to *E. sosorum* are not surprising considering the evolutionary history of central Texas perennibranchiate *Eurycea*. The entire clade consists of species that evolved and reside in spring-fed streams (Sweet 1977, 1982, 1984, Wiens *et al*. 2003, Hillis *et al*. 2001, Chippindale *et al*. 2001, Petranka 1998, Bowles *et al*. 2006). Higher flow velocities of streams and rivers are the dominant features distinguishing them from lakes and ponds (Leopold *et al*. 1992). Flowing water influences every part of the aquatic ecosystem (Wetzel 2001; Giller and Malmqvist 1998), from the amount of sediment (Nowell and Jumars 1984) and type of algae (Poff *et al*. 1990, Reiter and Carlson 1986) to the community of invertebrates and vertebrates (Vogel 1994). Faster, unidirectional water flow naturally favors growth of tightly attached algae (Stevenson 1983, Korte and Blinn 1983, Fritsch 1929), favors a diversity of stream-adapted invertebrates (Hynes 1972), and helps maintain high water quality (Spellman and Drinan 2001). Moreover, periodic disturbance imposed by variation in water flow also plays a critical role in stream ecosystems (Resh *et a*. 1988). Unfortunately, imperiled *E. nana* and *E. sosorum* are limited to habitats whose flow regimes have been altered by dams or other impoundments. Long-term effects of alteration of flow regime on the San Marcos River of central Texas decreased the frequencies of small and large floods, resulting in a shift in the dominant species from endemic specialists to generalists (Perkin and Bonner 2010). Permanent loss of natural flow regimes of Barton Creek and Barton Springs *Eurycea* may inhibit the ability of endangered endemic species to recover.

Barton Springs' *Eurycea* abundance varies within discharge from Barton Springs, which ranges ~ 10 - 125 cfs (citation). Six-month lag in discharge with salamander abundance is consistent with the 10-11 month lag in rainfall and salamander abundance, and synchronicity of total salamander abundance and increases in discharge documented by Gillespie (2011). Although water can travel quickly through karst aquifers, a single, average rainfall after a period of drought rarely results in immediate large increases in Barton Springs' discharge. It appears that it takes several months for rainfall to produce enough recharge water to the aquifer to result in biologically significant increases in discharge.

The severe drought of 2008-2009 resulted in reduced Barton Springs' discharge to 13 cfs, a level not seen since the drought of record in the 1950s (Smith and Hunt 2010). Parthenia Spring had higher flow than Eliza Spring, followed by Old Mill Spring, where surface habitat was reduced to a stagnant pool with undetectable flow velocity and therefore, discharge was at or near zero. Reduction in discharge was accompanied by significant increases in water temperature in the three spring sites, and decreases in flow velocity in Eliza and Old Mill Spring, thus, inhibiting processes and flow regime conditions that foster higher concentrations of dissolved oxygen (Levine 1978, Lampert and Sommer 1997, Giller and Malmqvist 1998, Wetzel 2001). Since dissolved oxygen and temperature can influence every aspect of the aquatic community (Cushing and Allan 2001; Giller and Malmqvist 1998 references therein; Wetzel 2001 and references therein), drought-related reductions in spring discharge can have strong effects on resident flora and fauna.

These changes are of biological significance to resident *E. sosorum*. Dissolved oxygen decreased in all sites to concentrations that are of concern for *E. sosorum*. Woods *et al*. 2010 showed that in metabolic responses of *E. nana* and *E. sosorum* to a range of dissolved oxygen concentrations are similar. They demonstrated that neither species habituates to low DO by reducing metabolic rate; metabolic rates increase until salamanders are approaching death. They demonstrated that 28-day dissolved oxygen concentrations of 4.5 mg/L, 4.2 mg/L, 3.7mg/L, and 3.4 mg/L result in mortality of 5%, 10%, 25%, and 50% of adult *E. nana*. Chronic 60-day exposure to 4.44 mg/L dissolved oxygen compromised growth of juvenile *E. nana*. Mean DO concentrations in Eliza Spring and Old Mill Spring during drought were below the growth inhibition and LC_5 thresholds (4.3 mg/L and 4.26 mg/L, respectively). Moreover, minimum DO concentrations in Eliza Spring (3.9 mg/L) dropped below the LC_{10} threshold, and the minimum in Old Mill Spring (1.04 mg/L) dropped below the LC_{50}. Fortunately, DO augmentation was implemented immediately after these concentrations were measured.

Variation in water temperature in the perennial springs of the Edwards Aquifer is typically less than in other surface waters (Brune 1981, Sweet 1982, Groeger *et al*. 1997), although it is not constant in Barton Springs (Mahler *et al*. 2010, Gillespie 2011). Increases in water temperature have detrimental effects on other Edwards Aquifer perennibranchiate *Eurycea* (Norris *et al*. 1963, McAllister and Fitzpatrick 1989, Berkhouse and Fries 1995) and it is reasonable to assume that Barton Springs' *Eurycea* could be similarly affected.

Thus, it should be no surprise that Barton Springs' *Eurycea* abundance was significantly lower during the drought. No *E. waterlooensis* were seen in any spring site during the drought. There were substantial decreases in *E. sosorum* of all size classes in all sites. The *E. sosorum* population in Old Mill was more severely affected by drought than those in Eliza and Parthenia Springs. There were 11 consecutive months during the 2008 - 2009 drought, when no salamanders of either species were found. During the less severe drought of 2006, there were 6 consecutive months of zero salamander abundance. This coupled with the dissolved oxygen concentrations during these droughts, suggests that when dissolved oxygen is below 4.0 mg/L and adult abundance is at or near zero, there is no reproduction, and hence no recruitment.

Eurycea sosorum abundance in Parthenia Spring decreased during the drought, but not as drastically as in Old Mill Spring. There were few juveniles and no evidence of recruitment during the drought, even though dissolved oxygen was the highest of all three sites and never dropped to concentrations of concern.

Abundance in Eliza Spring remained the highest of the three sites throughout the drought. We have some evidence from this site that salamanders retreated to inaccessible areas during the worst of the drought. In the month before rainfall broke the drought, only 27 young adult and 14 adult *E. sosorum* were seen in Eliza Spring. Six weeks after the rainfall, these abundances increased to 230 young adults, and 154 adults, which is too short a time for reproduction and recruitment to have occurred. In eight weeks, juveniles appeared in very low abundance, 12. Clearly, these salamanders went somewhere, but, whether they retreated to subterranean habitat or the inaccessible outflow pipe from the spring pool is unclear. Water flow is faster in the pipe and there is a vent to the atmosphere, so dissolved oxygen was likely higher than in the spring pool. However, condition of subterranean habitat is less certain. Regardless of where surviving salamanders retreated, comparison of November abundances with 2008 pre-drought highs of 256 adults, 535 young adults, and 568 juveniles shows a 98% decrease in juveniles, a 57% decreased in young adults, and a 40% decrease in adults.

The very small numbers of juveniles during the drought suggest that adult reproduction was very low, which is consistent with theoretical and empirical demonstrations of resource allocation for long-lived animals (Pianka 1983, Harris and Ludwig 2004, Takahashi and Pauley 2010). Adults that will have more than one lifetime opportunity to reproduce are expected to allocate metabolic energy to survival alone when environmental conditions are poor (Pianka 1983). Barton Springs' *Eurycea* are long-lived and reproduce more than once in a lifetime. The lack of constant, year-round reproduction, and extremely low abundance of juvenile *E. sosorum* during drought suggests that in the wild these salamanders suspend reproduction under adverse environmental conditions.

It is clear that drought imposes direct detrimental effects on survival, reproduction, and recruitment of *Eurycea sosorum*. It is also apparent that abundances and population sizes can increase rapidly when environmental conditions are good. What isn't clear is what triggers these bouts of reproduction and recruitment leading to the increases. In the fourteen months since the end of the 2008-2009 drought, *E. sosorum* and *E. waterlooensis* abundances have not returned to pre-drought levels. In Eliza Spring, juvenile abundance is *lower* after the drought then during; In Old Mill Spring, maximum number of salamanders seen after the drought, was 4; and in Parthenia Spring, abundances did not change after the drought. It may be that adult *E. sosorum* have not reached a level of metabolic energy where reproduction is favored, even though dissolved oxygen concentration returned to pre-drought concentrations. While this confirms the positive relationship between dissolved oxygen and discharge, it also suggests that indirect effects of lower dissolved oxygen on the ecosystem may persist after a drought. It also suggests that there may be other drought-related factors that affect salamanders, such as water temperature dips associated with winter rains (Gillespie 2011). The effects of frequent, repeated, extended drops in Barton Springs' discharge during severe droughts (Smith and Hunt 2010) on *E. sosorum* and *E. waterlooensis* may be dependent on not only the duration and frequency of low discharge, but also the duration of intervening non-drought conditions.

Conclusions

Populations of *E. sosorum* and *E. waterlooensis* vary within and among spring sites, as do ecological conditions. In general, there are more salamanders during periods of average or higher Barton Springs' discharge. Average abundance of *E. sosorum* increased in Parthenia and Eliza Spring after partial restoration of natural flow regimes. *Eurycea sosorum* prefers clean, rocky substrates in quickly flowing water and little sediment. Since 2003, there have been bouts of reproduction and recruitment in Eliza, Parthenia, and Old Mill Spring, and there have also been periods of drought during which there was little reproduction and recruitment. During droughts, dissolved oxygen is lower and water temperature is higher, both critical factors known to affect *E. sosorum*, *E. nana*, and other central Texas perennibranchiate *Eurycea*. Despite the recent severe drought, Eliza Spring remains the best habitat and harbors the largest and most robust *E. sosorum* salamander population, which likely has the best potential to weather adverse conditions. Since *E. waterlooensis* resides in subterranean habitat of the Barton Springs complex and has been observed in surface habitat of the three perennial springs, Eliza, Parthenia, and Old Mill, it is difficult to infer the status of the populations and the species. Lack of information on life history characteristics in wild populations further hampers assessment of reproduction and recruitment. However, *E. waterlooensis* depends on the same groundwater that feeds surface habitats of Barton Springs. Efforts to protect the quantity and quality of this groundwater associated with *E. sosorum* will also protect subterranean habitat for *E. waterlooensis*. What isn't clear is the natural degree of overlap of preferred microhabitats and resultant interspecific competition. Moreover, how anthropogenically derived increases in habitat overlap would affect both species is unknown.

The results presented here suggest two anthropogenic factors that impose significant threats to persistence of Barton Springs' *Eurycea*, alterations of natural flow regimes of the springs, and drought. While rainfall is the climatic cause of drought, the effects on Barton Springs' discharge are magnified by withdrawal of groundwater from the outlying watershed. By the 1950s, ~ 1 cfs of groundwater was regularly extracted from the Barton Springs Zone of the Edwards Aquifer upstream of Barton Springs, resulting in a low discharge from combined Barton Springs of 9.6 cfs during the drought of record in the late 1950s (Smith and Hunt 2010). As of today, demand for groundwater has increased to levels that threaten to cause cessation of flow from Barton and other Edwards Aquifer springs during droughts (Bowles and Arsuffi 2006). The effects of drought are magnified by dams, amphitheaters, and other impoundment structures (Giller and Malmqvist 1998) at Eliza, Parthenia, and Old Mill springs. Conservation of Barton Springs' *Eurycea* requires consideration of the evolutionary adaptations of each species, how anthropogenic changes impose selection countering those adaptations (contemporary evolution *sensu* Stockwell *et al*. 2003) and whether the species can adapt before they go extinct. Given the suite of characteristics that change with flow regime alteration, and the positive response of *E. sosorum* to partial restoration, continued efforts to reverse the effects of dams could not only improve habitat, it could potentially help mitigate the effects of drought.

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Table 1. Mean, standard deviation (S.D.), and standard error (s.e.) of *E. sosorum* and *E. waterlooensis* salamander abundance and density in each spring site for the period of record are listed below. Minimum (Min.) and Maximum (Max.) salamander abundance and number of surveys (N) are also listed.

	Abundance (#)					Density (#/sq. ft.)				
	Mean	**S.D.**	**s.e.**	**Min-Max**	**N**	**Mean**	**S.D.**	**s.e.**	**Min-Max**	**N**
Eurycea sosorum										
Eliza (1995-2011)	190.5	255.4	20.6	0-1234	154	0.35	0.34	0.03	0-1.54	103
Parthenia (1993-2011)	44.5	59.3	4.5	1-447	171	0.03	0.03	0.002	0.0-0.18	154
Old Mill (1998-2011)	15.4	19.7	1.7	0-97	134	0.02	0.02	0.002	0-0.09	134
Upper Barton (1997-2011)	8.0	12.9	1.3	0-100	92	0.02	0.02	0.002	0-0.15	92
All Sites Combined All Years	72.1	158.1	6.4	0-1234	551	0.09	0.21	0.009	0-1.54	483
Eurycea waterlooensis										
Eliza (1998-2011)	0.76	1.8	0.16	0-12	128	0.001	0.003	0.0003	0-0.02	89
Parthenia (1998-2011)	0.29	0.74	0.07	0-5	113	0.0001	0.0003	0.00003	0-0.001	98
Old Mill (1998-2011)	3.6	7.6	0.68	0-43	125	0.003	06	0.001	0-0.03	25
Upper Barton (1998-2011)	0	0	0	0	83	0.02	0.02	0.002	0-0.15	83
All Sites Combined (1998-2011)	1.3	4.4	0.21	0-43	449	0.001	0.004	0.0002	0-0.032	395

Table 2. Descriptive statistics of *E. sosorum* abundance and density in Eliza and Parthenia Spring for each year of record are listed below. n/a indicates that density cannot be calculated because exact area surveyed was not recorded. Changes in habitat management associated with federal protection of *E. sosorum* were implemented in 1997. Habitat reconstruction in Eliza Spring occurred from 2003-2004, in Parthenia Spring from 2004-2005.

	Abundance (#)						Density (#/sq ft)			
Year	**Mean**	**S.D.**	**s.e.**	**N**	**Min.**	**Max.**	**Mean**	**S.D.**	**s.e.**	**N**
Eliza										
1995	20.3	7.14	3.57	4	12	29	0.026	0.009	0.005	3
1996	7.7	8.19	2.47	11	1	23	0.01	0.009	0.003	10
1997	25.8	12.51	5.11	6	13	44	0.01	n/a	n/a	1
1998	14.9	5.16	1.72	9	8	23	n/a	n/a	n/a	
1999	6.6	4.04	1.35	9	1	13	n/a	n/a	n/a	
2000	1.6	2.68	0.85	10	0	8	n/a	n/a	n/a	
2001	4.1	2.36	0.83	8	1	7	n/a	n/a	n/a	
2002	4.5	2.45	0.87	8	2	8	n/a	n/a	n/a	
2003	39.8	44.24	14.0	10	3	148	0.04	0.06	0.02	10
2004	350.6	124.1	46.9	7	233	601	0.44	0.16	0.06	7
2005	369.6	197.2	62.4	10	151	673	0.44	0.25	0.08	10
2006	453.4	169.5	53.6	10	216	738	0.57	0.21	0.07	10
2007	437.0	166.7	50.3	11	280	701	0.55	0.21	0.06	11
2008	703.4	347.4	100.3	12	231	1234	0.88	0.43	0.13	12
2009	163.6	114.3	36.1	10	35	405	0.20	0.14	0.05	10
2010	155.6	88.7	31.4	8	53	360	0.18	0.12	0.04	8
2011	152.1	63.7	20.1	10	49	226	0.19	0.08	0.025	10
Parthenia										
1993	18.2	6.9	3.1	5	11	27	0.038	0.014	0.006	5
1994	15.2	7.8	2.2	12	3	28	0.031	0.016	0.005	12
1995	16.0	12.0	-	13	1	40	0.033	0.025	0.007	13
1996	21.4	12.6	3.2	16	7	45	0.044	0.026	0.007	16
1997	19.7	17.1	6.5	7	4	44	0.041	0.035	0.013	7
1998	29.6	10.6	3.4	10	10	42	0.059	0.012	0.007	3
1999	57.2	21.9	6.9	10	17	82	0.037	0.014	0.005	10
2000	17.7	14.1	4.7	9	3	42	0.012	0.009	0.003	9
2001	10.7	3.1	1.2	7	6	15	0.007	0.002	0.001	7
2002	22.0	8.1	2.7	9	5	32	n/a	n/a	n/a	n/a
2003	46.1	29.5	10.4	8	11	100	0.023	0.010	0.005	5
2004	37.2	38.9	13.0	9	5	127	0.015	0.016	0.005	9
2005	111.0	84.5	32.0	7	16	236	0.042	0.032	0.012	7
2006	86.9	124.6	41.5	9	1	300	0.034	0.045	0.015	9
2007	27.8	16.0	6.5	6	9	55	0.011	0.007	0.003	6
2008	177.6	110.6	36.9	9	76	447	0.081	0.042	0.014	9
2009	28.7	22.5	8.5	7	5	73	0.010	0.010	0.004	7
2010	54.9	33.8	11.9	8	13	111	0.013	0.006	0.002	8

Table 3. Descriptive statistics of *E. sosorum* abundance and density in Old Mill and Upper Barton Spring for each year of record are listed below. n/a indicates that density cannot be calculated because exact area surveyed was not recorded. Changes in habitat management associated with federal protection of *E. sosorum* were implemented in 1997. Habitat reconstruction in Eliza Spring occurred in 2003, in Parthenia Spring from 2004-2005.

	Abundance (#)						Density (#/sq ft)			
Year	**Mean**	**S.D.**	**s.e.**	**N**	**Min.**	**Max.**	**Mean**	**S.D.**	**s.e.**	**N**
Old Mill										
1997	39.6	23.3	11.7	4	8	60	0.058	0.037	0.019	4
1998	27.9	18.1	6.0	9	4	51	0.027	0.021	0.007	9
1999	5.9	4.4	1.5	9	0	13	0.004	0.003	0.001	9
2000	2.0	2.6	0.9	8	0	7	0.002	0.004	0.001	8
2001	27.6	17.6	5.6	10	8	56	0.031	0.023	0.007	10
2002	19.1	9.5	3.2	9	4	33	0.016	0.010	0.003	9
2003	27.6	18.8	5.9	10	1	52	0.021	0.014	0.004	10
2004	42.8	16.9	5.7	9	6	67	0.032	0.013	0.004	9
2005	13.4	6.7	2.4	8	7	23	0.007	0.003	0.001	8
2006	0.8	1.3	0.4	9	0	3	0.001	0.001	0.0003	9
2007	6.5	4.4	1.8	6	1	14	0.005	0.003	0.001	6
2008	32.5	38.2	13.5	8	0	97	0.026	0.030	0.011	8
2009	0.9	2.1	0.6	12	**0**	7	0.001	0.001	0.0004	12
2010	1.5	1.2	0.4	11	**0**	4	0.001	0.001	0.0002	11
Upper Barton										
1997	5.8	5.3	2.4	5	1	14	0.013	0.012	0.005	5
1998	1.9	1.3	0.4	9	0	4	0.004	0.003	0.001	9
1999	1.0	10.6	0.3	6	0	2	0.002	0.001	0.001	6
2000	5.0	3.5	2.0	3	3	9	0.011	0.008	0.004	3
2001	5.4	5.0	1.6	10	0	14	0.012	0.011	0.004	10
2002	5.0	3.6	1.1	10	0	12	0.011	0.008	0.003	10
2003	2.9	1.9	0.6	9	0	5	0.006	0.004	0.001	9
2004	7.3	4.5	1.6	8	1	14	0.016	0.010	0.004	8
2005	4.4	3.1	1.4	5	1	9	0.010	0.007	0.003	5
2007	5.3	5.1	1.7	9	0	13	0.010	0.010	0.003	9
2008	20.3	12.5.	6.3	4	3	30	0.051	0.036	0.018	4
2009	9.0	9.9	7.0	2	2	16	0.013	0.012	0.009	2
2010	28.1	27.0	8.1	11	4	100	0.043	0.042	0.013	11

Table 4. Descriptive statistics of *E. waterlooensis* abundance and density in Eliza and Parthenia, Spring for each year of record are listed below. n/a indicates that density cannot be calculated because exact area surveyed was not recorded. Changes in habitat management associated with federal protection of *E. sosorum* were implemented in 1997. Habitat reconstruction in Eliza Spring occurred in 2003, in Parthenia Spring from 2004-2005.

	Abundance (#)						**Density (#/sq ft)**			
Year	**Mean**	**S.D.**	**s.e.**	**N**	**Min.**	**Max.**	**Mean**	**S.D.**	**s.e.**	**N**
					Eliza					
1998	0	0	0	5	0	0	0	0	0	5
1999	0	0	0	9	0	0	0	0	0	9
2000	0	0	0	10	0	0	0	0	0	10
2001	0	0	0	8	0	0	0	0	0	8
2002	0	0	0	8	0	0	0	0	0	8
2003	0	0	0	10	0	0	0	0	0	10
2004	1.1	1.1	0.4	7	0	3	0.001	0.001	0.001	7
2005	0.9	1.7	0.6	9	0	5	0.001	0.005	0.001	10
2006	3.7	4.5	1.7	10	0	12	0.005	0.006	0.002	10
2007	1.2	1.1	0.4	10	0	3	0.002	0.001	0.0005	11
2008	1.0	4.5	0.4	12	0	4	0.001	0.002	0.001	12
2009	0.1	0.3	0.1	10	0	1	0.0001	0.0004	0.0003	10
2010	0	0	0	8	0	0	0	0	0	8
					Parthenia					
1998	0.2	0.5	0.2	10	0	1	0.0003	0.0005	0.0003	2
1999	0	0	0	10	0	0	0	0	0	10
2000	0	0	0	9	0	0	0	0	0	9
2001	0	0	0	7	0	0	0	0	0	7
2002	0.3	0.5	0.2	9	0	1	n/a	n/a	n/a	n/a
2003	0.6	0.9	0.3	8	0	2	0.0003	0.0004	0.0002	5
2004	0.1	0.3	0.1	9	0	1	0.00005	0.0002	0.00005	9
2005	0.1	0.4	0.1	7	0	1	0.00005	0.0001	0.00005	7
2006	0.3	0.7	0.2	9	0	2	0.0001	0.0003	0.0001	9
2007	0.7	0.8	**0.3**	6	0	2	0.0003	0.0004	0.0002	6
2008	0.2	0.7	0.2	9	0	2	0.0001	0.0003	0.0001	9
2009	0.1	0.4	0.1	7	0	1	0.00003	0.0001	0.00003	7
2010	1.1	2.0	0.8	7	0	5	0.0003	0.0004	0.0002	7

Table 5. Descriptive statistics of *E. waterlooensis* abundance and density in Old Mill and Upper Barton Spring for each year of record are listed below. n/a indicates that density cannot be calculated because exact area surveyed was not recorded. Changes in habitat management associated with federal protection of *E. sosorum* were implemented in 1997. Habitat reconstruction in Eliza Spring occurred in 2003, in Parthenia Spring from 2004-2005.

	Abundance (#)						**Density (#/sq ft)**			
Year	**Mean**	**S.D.**	**s.e.**	**N**	**Min.**	**Max.**	**Mean**	**S.D.**	**s.e.**	**N**
					Old Mill					
1998	1.2	1.1	0.5	5	0	2	0.001	0.001	0.0004	5
1999	0.3	1.0	0.3	9	0	3	0.0003	0.001	0.0003	9
2000	0.5	0.8	0.3	8	0	2	0.001	0.001	0.0004	8
2001	9.1	12.4	3.9	10	0	37	0.008	0.009	0.003	10
2002	9.1	6.5	2.2	9	1	21	0.007	0.005	0.002	9
2003	15.5	15.3	4.8	10	0	43	0.012	0.011	0.004	10
2004	8.8	5.3	1.8	9	0	16	0.007	0.004	0.001	9
2005	1.5	1.8	0.6	8	0	5	0.001	0.001	0.0005	8
2006	0.4	0.7	0.2	9	0	2	0.0003	0.001	0.0002	9
2007	0.2	0.4	0.2	6	0	1	0.0001	0.0003	0.0001	6
2008	1.8	2.4	0.9	8	0	6	0.001	0.002	0.001	8
2009	0	0	0	12	**0**	0	0	0	0	12
2010	0.1	0.3	0.1	11	**0**	1	0.00005	0.0002	0.00005	11
					Upper Barton					
1998-2010	0	0	0	83	0	0	0	0	0	83

Table 6. Spearman Rank correlation coefficients (ρ) and significance values (p) of habitat and *E. sosorum* density in Eliza Spring from July 2003 through December 2010 are presented below. Mean ± Standard Deviation of each variable is also listed. Water and sediment depth are listed in inches, velocity in feet per second.

Variable	Salamander Density	Sediment Depth	% Sediment Cover
Mean ± SD	348.9 ± 274.5	0.68 ± 0.51 in.	36.2 ± 23.2
Flow Velocity 0.57 ± 0.55 ft./sec.	ρ=0.067 p= 0.016	ρ=-0.058 p= 0.581	ρ= 0.320 p= 0.002
Water Depth 15.2 ± 8.3 in.	ρ=-0.305 p=0.024	ρ= 0.219 p= 0.002	ρ= 0.471 p=0.0003
% Sediment Cover 36.2 ± 23.2	ρ=-0.166 p= 0.011	ρ= 0.173 p= 0.002	.

Table 7. Mean, standard deviation (S.D.), and standard error (s.e.) of dissolved oxygen (DO) abundance and density of each size class of *E. sosorum* in Eliza Spring from 2003 – 2010 before the severe drought, during, and after the drought. Totals and values for each size class are included. Minimum (Min.) and Maximum (Max.) salamander abundances and dissolved oxygen concentrations are also listed.

	Abundance (#)						Density (#/sq ft)		
Eliza	**Mean**	**S.D.**	**s.e.**	**N**	**Min.**	**Max.**	**Mean**	**S.D.**	**s.e.**
No Drought 7/03-5/08									
Total	430.7	281.9	39.5	51	29	1234	0.54	0.36	0.05
Juvenile	116.7	124.7	17.5	51	0	568	0.16	0.16	0.02
Young Adult	177.2	123.1	17.4	50	14	535	0.22	0.16	0.02
Adult	130.9	88.4	12.5	50	2	365	0.16	0.11	0.02
DO	5.08	0.88	0.14	39	4.35	7.64	n/a	n/a	n/a
H_2O Temp.(C°)	21.0	0.57	0.06	78	19.0	22.1	n/a	n/a	n/a
Drought 6/08-9/09									
Total	253.4	211.1	58.55	13	35	642	0.32	0.26	0.07
Juvenile	47.23	59.8	16.6	13	3	195	0.06	0.08	0.02
Young Adult	151.0	125.7	34.9	13	17	374	0.19	0.16	0.04
Adult	48.9	27.4	7.6	13	14	91	0.06	0.03	0.01
DO	4.30	0.34	0.10	12	3.88	5.03	n/a	n/a	n/a
H_2O Temp.(C°)	21.5	0.17	0.05	15	21.2	21.8	n/a	n/a	n/a
No Drought 10/09-12/10									
Total	193.2	115.1	36.4	10	53	405	0.23	0.15	0.05
Juvenile	9.9	7.9	2.5	10	0	24	0.01	0.01	0.003
Young Adult	85.4	70.5	22.3	10	15	230	0.10	0.09	0.03
Adult	87.7	47.5	15.0	10	22	168	0.10	0.06	0.02
DO	6.48	0.78	0.25	10	5.6	8.12	n/a	n/a	n/a
H_2O Temp.(C°)	20.6	1.11	0.31	13	18.4	21.9	n/a	n/a	n/a

Table 8. Mean, standard deviation (S.D.), and standard error (s.e.) of dissolved oxygen (DO) abundance and density of each size class of *E. sosorum* in Parthenia Spring from 2003 – 2010 before the severe drought, during, and after the drought. Totals and values for each size class are included. Minimum (Min.) and Maximum (Max.) salamander abundances and dissolved oxygen concentrations are also listed.

	Abundance (#)						**Density (#/sq ft)**		
Parthenia	**Mean**	**S.D.**	**s.e.**	**N**	**Min.**	**Max.**	**Mean**	**S.D.**	**s.e.**
No Drought 7/03-5/08									
Total	72.6	78.2	12.2	41	1	300	0.029	0.03	0.005
Juvenile	26.1	25.7	4.0	41	0	102	0.010	0.010	0.002
Young Adult	34.6	42.6	6.7	40	0	175	0.014	0.016	0.003
Adult	11.7	16.2	2.6	40	0	58	0.005	0.006	0.001
DO	6.02	0.71	0.11	41	4.57	7.44	n/a	n/a	n/a
H_2O Temp.(C°)	21.1	0.55	0.07	70	19.1	22.0			
Drought 6/08-9/09									
Total	116.1	136.5	43.2	10	5	447	0.054	0.057	0.018
Juvenile	45.5	66.6	21.1	10	0	204	0.020	0.027	0.009
Young Adult	55.0	58.3	18.4	10	3	199	0.027	0.027	0.008
Adult	11.9	13.0	4.1	10	0	36	0.005	0.006	0.002
DO	4.57	0.32	0.10	10	4.13	5.00	n/a	n/a	n/a
H_2O Temp.(C°)	21.4	0.52	0.14	15	19.6	21.8	n/a	n/a	n/a
No Drought 10/09-12/10									
Total	49.5	32.1	10.2	10	13	111	0.010	0.006	0.002
Juvenile	14.3	13.2	4.2	10	2	41	0.003	0.002	0.001
Young Adult	24.4	14.4	4.5	10	4	51	0.006	0.003	0.001
Adult	9.9	7.1	2.2	10	1	22	0.002	0.001	0.0005
DO	6.40	0.52	0.16	10	5.80	7.24	n/a	n/a	n/a
H_2O Temp.(C°)	20.4	1.02	0.32	10	18.7	21.7	n/a	n/a	n/a

Table 9. Mean, standard deviation (S.D.), and standard error (s.e.) of dissolved oxygen (DO) and abundance and density of each size class of *E. sosorum* Old Mill Spring during drought and non-drought. The droughts of 2006 and 2008 are pooled. Minimum (Min.) and Maximum (Max.) salamander abundances, dissolved oxygen concentrations, and water temperatures are also listed.

	Abundance						**Density (#/sq ft)**		
Old Mill	**Mean**	**S.D.**	**s.e.**	**N**	**Min.**	**Max.**	**Mean**	**S.D.**	**s.e.**
Droughts 10/05-10/06, 6/08-9/09									
Total	4.1	14.4	2.9	25	0	71	0.003	0.013	0.003
Juvenile	1.2	4.7	0.9	25	0	23	0.001	0.004	0.001
Young Adult	2.2	7.7	1.5	25	0	38	0.002	0.007	0.001
Adult	0.7	2.1	0.4	25	0	10	0.001	0.002	0.0004
DO	4.26	2.12	0.41	27	1.04	9.07	n/a	n/a	n/a
H_2O Temp.(C°)	21.6	3.2	0.62	27	10.8	30.2	n/a	n/a	n/a
No Drought 7/03-9/05, 11/06-5/08, 10/09-12/10									
Total	21.8	23.6	3.6	43	0	97	0.016	0.018	0.003
Juvenile	5.4	7.3	1.1	43	0	24	0.004	0.006	0.001
Young Adult	9.7	11.8	1.8	43	0	45	0.007	0.009	0.001
Adult	6.1	6.6	1.0	43	0	22	0.004	0.005	0.001
DO	5.83	0.65	0.07	83	4.3	7.56	n/a	n/a	n/a
H_2O Temp.(C°)	20.8	1.2	0.13	82	11.4	21.9	n/a	n/a	n/a

City of Austin WATERSHED PROTECTION

Estimating population trends for the Barton Springs Salamander using two different statistical methods

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Abstract

This report summarizes the status of the Barton Springs salamander (*Eurycea sosorum*) by determining population trends using multivariate auto-regressive state-space (MARSS) models and generalized linear regression models (GLMs). We explicitly modeled process and observation error in *E. sosorum* counts using a MARSS analysis in order to attain estimates of population trend and process error variance and test for density dependence. We also explored the adequacy of a negative binomial GLM to determine population trends with and without the effect of environmental covariates. Our GLM models were improved by the addition of environmental covariates, although overall model fit was questionable. The GLM models showed counts at Eliza and Old Mill Springs trending downward, while they remained stable at Parthenia and increased at Upper Barton Spring. However we found no evidence of population trends in adult counts from 2004-2011 at Eliza or Parthenia Springs in MARSS models. Additionally, the MARSS analysis showed a mean-reverting pattern for adult counts, consistent with density-dependent population growth. The zero long-term population growth indicated by the MARSS analysis is a positive indication for population viability, although the limited range of *E. sosorum* coupled with ongoing threats to water quality and quantity remain a concern.

Introduction

A key question in understanding the status of a species of concern is whether populations are increasing, decreasing, or stable (i.e., not increasing or decreasing). We may ask whether population size has increased or decreased during some chosen period. Alternatively, we may ask what the average change in a population is per year (the population growth rate). Populations regulated by their own density (often *not* the case for imperiled species) have a mean population growth rate of zero over a long period of time. A density-dependent population may have an increasing or decreasing population size in the short-term, but a stable population size over the long-term. Density-dependent populations tend to return to a point of equilibrium, and those that have a high capacity of returning to equilibrium after a perturbation (such as a drought event) are less likely to go extinct (Sibly et al. 2007). The strength and form of density-dependence can also have a strong effect on the probability of extinction of a population (Ginzburg et al. 1990). For these reasons, it is important to test whether populations of *Eurycea sosorum* follow a density-dependent or density-independent growth pattern.

Here, we use two different statistical approaches to test 1) whether salamander populations from 2004 to 2011 exhibit an increasing or decreasing trend in size, and 2) whether salamander populations from 2004 to 2011 have a density-dependent or density-independent growth pattern. We use two different types of models, a multivariate auto-regressive state-space (MARSS) model and a generalized linear model (GLM) to address question 1 and a MARSS model to address question 2.

Generalized linear models such as a Poisson regression are commonly used to model count data, and have been used to examine trends in animal populations (e.g. Link & Sauer 1998; Link et al. 2006; Royle & Nichols 2003; Sauer & Link 2002; Thogmartin et al. 2004, 2007). Although the primary goal of this report is to examine the population trends of *E. sosorum*, we also conduct a preliminary analysis on the effect of several environmental variables using our GLM model. Others have previously explored the correlations of numerous environmental variables at various lags on *E. sosorum* abundance (Turner 2009; Gillespie 2011), identifying dissolved oxygen, spring discharge, and water temperature as significant factors. Therefore, we chose to determine whether the inclusion of dissolved oxygen, spring discharge, and water temperature improve our estimates of population trends. To that end, we specifically ask whether these environmental covariates improve our GLM models.

Population modeling (including trend estimation and population viability analysis) using state-space models is also well documented in the literature, and Holmes & Ward (2011) provide a list of references. In addition to estimating long-term trend in population size (hereafter "trend"), we also use MARSS analyses to test for density-dependence in populations of *E. sosorum* (question 2). An advantage of using MARSS over GLM is that MARSS can account for serial auto-correlation in the dataset as well as partition two types of variability, process error and observation error. Observation error is the variation in the relationship between the true population size and the observed count (Dennis et al. 2006). Process error is the unexplained variation in the changes in the true population size, and represents environmental variability (Dennis et al. 1991). By accounting for these two types of error using MARSS models, we expect to get a better estimate of the population trend compared to our GLM approach. Finally, we use results from the best MARSS model in a population viability analysis to estimate the quasi-extinction probability for Eliza and Parthenia populations.

Survey Data

We begin with a description of the data sets, including some differences in how the data were treated between the two modeling approaches and justification for why we chose one particular dataset over another.

Time Periods and Survey Sites

The raw data are partitioned by section at each site. The Parthenia series we use here only includes survey data from three sections: main, little main, and side spring; other sections in Parthenia were excluded due to inconsistency in survey frequency. All sections from Eliza and Upper Barton were used. We excluded the Old Mill stream data and only included the main site.

For both GLM and MARSS analyses, we used counts of *E. sosorum* from January 2004 to April 2011. We used data from this time period to ensure that time series from both sites started at the same time and excluded earlier data based on inconsistencies between survey methods and differences before and after habitat restoration at Eliza Spring. Thus, our inference will be based on the same period of time for the same survey areas (see Appendix A for a detailed description of how we suggest to partition data for each site).

Grouping Data by Size Class

Available data from 2004-2011 surveys includes three size classes of *E. sosorum*: <1”, 1-2”, and ≥2” total length (TL). We modeled counts for two size classes: <1” and ≥1” (TL). For simplicity, we refer to these size classes as juveniles and adults, respectively. Individuals less than one inch are assumed to be juveniles, however individuals between one and two inches TL may be juveniles or adults. There is no direct evidence of the exact body length *E. sosorum* reaches sexual maturity, although there are data available for other closely related central Texas *Eurycea* salamanders. Sexual maturity of *E. neotenes* from two different populations was documented as 25-26 mm SVL or approximately 1” snout-vent-length (SVL) (Bruce 1976). *Eurycea nana* reaches sexual maturity from 19-21mm SVL (Petranka 1998). In the original species description of *E. sosorum*, Chippindale et al. (1993) assumed individuals greater than 22.5mm SVL to be sexually mature, although they did not give a justification for using this size threshold. The relationship between SLV and TL in *E. sosorum* was determined by a linear regression model

$$SVL(\text{mm}) = 3.171 + 0.476 * TL(\text{mm})$$

(City of Austin, unpublished data), indicating that *E. sosorum* may reach sexual maturity at 40.6mm TL (1.6 inches) according to the 22.5mm criterion of Chippindale et al. (1993), 45.9mm(1.8 inches) according to *E. neotenes* size at maturity (Bruce 1976), or 33.3mm (1.3 inches) following the size at sexual maturity for *E. nana* (Petranka 1998).

Therefore, the 1-2” (“adult”) size class likely includes both small adults and large juveniles. The ≥2” or “large adult” size class consists entirely of adults, but excludes young, sexually mature salamanders.

Month-to-month changes in abundance are unlikely to be solely influenced by monthly changes in reproduction, because it takes longer than one month for *E. sosorum* to complete a reproductive cycle (City of Austin, unpublished data). Thus, at least for the MARSS modeling that follow at auto-regressive order of 1, the status of an individual as a breeder is less likely to directly influence the month-to-month population dynamics; adults will not produce new adults within a single month. By analyzing juveniles and adults separately, any differences in growth patterns between these two life stages may shed light on important population dynamics. For example, a declining trend in juveniles, but a stable adult trend could indicate a decline in reproduction relative to the total population size.

Size classes, however, are not only a surrogate for *E. sosorum* life stages. Size by itself may also play a crucial role in the population dynamics of *E. sosorum*. The size of an individual is linked to ecological factors that affect its survival probability. For example, aquatic insect predators such as larval damselflies may prey on approximately 0.5" *Eurycea tonkawae* (NB*, personal observation*) although salamanders much beyond that size would likely be too large a prey item. In this sense, larger salamanders have fewer predators. This predator-prey relationship can translate into different population dynamics for different size classes of animal, and perhaps have a greater effect on month-to-month changes in surface abundance than sexual maturity alone. Although we lump both juveniles and adult salamanders in the "adult" (i.e. > 1") category, the size of the individuals may have more to do with survival (and thus, short-term population dynamics) than any developmental changes that occur during sexual maturation.

Ultimately, we recognize that our models are relatively simple for a species with a complex population structure due to the fact that *E. sosorum* are iteroparous, non-seasonal breeders (and in fact, breed year round). The MARSS model requires that the count at time t is dependent on the count at time t-1 (i.e., a Markov process). By separating size classes (and not using the total count), we are modeling adult and juvenile abundances as functions of their previous abundances in the prior month, independent of each other. However, in reality, these abundances are not independent. The implication is that individuals at time t-1 are also recounted at time t, and the difference is due to births/recruitment into the larger size class, mortality, and migration. However, modeling recruitment (for example) simply as a function of the prior month's adult abundance is unrealistic, since it takes more than a single month for a new cohort to reach 1" ("adult" size). Thus, the interpretation of how the abundance at time t is manifested from the state at time t-1 is less clear for this particular analysis than it would be for a non-age structured population, although the Markov assumption is not necessarily unrealistic for age-structured populations (Dennis and Taper 1994).

GLM Data Analysis Methods

We used a generalized linear model (GLM) to examine the effect of environmental covariates on counts and to detect trends in *E. sosorum* abundance from 2004 to 2011 at all four spring sites. This model is designed to fit both trends over time and population fluctuations driven by the covariates. The GLM models were fit using the GENMOD procedure in SAS, which uses maximum likelihood to estimate the parameters. Wald

95% confidence limits were calculated for each parameter estimate and the Wald Chi-square was used to test for significance. AIC scores were used to compare models. Parameters were retained in the model if they improved (lowered) the AIC score even if they were not significantly different from zero. We also examined Pearson residuals of each model to assess model fit.

Model Description and Approach

We modeled salamander counts as negative binomial random variables, instead of using overdispersed Poisson regression, because the negative binomial model had better fit to the data in our initial model tests (results not shown). The negative binomial model, like an overdispersed Poisson, also accommodates overdispersion of counts. Consider a negative binomial multiple-regression of counts on time, with three environmental covariates:

$$\log(count_i) = \alpha + \beta 0 * time_i + \beta 1 * DO_i + \beta 2 * temp_i + \beta 3 * discharge_i .$$

Each population was modeled independently, with unique slope and intercept parameters. The intercept (α) and slope parameters (β) were modeled as fixed effects. We included environmental covariates of temperature, dissolved oxygen (both measured at Parthenia Spring) and cumulative spring discharge (with 0, 1, 3 and 6 month lags) to determine if adding covariates (at various lags) changed our estimate of population trend and improved the GLM models. Interaction effects among the environmental covariates could also be added, however these were excluded in our analyses to reduce model complexity. The $\beta 0$ parameter is of most interest, as this is the trend in counts over time. Due to conventions used by SAS software (SAS institute), time is expressed as the number of days since 1960.

Covariates

Data are typically collected on water temperature, dissolved oxygen, and spring discharge when salamander surveys are conducted at each spring site. Salamander surveys were conducted predominantly on a monthly basis, although some surveys were missed periodically and typically do not fall on the same date of each month. Spring-specific covariate data not collected at exactly equal time intervals made the process of assigning lagged covariates impossible for the corresponding periods of time where surveys were not conducted. Although the same data set for a particular covariate is effectively "shifted" when computing a lag of that covariate relative to a particular survey, the missing data shift as well. Because these missing data are not included in the GLM when a model is fit, this results in several models with different groups of missing data, and thus, different data sets. This essentially results in a propagation of missing data. Computing lagged covariates with missing values is problematic since it precludes our use of AIC as a model comparison tool, as models fit from different data sets cannot be directly compared using AIC. In order to correctly compare models with different sets of missing data, this would require removal of missing data across all rows.

However, continuous data for water temperature and dissolved oxygen were collected from Parthenia spring by the U.S. Geological Survey via a Hydrolab datasonde, and this dataset is relatively complete for the period of interest. The DO concentrations in Parthenia and Eliza are very close, and the DO in Old Mill is fairly consistently offset from the DO at Parthenia (Figure 1). This indicates that although DO values differ among sites, there is a correlation due to the similarity of the source water for each spring (Hauwert et al. 2004) and similar overall environmental conditions affecting each site. Therefore we used covariate data from Parthenia as a surrogate for all sites, rather than throw out a large amount of data, to test site-specific covariates at different lag intervals.

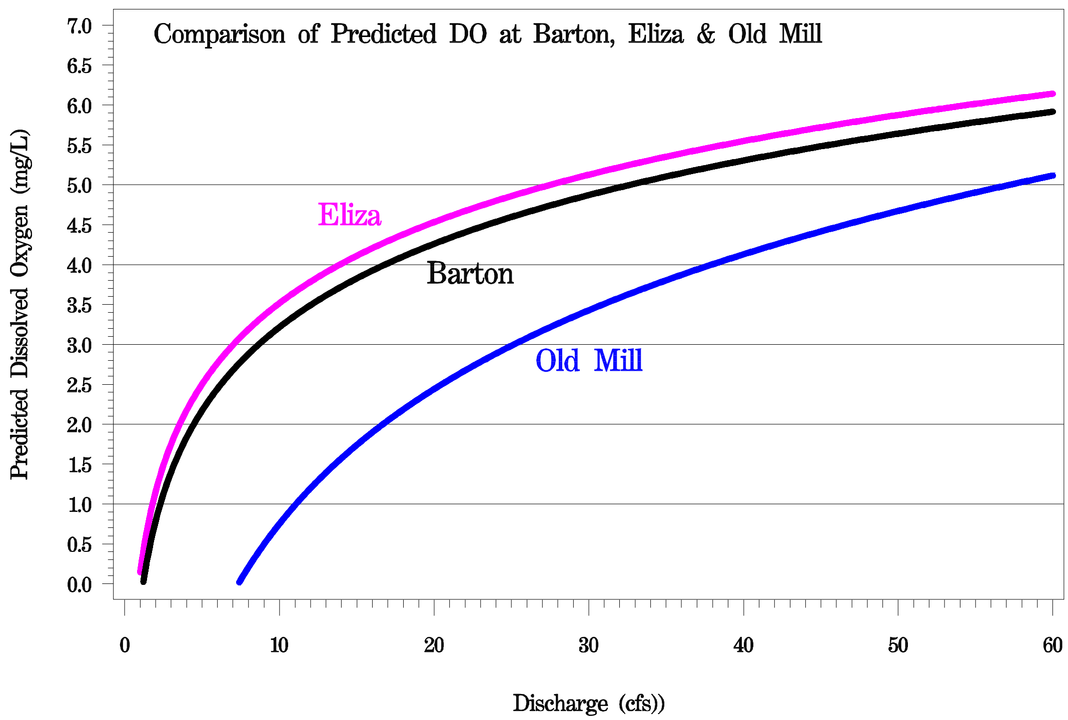

Figure 1. Comparison of predicted values of dissolved oxygen at Eliza, Parthenia (Barton) and Old Mill springs from Turner (2009).

Despite the relative completeness of the data from the datasonde in Parthenia, some missing values did exist. The number of missing temperature data points was small and visual examination of the data indicated that linear interpolation would be an appropriate method to estimate that data. There were larger gaps in the DO data but none in the discharge record. The relationship between discharge and DO is strong (Turner 2009) and was used to estimate the missing DO:

$$DO = -0.25268 + 1.50637 * \text{Ln}(Discharge).$$

The covariates were chosen since they have demonstrated statistical relationships with counts (Turner 2009; Gillespie 2011). We chose the general range of lag periods based on how we suspected salamander migration patterns or changes in population size could be influenced by changes in aquifer conditions in addition to the length of time we suspected these changes would be biologically relevant. For example, favorable conditions might influence salamanders to remain at the surface or migrate to the surface the following month, as we have observed large changes in population abundance not directly attributable to recruitment or population growth alone in relatively short periods of time (Figure 2). Alternatively, population growth may be influenced by favorable conditions, but the amount of time required for salamander courtship, egg-development, egg-laying and hatching may be as little as two months based on observations in captivity (Dee Ann Chamberlain, *personal communication*), but may also take much longer. Because we do not have life-cycle data for wild populations of any central Texas *Eurycea*, we felt six months was a reasonable upper bound.

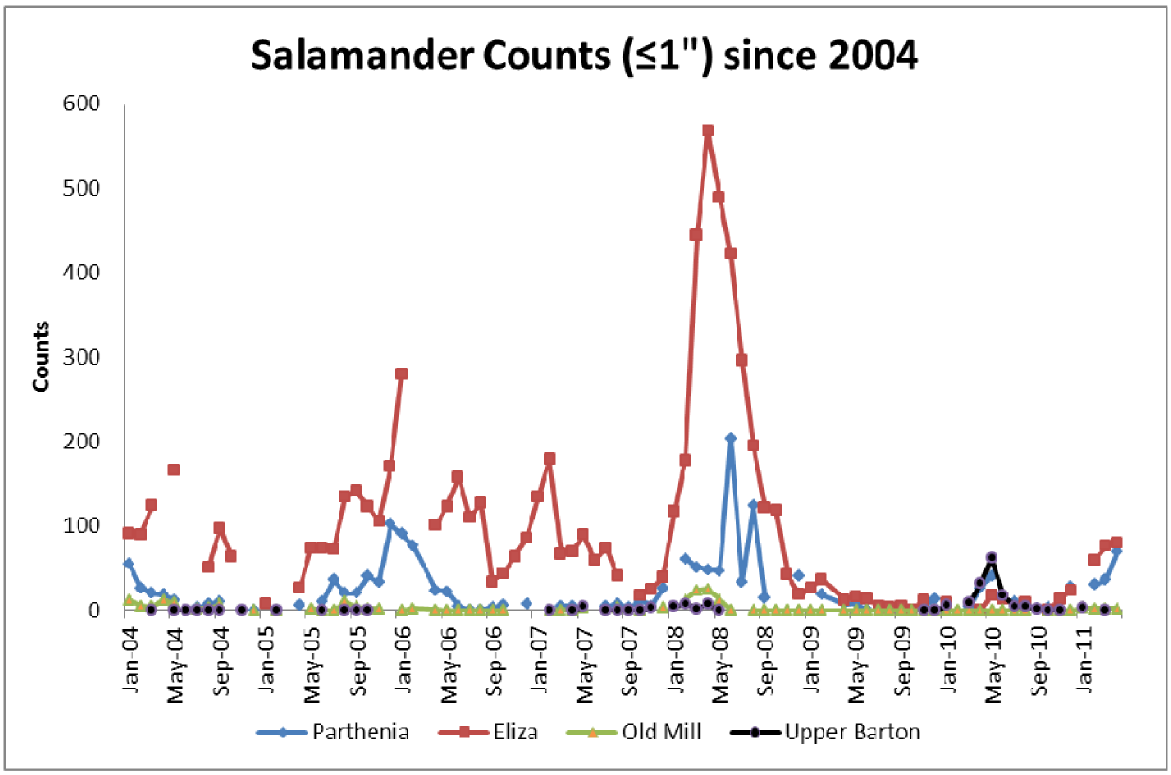

Figure 2. Total counts of salamanders <1" ("juveniles") at the four spring outlets of Barton Springs from January 2004 through April 2011. Gaps in the time series indicate periods where surveys were not performed.

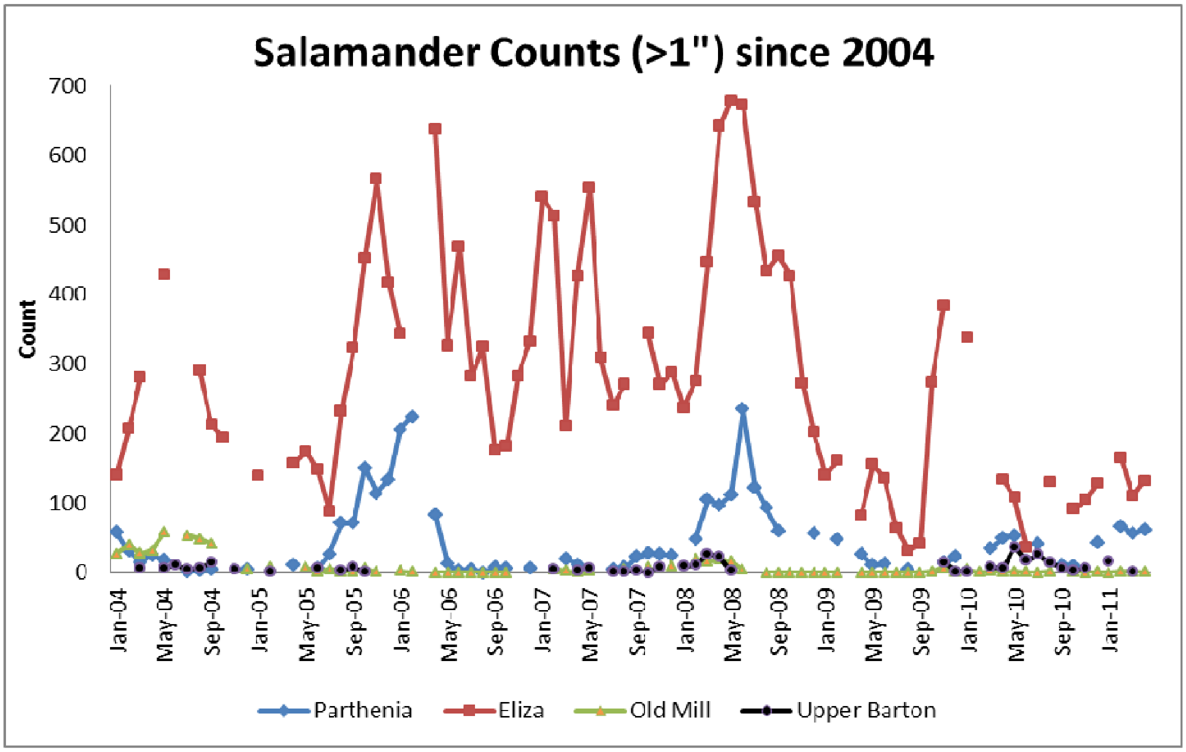

Figure 3. Total counts of salamanders ≥1" ("adults") at the four spring outlets of Barton Springs from January 2004 through April 2011. Gaps in the time series indicate periods where surveys were not performed.

While we can use this model to determine which environmental covariate lags have the largest effect on salamander counts, we forego any specific conclusions about individual covariates. Including environmental covariates in our model allows us to account for these effects while obtaining an estimate of the trend minus any variation in salamander counts that is associated with the stochasticity associated with those covariates. Ignoring the individual effects removes the potential for multicollinearity confounding our interpretation of covariate parameter estimates, which arises from correlation between variables. If trends differ between covariate and non-covariate models, we can attribute those differences to the effects of the covariates, collectively.

GLM Results and Discussion

Including the covariates dissolved oxygen, temperature (both measured at Parthenia Spring), and Barton Springs discharge generally improved overall model fit compared to models with fewer or no covariates. However, inclusion of the covariates did not alter the direction or significance of trend in any analysis. Summaries of the best model for each dataset are shown in Table 1. Summary of best negative binomial GLM models. The trend column indicates whether the temporal trend in salamander counts was significant (α=0.05), and if so, the direction of the temporal trend in counts.

Site	Size	Lag (mo.)	Trend (β0)	Covariates included in Model with lowest AIC	AIC
Parthenia	Adult	6	Not sig.	DO discharge temperature	582
	Juvenile	6	Not sig.	DO discharge temperature	511
Eliza	Adult	0	Decreasing	DO discharge	911
	Juvenile	6	Decreasing	DO discharge temperature	771
Old Mill	Adult	0	Decreasing	DO discharge temperature	334
	Juvenile	6	Decreasing	DO discharge temperature	225
Upper Barton	Adult	1	Increasing	DO discharge	248
	Juvenile	3	Increasing	DO	149

. The explanatory power of non-significant covariates outweighs the additional penalty of an added parameter on the AIC score.

We found no evidence of a population trend in adult (classified as ≥1") or juvenile salamanders at Parthenia. Eliza adult and juvenile populations did exhibit a downward trend, perhaps as a result of the effects of the 2008-2009 drought. The negative trend at Old Mill reflects the higher counts observed at that site in 2004 after which counts slumped to low levels which continue to the present day (Figure 2 and Figure 3). This cannot be ignored as a trend driven by an outlier since higher counts were also observed prior to 2004 (collected under different protocols). In contrast, Upper Barton shows higher counts more recently during high flow conditions in 2008 and 2010, and this is reflected in the significant positive trend at that site. Neither Upper Barton nor Old Mill appear to harbor permanent populations of *E. sosorum* at the surface; Upper Barton frequently dries up, and counts at both Old Mill and Upper Barton are frequently too low to constitute a viable population (< 5 adults). Old Mill and Upper Barton may be population sinks that are periodically inhabited when habitat and aquifer conditions are suitable.

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Upper Barton	Adult	1	Increasing	DO discharge	248
	Juvenile	3	Increasing	DO	149

Table 2. Slope estimates for trend-only negative binomial GLM models. *Indicates trend is statistically significant at α=0.05.

Site	Size	Trend
Parthenia	Adult	0.0000
	Juvenile	0.0001
Eliza	Adult	-0.0003*
	Juvenile	-0.0004*
Old Mill	Adult	-0.0013*
	Juvenile	-0.0007*
Upper Barton	Adult	0.0004*
	Juvenile	0.0019*

Models that included lags on the covariates (DO, temp. and, discharge) performed better overall than non-lagged models most of the time (Table 1. Summary of best negative binomial GLM models. The trend column indicates whether the temporal trend in salamander counts was significant (α=0.05), and if so, the direction of the temporal trend in counts.

Site	Size	Lag (mo.)	Trend (β0)	Covariates included in Model with lowest AIC	AIC
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; APPENDIX B). The lag-6 model (i.e. all covariates have a six month lag relative to salamander count) was the best in half of analyses, indicating that counts at each site are influenced by environmental conditions up to six months prior.

The addition of environmental covariates did not alter the direction or significance of the trend predictions of the GLM models. Any trend observed during this period, therefore, cannot be explained solely by variation in temperature, dissolved oxygen, or discharge, as represented in our models.

Table 3. Parameter estimates (including coefficients of covariates) from best negative binomial GLM models. Shaded values indicate parameter was significant at the α=0.05 level.

Site	Size	Lag (mo.)	Intercept	Time (days)	DO (mg/L)	Discharge (ft^3/sec)	Water Temp. (°C)	Error
Parthenia	Adult	6	-19.2861	0.0002	0.6595	0.0108	0.7212	0.8826
	Juvenile	6	-26.1306	0.0001	0.8877	0.0066	0.0543	0.8772
Eliza	Adult	0	10.1884	-0.0003	0.3516	-0.0123		0.3149
	Juvenile	6	-14.4447	-0.0008	0.9023	-0.0012	1.2723	0.7888
Old Mill	Adult	0	-21.2324	-0.0010	2.5456	-0.0333	1.2920	1.0411
	Juvenile	6	-13.5637	-0.0013	0.5326	0.0311	1.4394	1.7263
Upper Bart.	Adult	1	-8.1451	0.0004	0.8491	-0.0183		0.5318
	Juvenile	3	-28.1925	0.0011	1.4366			1.2242

Plots of the predicted mean counts to the observed counts are shown in Figures 5 and 6. In general, population fluctuations are accommodated by the covariates. However the peak counts during large population increases are frequently under-predicted (see the 2009 predictions). Also there is a period from mid-2004 to mid-2005 when environmental conditions were such that the models predict high counts but observed counts were low. Additional work is needed to determine what factors result in the poor model fit during this period.

The fit for Eliza Spring adult counts differs from the other model fits. During 2006 and 2007 there was a great deal of variation in the adult counts in Eliza Spring that was not explained by the model. A downward trend of the counts was predicted during this period, but population swings are not incorporated. In addition to the fluctuations that were not predicted, the observed peaks during this period were further above the predicted values than the observed minimums were below them. This can be seen in both the plots of the predicted vs. observed counts (Figure 5 and Figure 6) and in the plot of the residuals (Figure 4, Eliza Spring). Factors may be affecting Eliza which are not an issue in the other springs. Salamander density is much higher in Eliza Spring and density-dependent factors (see the MARSS analysis results) may be implicated. Pearson residuals (Figure 4) for the models also indicate model fit is not ideal.

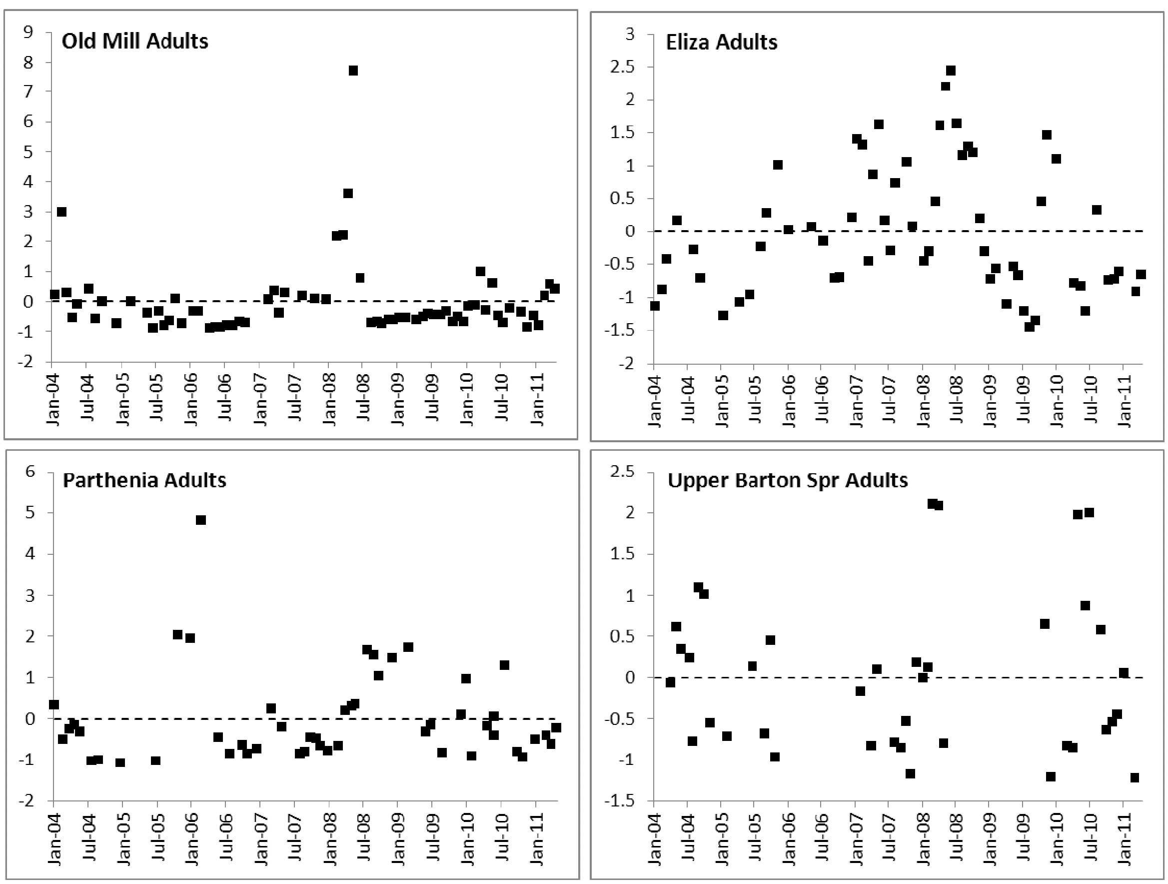

Figure 4. Pearson residuals from the best GLM models of adults for each time series.

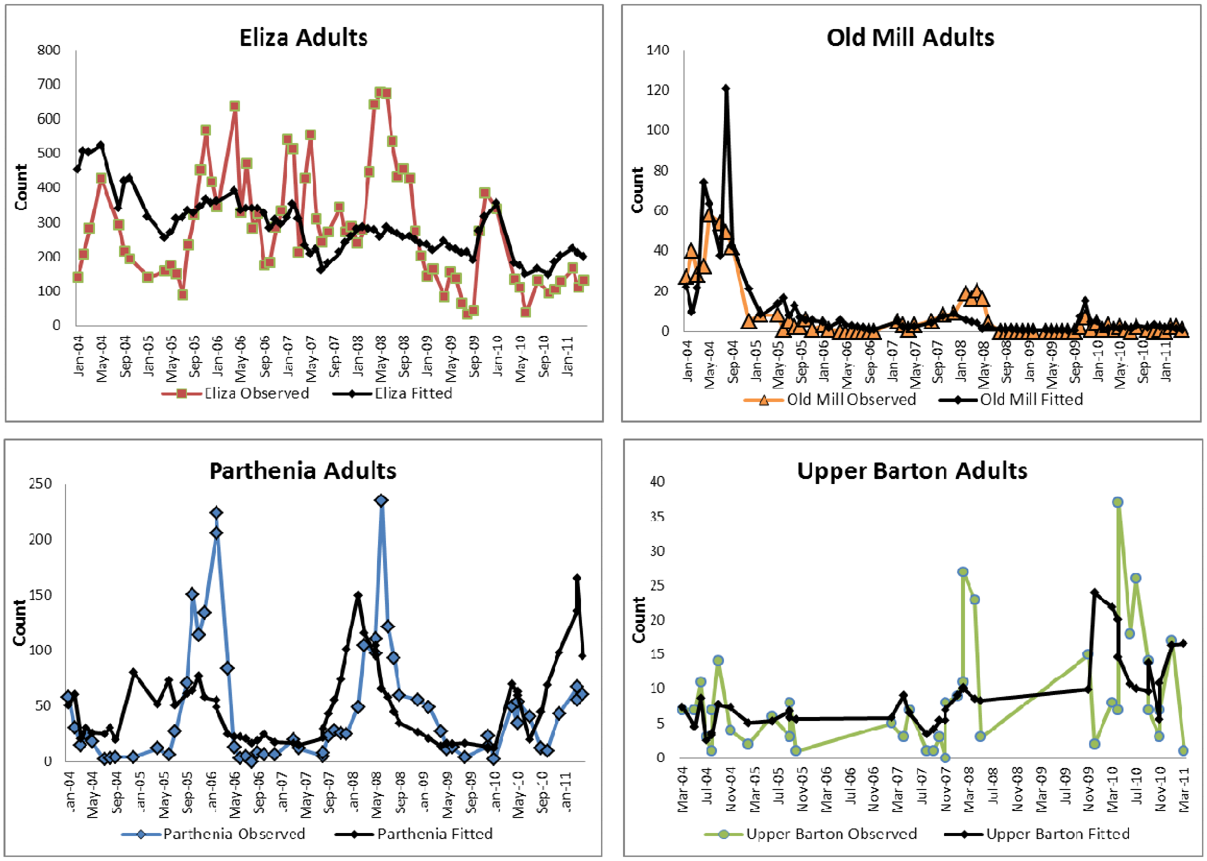

Figure 5. Fitted vs. observed values for GLM models of adult salamander counts.

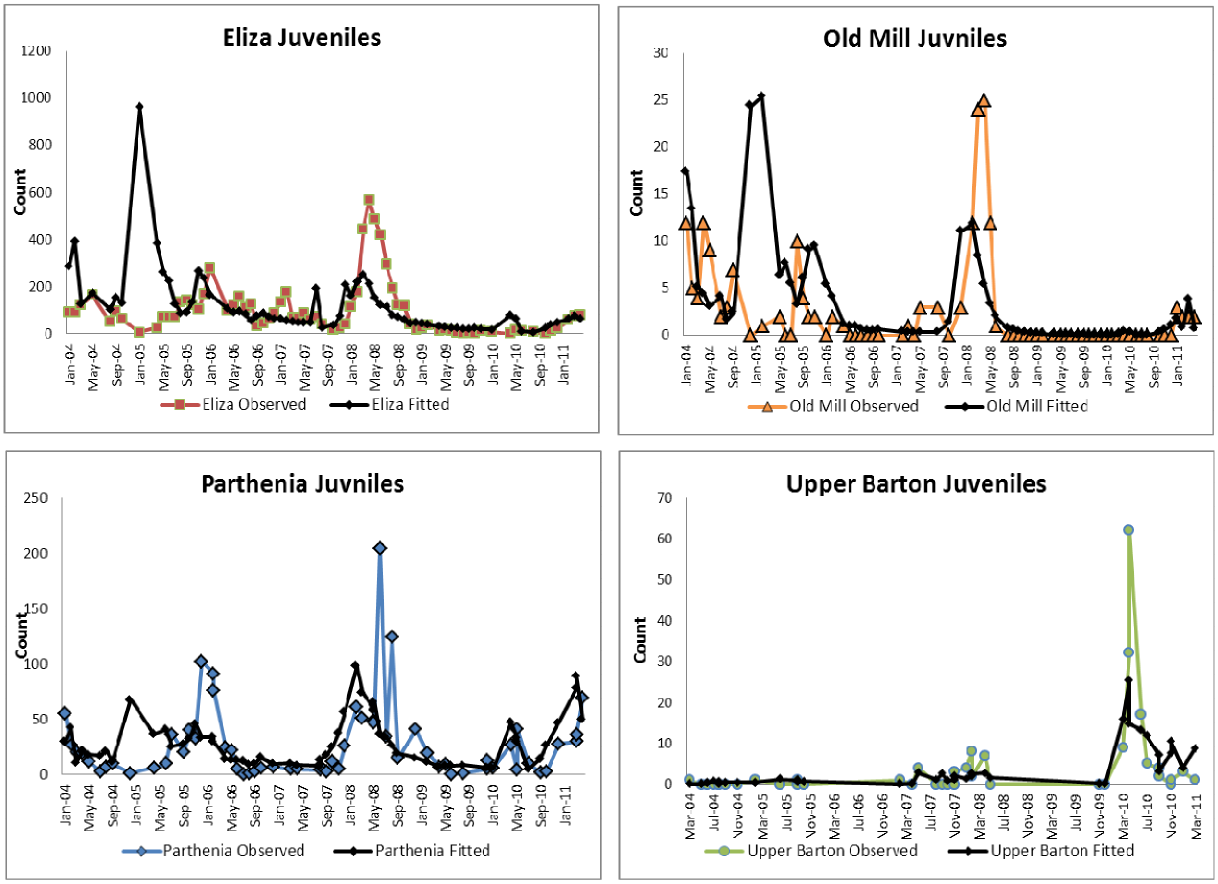

Figure 6. Fitted vs. observed values for GLM models of juvenile salamander counts.

Multivariate Auto-Regressive State-Space (MARSS) Data Analysis Methods

In contrast to the GLM method used above to estimate population trends, MARSS explicitly incorporates serial autocorrelation of the time series data into the model. Additionally, it partitions two types of variation from the time series; one, arising from the natural fluctuations in population size ("process" error) and another, produced by random fluctuations in the observation of the population ("observation" error). The "observation" error is modeled as "white noise" in the data, and is typically interpreted as a result of random differences in the observed vs. the true population, relative to the area being sampled. The "process" error reflects the differences in population size not due to white noise, but a result of changes due to environmental conditions; this error may be manifested by month-to-month changes in survival, recruitment, or migration patterns, i.e. population processes that change the underlying population size.

We use an AIC-based comparison of different MARSS models, explained in more detail below, to determine whether *E. sosorum* populations at Parthenia and Eliza springs are stable (zero-trend), increasing, or decreasing over time, and additionally, whether they exhibit a pattern of density-dependent population growth. Additionally, we use results from the best model to compute a probability of quasi-extinction (a population viability analysis).

Model Description

We implemented our multivariate auto-regressive state-space analysis using the package MARSS (Holmes et al. 2011) in program R (R Development Core Team 2011). The general form of the MARSS model includes two separate models as a hierarchical model with process error and observation error being modeled separately (Holmes and Ward 2011):

$$\text{Process model: } x_i = \mathrm{B}\ x_{i-1} + u\ + w_i \text{ where } w_i \sim \mathrm{MVN}(0,\mathrm{Q})$$

$$\text{Observation model: } y_i = x_i + v_i \text{ where } v_i \sim \mathrm{MVN}(0,\mathrm{R})$$

The observation model describes how the data *y* (the natural log of the salamander count) are related to the unobserved parameter *x* (the "state" parameter; the "true" salamander population size) during month *i*. The matrix R is a variance-covariance matrix that describes the relationship between the observation errors for different time series. For a data set with time series of salamander counts from two sites, the variance-covariance matrix

$$\mathrm{R} = \begin{bmatrix} r_1 & 0 \\ 0 & r_2 \end{bmatrix}$$

indicates that the observation error variance, r_j, is estimated separately for two sites, and these estimates are independent of each other (i.e. there is no covariance).

The process model (a Gompertz growth function; Dennis et al. 2006) describes how the population changes based on the previous population size (x_{i-1}, a Markov process), the overall trend (or mean, if B<1) in population size (*u*), and any unexplained environmental variation (Q).

The matrix Q is also a variance-covariance matrix; it describes the relationship between the process errors for different time series and can be used to specify different population substructures. For example, the matrix below describes the process variances for two time series from independent sub-populations, assuming equal process variances, perhaps because they share similar environmental conditions and prey, but are independent since the populations are not strongly inter-connected by migration:

$$\mathrm{Q} = \begin{bmatrix} q & 0 \\ 0 & q \end{bmatrix}.$$

However, we may also postulate that populations experience different environmental conditions (e.g., surface conditions are very different at Parthenia and Eliza Springs), but fluctuations in salamander abundance are dependent (e.g., good years and bad years are correlated). In this case, the process variance matrix would be

$$Q = \begin{bmatrix} q_1 & c_{1,2} \\ c_{1,2} & q_2 \end{bmatrix}.$$

Thus, we may explore whether errors due to environmental variation are shared among sites or unique by varying the structure of the Q matrix.

The parameter B is a matrix that describes the correlation between the different time series and whether populations exhibit density dependence or not. If we expect each site to be effectively independent (i.e. no direct interactions), we may set the off-diagonals of the *B* matrix to zero for each site. For example, a *B* matrix for two populations with density dependence is

$$B = \begin{bmatrix} B11 & 0 \\ 0 & B22 \end{bmatrix}.$$

However, to specify a random-walk model without density dependence, we set B to equal an identity matrix (1's on the diagonal).

The *u* parameter represents the long-term change in abundance, i.e. the population growth rate when B=1. When B<1, *u* is the population mean (although B and *u* are confounded in this case). We can represent *u* for more than one population as U, an *m x 1* matrix where *m* is the number of time series where *u* is estimated. The parameter (*u*) can be set to zero if the data are demeaned (mean is removed from the data) and B<1, or it can be estimated from the model.

As with GLMs, MARSS models can be compared based on their AIC values. For MARSS models, we use AICb, a small-sample corrector for autoregressive state-space models (Holmes and Ward 2011). The model parameters, confidence intervals, and AICb were calculated using the MARSS package in program R, which provides maximum-likelihood estimation of parameters via an Expectation-Maximization algorithm using the Kalman filter (Holmes and Ward 2011).

Data Manipulation

Several data preparation steps were required to conform to the MARSS modeling framework. Surveys were conducted predominantly on a monthly basis, although occasionally there were deviations from this pattern. The MARSS analysis requires that each unit of time be equivalent, and therefore we assigned each survey to a period corresponding to the month and year when that survey was conducted. However, surveys among different sites are typically 1-3 weeks apart, and so any temporal correlation in the model will be influenced by the adjustment of survey times. That is, a survey conducted at each of the four sites for four different weeks within one month were all treated as being conducted at the same time during that month, when in fact, they were not. This adjustment is a necessity, but should only introduce bias if environmental variation is correlated.

The MARSS model employed here is a Gompertz growth process (e.g. Dennis et al. 2006), which requires taking the natural logarithm of each count. This makes MARSS models a poor choice for datasets with lots of zeros. Because our data sets include zeros, we either added 1 to each value in order to meet the requirements of the Gompertz process, or excluded the time series with many zeros. Data were demeaned to facilitate numerical convergence and parameter estimation.

Counts from Old Mill (a.k.a. Sunken Garden) and Upper Barton Springs were excluded from the MARSS analysis due to the sparseness of the data (Figure 2 and Figure 3). Population survey data from Old Mill contained 26% zeros, and over half of the data contain salamander counts equal to or less than five. Since the MARSS population growth models requires that data are logged, the solution of adding one (since ln(0) is undefined) to all Sunken Garden data points would be excessive data manipulation in our opinion, and likely generate an artificial signal. Ones were added to Eliza and Parthenia data, although very low counts are rare in these data sets, and we do not believe this transformation would unduly alter our results.

The Upper Barton Spring site is intermittent, and ceases to flow when Barton Springs discharge is less than approximately 40 ft^3/s. As a result, 56% of the monthly survey data from Upper Barton are missing values, many of which are consecutive strings, which are likely to result in imprecise parameter estimates for the MARSS model. Thus, this site was also excluded from MARSS analysis. In contrast, count data from Parthenia and Eliza have few zeros, and missing data are less prevalent and more evenly distributed throughout the time series.

Modeling Approach

We compared a suite of MARSS models in order to test 1) how long-term population growth (*u*) varies among sites; 2) whether *u* indicates an increasing, decreasing, or stable population; and 3) whether populations exhibit density-dependence or not. Our approach in first testing for long-term population growth, following a statistical test for density-dependence is similar to the approach suggested by Schmidt and Meyer (2007) as a test for population stability.

Because of the uncertainty about how aquifer conditions (which are correlated among sites; Figure 1) and surface conditions (which can be very different among sites) may affect environmental variability at each site, we tested different models corresponding to different population substructures in relation to their process error (*q*). Hypotheses of population substructure can by tested by specifying different models of the process error, as mentioned above.

We initially estimated observation error (*r*), but found that estimates of observation error (*r*) for Eliza adults consistently dropped to zero for the equal process variance models (see Model Description). In order to remedy this problem, R was fixed using estimates from each time series modeled individually.

Population Viability Analysis

To estimate extinction risk (for adults), we simulated time series data using parameters from the best model. Maximum likelihood parameter estimates from the data were used to simulate 1,000 time series with 50 time-steps (i.e. months into the future) for Eliza and Parthenia populations. We set R=0 and estimated U (which represents the mean of each time series). To calculate the probability of quasi-extinction, assuming the future time series is governed by the same parameter estimates, we calculated the percentage of times each projection fell below the quasi-extinction threshold. We chose a quasi-extinction threshold corresponding to a 90% decline, or 10% of the last population size estimate.

MARSS Results and Discussion

Estimates of *r* for Eliza adults consistently dropped to zero for the equal process variance models, and we therefore fixed R (matrix of *r*, for both sites) in order to generate accurate calculations of the log-likelihood (necessary for AICb calculation). This behavior may be an indication that these models are not suitable for the data, and that estimates of *q* are unreliable in models where *r* slides to zero (Eli Holmes, *personal communication*). However, we also tested R=0 and found no differences in the overall results except minor shifts in AIC values between fixed R, R=0, and R as a free parameter (excluding models that did not converge). The one exception was the single population model, which had a high AICb value of 305 with R as a free parameter, but more than quadrupled when R was fixed (AICb=1422.5, Table). Despite problems with R estimates, observation error appears to be relatively small compared to process error.

Models where U=0 consistently outperformed those with unequal and equal U, indicating that long term population trends are not statistically different from zero (Table and Table 5). We also tested density-dependent (mean-reverting) models, which include estimates of *B*, a density dependence term (*B* is an identity matrix in density-independent models). In this case, models with density dependence consistently outperformed (i.e., they had lower AICc values) density-independent models for both size classes, regardless of the structure of the process variance (Tables 4 and 5).

Table 4. Population substructure MARSS model AIC*b* scores for counts of salamanders ≥1" at Parthenia (site 1) and Eliza (site 2) springs. Observation errors for Parthenia and Eliza were estimated from single site models and are approx. 0.04 and 0.01, respectively. However, fixing the observation error affects estimates of process error. Each model was fit to logged and centered (demeaned) count data.

Population structure	Process Error (Q)	AICb			
		Equal trends (*u1*=*u2*)	Unequal trends (*u1*,*u2*)	No trends (U=0)	Density-dependent (*B*1,*B*2, U=0)
One population	Equal var	1422.5	NA	NA	NA
Sub-populations	Equal var	259.2	261.5	256.8	247.0

Sub-populations	Unequal var	254.9	257.2	252.4	240.6
Sub-populations	Equal var and cov	261.6	263.5	258.6	250.4
Sub-populations	Unequal var and cov	256.7	259.1	254.6	244.2

Table 5. Population substructure MARSS model AICc scores for counts of salamanders <1" at Parthenia (site 1) and Eliza (site 2) springs. Observation errors for Parthenia and Eliza were not fixed, but estimated from each model (not shown). Each model was fit to logged and centered (demeaned) count data.

Population structure	Process Error (Q)	AICb			
		Equal trends (*u1*=*u2*)	Unequal trends (*u1*,*u2*)	No trends (*u*=0)	Density-dependent (*B*1,*B*2, *u*=0)
One population	Equal var	372.3	NA	NA	NA
Sub-populations	Equal var	344.9	347.1	342.7	332.9
Sub-populations	Unequal var	347.1	349.3	344.8	336.2
Sub-populations	Equal var and cov	338.5	340.7	336.3	326.7
Sub-populations	Unequal var and cov	340.7	343.0	338.5	328.9

Although the Gompertz model is a relatively simplistic model of density-dependent population growth, these results highlight the possibility that *E. sosorum* population dynamics are regulated to some degree by density. However, large shifts in adult abundance over short periods of time (e.g. 50% between one month periods; Figure 2), and adult populations recovering from very small (or even zero) counts suggest that densities are not only affected by changes in mortality and recruitment, but also by temporary migration patterns. This makes drawing conclusions about the extinction risk of these populations difficult. On the one hand, high variability in population size and/or low population sizes that are encountered during poor conditions such as droughts can translate into high extinction risk. However, if migration to and from the surface habitat accounts for a significant portion of the variability we observe, an estimate of extinction risk based on these data will be negatively biased.

The PVA for Eliza spring resulted in an estimated quasi-extinction probability of <1% over the next 50 months, based on a quasi-extinction threshold of 13 adult individuals. The most recent count of adults in Parthenia for our data set was 61 individuals, and a 90% decline corresponds to six individuals. The PVA based on simulated future realizations of the Parthenia time series resulted in a quasi-extinction probability of approximately 86%. However, counts have reached six individuals or lower nine times in 61 surveys (including one zero count), and these slumps have been followed by observations of over 200 individuals. Thus, we need only look at the actual data set to see that "quasi-extinction" has been reached multiple times at Parthenia without the population actually going extinct, exemplifying the futility of computing a population viability metric for count data that are not a complete census, and in fact, may be a drastic underrepresentation of the true size of the "superpopulation."

However, it is important to clarify what we mean by "complete census" and superpopulation size. A complete census, in this case, is referring to a census which includes all individuals of the metapopulation of *E. sosorum* for a particular spring site. By our definition, this includes individuals at the surface (the sampled area), but also those not currently present at the surface (i.e. temporary migrants), consistent with the concept of a superpopulation from capture-mark-recapture theory (e.g. Kendall 1999). Changes in migration, births and deaths will likely be manifested in the model as process error, assuming these perturbations do not follow the white-noise model of observation error. Our result of low observation errors for Eliza and Parthenia (r=0.01 and r=0.04, respectively) may indicate that surface counts do not suffer from large amounts of error, and that the large swings in population size we observe in the counts are due to real changes in the population size at the surface, but may or may not be due to real changes in the superpopulation.

Despite large swings in population size that can result in numbers of adults fewer than 10% of the average population size, the lack of evidence for any long-term trend in population counts combined with the indication of density-dependence increases our confidence in the viability of *E. sosorum*. This is because populations that reach densities near carrying capacity are less subject to demographic stochasticity, which can be a very important factor in the extinction rate of small populations (Lande 1993; Morris and Doak 2002). However, when population sizes become smaller during large swings in population size of *E. sosorum*, demographic stochasticity is more likely to have a substantial effect on the population. What is unknown, however, is how large the superpopulation is when surface counts do reach low levels during these fluctuations. Very low count totals followed by a population recovery, in addition to several-fold increases in population size between one month survey intervals (e.g. after a dramatic increase in spring discharge; data not shown), suggest that migration to and from the surface (i.e. temporary migration) probably plays a role in the pattern of counts we observe. How much the pattern of migration is exaggerating the observed declines in surface counts is a critical question, because we do not know how small the true population size is, and therefore, how vulnerable it may be to the effects of demographic or environmental stochasticity. This information is necessary in order to determine if long periods of low surface density are a threat to *E. sosorum* population viability.

Table 6. Maximum likelihood parameter estimates and confidence limits from 1000 bootstrap replicates. Estimates for Eliza and Parthenia are indicated by "E" and "P", respectively. B=density dependence; Q=process variance. Observation errors for Parthenia and Eliza were estimated from single site models and are approx. 0.04 and 0.01, respectively.

Param	*ML.Est*	*Std Error*	*2.5% CI*	*97.5% CI*	*Est.Bias*	*Unbias.Est*
B.P	0.842	0.653	0.662	0.924	0.01672	0.852
B.E	0.773	0.0724	0.593	0.877	0.01484	0.788
Q.P	0.393	0.0874	0.234	0.590	0.00334	0.396
Q.E	0.178	0.0307	0.117	0.234	0.00414	0.182

Relative to the other sites, higher population counts (Figure 2 and Figure 3), lower variation in population size (*q*), and stronger density dependence (B; Table) at Eliza suggest that this surface population has the least risk of extinction. This comparison, however, is only valid if the relative surface abundances can be compared equally among all sites. For example, do surface counts at Eliza represent a different proportion of the total population than for Parthenia? Additional information is required to determine the extent of migration between the surface and subsurface, how these migration patterns change according to environmental conditions, how they affect the ratio of surface abundance to total population size at each site, and whether they explain the pattern of density-dependence.

Whether the density-dependent pattern observed is manifested from migration patterns or birth and death processes, it is also important to determine what environmental factors may drive the surface population abundance. If some environmental variable is the primary driver for *E. sosorum* surface abundances, identifying which covariates are important should improve model adequacy, as it did for the GLM, and lead to a more comprehensive understanding of *E. sosorum* population dynamics. Alternatives to the use of data from Parthenia as a surrogate for covariate data for all sites to facilitate model comparison using different lags should be explored. A potential solution may be incorporating covariates in a future MARSS analysis, which will allow us to model the observation processes of covariates. Additionally, we may also extend the MARSS model presented here to include higher-order density dependence (e.g. King et al. 2009). Serial dependence in the data goes beyond a single time step, and this should be addressed in future modeling efforts. The survey frequency is likely smaller than the generation time for *E. sosorum* (at least several months; City of Austin, unpublished data), and there is some evidence of cyclicity in adult populations (particularly Parthenia) from auto-correlation plots (e.g. Figure 7; Gillespie 2011).

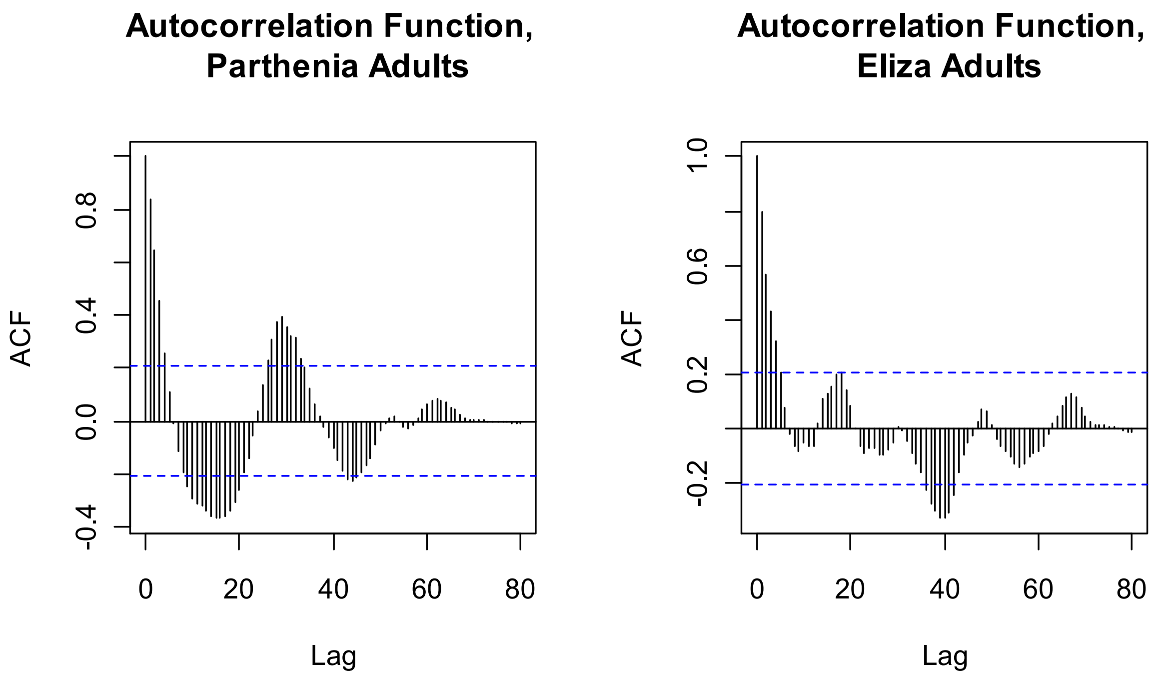

Figure 7. Autocorrelation plots of adult time series at Parthenia and Eliza. Bottom axis represents number of time steps. Missing data were interpolated using the spline function in R.

Model Comparison

The MARSS approach has several advantages over the GLM, as used here. The MARSS model explicitly specifies the serial dependence structure of the data within the state process. Furthermore, the ability to test for density dependence using MARSS is another advantage over our GLM approach. However, some evidence of cyclicity (Figure 7) may negatively affect MARSS model fit (Holmes and Ward 2011). Alternative methods may be more appropriate for dealing with cyclicity (e.g. Holmes 2001), or alternatively, identifying which factors are driving the cycles (e.g. some environmental covariate).

The ability to partition observation from process error is another theoretical advantage of the MARSS approach, although the Eliza and Parthenia data did not exhibit a substantial amount of observation error compared to process error. However we refrain from drawing any conclusion about the differences in observation error since R was forced to zero in some of the models, and this may be an indication of poor model fit. It may also indicate that in general, observation error is typically low for these data. Identifying which factors are driving these population dynamics may solve the *r* variance estimation problem (Eli Holmes, *personal communication*). Inclusion of environmental covariates in the regression analysis improved most models, and we suspect this will be the case for a future MARSS analysis as well.

Pearson residuals for adult count data indicate potential problems with the GLM fit, with the exception of Upper Barton Spring (Figure 4). The MARSS models did not indicate any statistically significant trends among the time series analyzed. In contrast, the GLM model indicated significant negative trends for both size classes at Eliza.

One advantage of the GLM approach we used is that it did not require our raw counts to be log-transformed, allowing us to model the population trends at Sunken Garden and Old Mill without the need to induce overly-aggressive data manipulation (i.e. adding 1 to count data changes small counts by a large proportion). Although our GLM model did not incorporate any parameters to account for serial dependence in the data, we will explore this option in the future. However, incorporation of environmental covariates was very straightforward. Despite GLM model fit being less than ideal, we are confident that model improvements due to the addition of environmental covariates at various lags were real, and information from the GLM models will be useful in guiding future analyses of these data.

Future Analyses

Future analyses will include the addition of covariates in MARSS modeling as well as the inclusion of other, potentially informative covariates. Additional covariates may help partly explain the pattern of density dependence, such as data on predator-prey interactions which are not currently available. The GLM models use a distributional assumption that is more realistic for count data, although our implementation did not accommodate serial dependence (an assumption of the model). Future analysis may include an auto-correlation structure and/or additional smoothing parameters to help improve model fit.

The MARSS model, as implemented here, only includes an AR1 dependence structure. Future analyses should test for higher-order density dependence (e.g. King et al. 2009). Because the resolution of our observations is at a much finer scale than the generation time for *E. sosorum*, it is likely that population density is regulated by population sizes in periods beyond the previous month.

Conclusions

Trend analysis using MARSS do not indicate any significant temporal trends in adult or juvenile salamanders at Eliza or Parthenia Springs, the most frequently inhabited *E. sosorum* sites, suggesting that *E. sosorum* populations were stable (not having a long-term population decline or increase) from 2004 to 2011 at these sites. In contrast to our MARSS results, the GLM models indicate declining trends for Eliza and Old Mill.

The negative trends predicted by the GLM are likely influenced heavily by lower salamander abundances during two consecutive extreme droughts at the end of the sampling period. It is possible that changes in environmental stressors, such as DO dropping to levels below those we think occurred in historical droughts (Turner 2004), are altering the previously observed cyclic patterns in salamander populations. A historically stable population cycling around a mean can be adversely affected by the addition of a new stressor. Changing environmental stressors could result in a population that maintains the same mean but has larger swings, the population mean could reset to lower levels or the population could become no longer viable.

Both Old Mill and Upper Barton are only sporadically inhabited by salamanders or inhabited at very low densities for long periods of time, making estimation of population dynamics difficult. The Old Mill time series contains frequent low- or zero-count survey results, while Upper Barton Spring frequently runs dry, resulting in many missing data points. These missing data and zeros made it difficult to practically use MARSS models for these sites. The GLM method was more amenable to zeros and missing data, and indicated a strong downward trend for Old Mill adults and juveniles. The slope, which indicates the strength of the downward trend, was 4 times larger at Old Mill than at Eliza. Dissolved oxygen concentrations fell below lethal levels (Woods et al. 2010) at Old Mill for extended periods in 2006 and 2008-2009 (Turner 2009). Further examination of the potential sources for the observed decline at Old Mill may aid in preventing similar declines in other sites.

The GLM of the Upper Barton data showed an increase in juvenile and adult counts since 2004. The surface at this site goes dry when combined Barton Spring discharge is less than 40 ft^3/s. It remains to be seen if the higher counts will be found at this site when the current drought ends. Improvements in the GLM model, possibly including the addition of new covariates to the GLM to account for factors driving the observed density-dependent suggested by the MARSS model, are needed to better evaluate the observed declining population trends and improve GLM model fit.

Non-significant trends and density-dependent growth patterns indicated by the MARSS models indicate that the Eliza and Parthenia populations have fluctuated around an equilibrium population size during the years 2004-2011. The strength of density-dependence was stronger for Eliza adults than Parthenia, but Eliza also exhibited a higher mean population size and lower variability. In comparison, Eliza may be more robust to due to its higher mean population size and lower variability. Since both juvenile and adult time series exhibited a density-dependent growth pattern, we suspect that combining both size classes would not significantly alter our conclusions. However, we recognize that an ideal analysis would incorporate the age or stage structure of this data, and complications in the interpretation of density dependence may arise from inherent lags in individual development and life history (see Lande et al. 2006).

The discovery of density-dependence in *E. sosorum* populations at Eliza and Parthenia is an important one, because small populations that are close to extinction typically do not exhibit density-dependent population growth (Morris and Doak 2002). Although density-dependence does not guarantee population viability, it is a positive indicator of population viability compared to a small, density-independent population that cannot reach a carrying capacity.
If *E. sosorum* populations are periodically reaching carrying capacity, habitat size or habitat quality may be the limiting factor and future improvements to habitat should correspond to increases in population size.

These results increase our confidence in the viability of *E. sosorum,* particularly for the Parthenia and Eliza populations, although our optimism must be tempered by several factors. First, although our time series were relatively long (61 and 71 time-steps respectively for Parthenia and Eliza, excluding missing data), they only encompass 7 years of monitoring data. We purposely excluded additional data available from Parthenia and Eliza in this analysis because we were interested in comparing sites during similar conditions (see Appendix A for more detail). Such a short time period (seven years) may not be adequate for assessing the long-term viability of this species.

Second, the effects of the 2008-2009 drought can be seen in the raw counts (Figure 2 and Figure 3), and the populations do not appear to have fully recovered. Future data and analyses will shed some light on whether this drought event, along with the current drought of 2011, has any long-term effects on the population dynamics of *E. sosorum.*

Third and perhaps most importantly, threats to water quality and water quantity of Barton Springs still remain. While the declining water quality of Barton Springs is well documented (Herrington and Hiers 2010; Mahler et al 2011) this point bears repeating. Because *E. sosorum* is endemic only to Barton Springs, its future viability depends upon sustaining the Barton Springs Segment of the Edwards Aquifer as a clean and permanent source of water, a future condition that is far from certain.

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Appendix B. Conservation Measures Rationale

The conservation program described in the body of the Habitat Conservation Plan (HCP) is a set of measures to minimize and mitigate detrimental effects on *E. sosorum* and *E. waterlooensis* of the operation and maintenance of Barton Springs Pool and Upper Barton Spring for public use. Each measure is a mechanism for reaching an explicitly stated minimization or mitigation goal. This document describes the scientific information that supports the assumption that the measures will meet the stated conservation goals.

Identification and development of the measures in the amended HCP were based on data and information gathered since implementation of the first HCP approved by the Service in 1998. Many of the new or modified measures are based on evaluations of the effectiveness of measures in the previous HCP. The primary focus of the previous HCP was ensuring short-term survival of protected salamanders by limiting actions that would have immediate lethal effects, with a secondary focus on non-lethal effects that influence long-term persistence of the species (*e. g*., reproduction and recruitment). Implementation of most of the measures in the previous HCP was successful in reducing mortality and guiding the acquisition of critical scientific information. The amended HCP builds upon the knowledge and experience acquired since 1998 by shifting the focus to species persistence while maintaining the measures that successfully reduce mortality. In some cases, the benefits of a particular measure are obvious, while the benefits of others require closer examination. Described below is the information used to develop and support the measures in the amended HCP. For each of these measures, we present below the conservation goal, measures whose benefits may not be obvious, and the rationale supporting each of these measures. The measures are considered in numerical order.

6.1.1 The City will maintain habitat for *Eurycea sosorum* and *Eurycea waterlooensis* by maintaining or restoring natural ecosystem characteristics, the native aquatic species community, and an ecologically-healthy, native riparian community to the greatest extent feasible.

6.1.1.1 The City will develop written habitat management plans for each spring site within one year of permit issue. These plans will include ongoing activities to improve the quality of aquatic habitat and ecosystem health. This includes but is not limited to introduction of native aquatic plants and maintenance of adequate tree canopy cover. Habitat management plans will be provided to the Service for review. The City will revise these plans with the written or verbal approval of the Service as necessary.

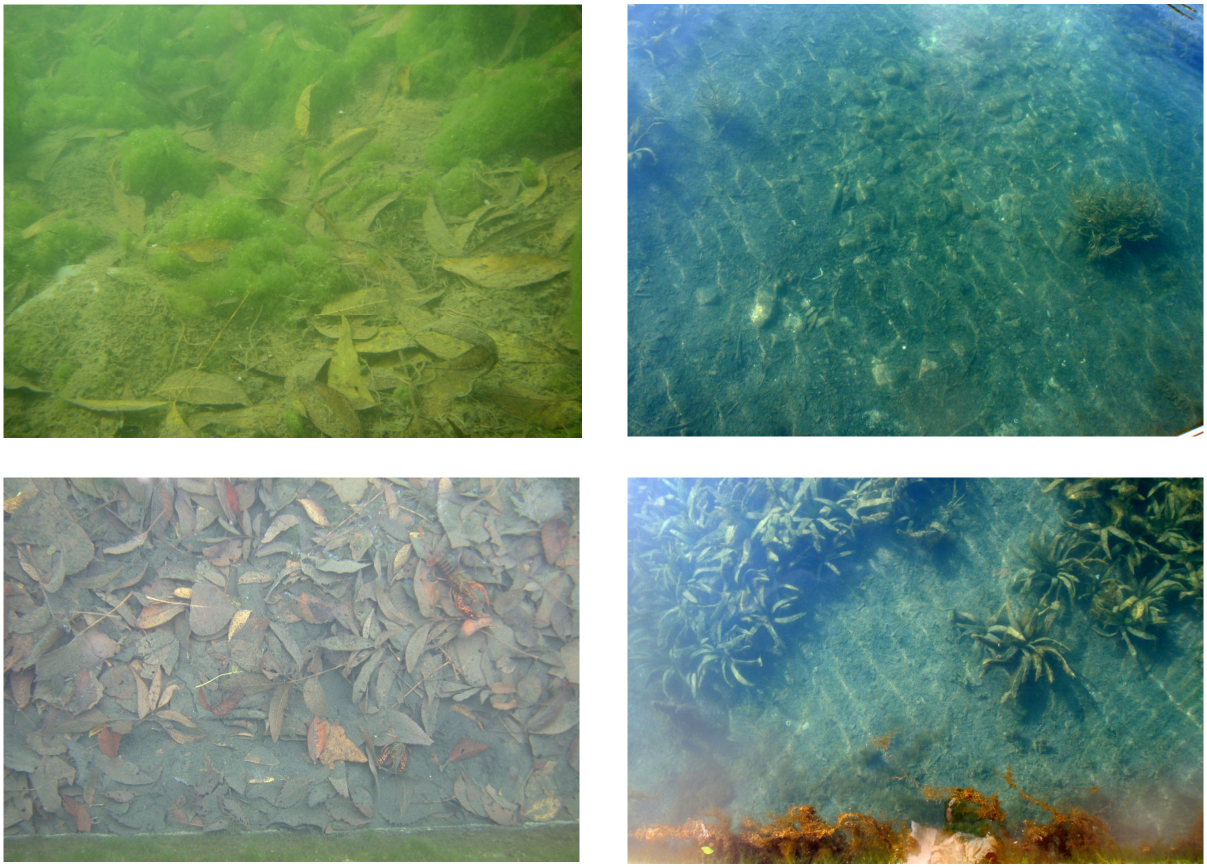
<u>Justification:</u> Written habitat management plans provide a clear framework for improving habitat. The success of these plans can be readily evaluated by staff of the Service, the City, and other interested parties (see HCP section 6.5 Adaptive Management). The plans can also be easily revised based on these evaluations.

6.1.1.2 With the verbal or written approval of the Service, the City will redraw the footprint of protected salamander habitat in Barton Springs Pool (Figure

16) to include more habitat that is, and can be maintained as, suitable for salamander residence and exclude unsuitable habitat based on monitoring data and habitat condition. The total square footage of protected habitat in Barton Springs Pool will not be less than that delineated in the previous Habitat Conservation Plan.

Justification: Redrawing the footprint of protected salamander habitat in Barton Springs Pool will allow for inclusion of more area associated with groundwater flowing from Parthenia Spring, while excluding an area distant from the spring that is chronically poor quality habitat where no salamanders reside. The footprint of protected salamander habitat in Barton Springs Pool in the previous HCP included some of the area where groundwater exits the aquifer (Parthenia Spring) and a large area along the north wall of the Pool channel, known as the Beach (HCP Figure 12). Since the lowering of the substrate elevation the Beach in 2000, habitat quality of a large portionof the Beach downstream of Parthenia Spring (Beach 2 and Beach 3, HCP Figure 12) has degraded. Deeper water has reduced the speed of water flow, large amounts of sediment are deposited during floods and periphytic algal abundance is low while nuisance algal abundance is high (Figure B1, Colucci 2009). In 2011, mean sediment depth and percent of area covered by sediment this portion of the Beach were 6.6 inches (169.6 mm) and 89 %. Both values are much higher than depth and cover in Eliza Spring in 2011, 0.35 inches (9.0 mm) and 40.7%, respectively. Deeper sediment, greater percentage of sediment cover, and less periphyton are all factors associated with lower salamander abundance in Eliza Spring (Appendix A).

Figure B1. Substrate of downstream portion of the Beach, showing deposited sediment. Though algae and leaf litter are present, the accumulated sediment makes the habitat unsuitable for salamanders.



Downstream sections of the Beach are chronically unsuitable for salamander residence and no salamanders have been found in these areas since implementation of several measures in the previous HCP in 2000. Repeated efforts to manually clean habitat of these areas of the Beach over the past 15 years have been unsuccessful and a recent study of the effects on habitat of mechanically re-circulating water along substrate (Colucci 2009) illustrated the limitations of this approach to improving habitat. It is not realistic to assume that repeated cleaning will result in persistently good habitat for salamanders in this area.

However, there is an area of fissures of Parthenia Spring that was excluded from designated habitat in the previous HCP. These fissures are located along the south wall of the channel immediately downstream of the diving board (HCP Figure 16.) Mean sediment depth and percent sediment cover are less than sections 2 and 3 of the Beach, 1.1 inches (27.0 mm) and 76%, respectively. Furthermore, habitat in these fissures can be further improved because they can be, and often are, cleaned regularly, along with the rest of primary salamander habitat of Parthenia Spring. In contrast with the downstream portion of the Beach, salamanders have been observed in and around these fissures since 1998. Since these fissures carry spring water flowing from the aquifer and salamanders are already found there, they are already more suitable as salamander habitat. It is also more feasible to maintain and improve habitat condition in these fissures. Therefore, replacing the downstream portion of the Beach with this habitat area is more likely to result in a larger area of suitable habitat, and thereby foster higher salamander abundance in Parthenia Spring.

6.1.1.3 The City will be responsible for the management of aquatic and riparian habitats of:

a. Barton Springs Pool and Parthenia Spring (fissures, springs, and Beach habitat; Figure 1),
b. Eliza Spring (spring pool, outflow pipe and/or stream; Figure 1),
c. Old Mill Spring (spring pool and outflow stream; Figure 1),
d. Upper Barton Spring (spring and outflow streams; Figure 1).

Justification: This measure clearly delineates the habitats included in this Habitat Conservation Plan, which allows for clear allocation of resources.

6.1.1.4 The City will continue improvement and maintenance of suitable substrates in salamander habitat. If replacement of rocky substrate of salamander habitat is necessary, the City may use only limestone gravel or cobble in order to maintain the natural groundwater buffering of karst aquifers.

Justification: In the past, large amounts of concrete, granite, and other non-limestone rock have been added to the surface substrate in Barton Springs Pool, Eliza Spring, and Old Mill Spring. These types of materials do not occur naturally in Barton Springs and do not react with water the same way as the natural limestone of the Edwards Aquifer. The natural limestone influences chemical characteristics of groundwater in epigean and subterranean habitats of *E. sosorum* and *E. waterlooensis* (Culver and Pipan 2009, Wetzel 2001). The limestone buffers acidic rainwater as it travels underground through the aquifer, resulting in neutral or nearly neutral pH (reviewed in Culver and Pipan 2009). Natural geochemical reactions of limestone and water result in high concentrations and super-saturation of dissolved carbon dioxide (Benavente *et al*. 2010), and under-saturation of dissolved oxygen relative to surface waters (Nelms and Harlow, Jr. 2003). *Eurycea* species endemic to Barton Springs have evolved under these conditions and would likely be stressed in un-naturally acidic water or unnatural dissolved gas compositions, as is typical of other freshwater vertebrate species (Moyle and Chech 1988, Pierce 1985 and references therein). Anthropogenic activities can increase acidity of rainwater (Patrick *et al*. 1981). This can affect the groundwater feeding Barton Springs by lowering pH and altering dissolved gas composition (Schindler 1988, Petrin *et al*. 2008). Alterations in dissolved gas composition affect respiration of *E. sosorum* (Woods *et al*. 2010) and *E. waterlooensis* (L. Dries and D. Chamberlain personal observations), which can affect survival and reproduction. Therefore, if replacement or addition of rock to substrate of Barton Springs is necessary, materials should be limited to naturally occurring local limestone to retain or enhance natural geochemical processes typical of karst aquifers.

6.1.1.5 The City will make visual inspections of all protected habitat areas (spring sites when flowing) at least four days a week. City of Austin Parks and Recreation Department staff will be present at Barton Springs Pool when it is open and will visually inspect Parthenia Spring daily. Inspections will note any problem conditions such as vandalism, trash, or debris, introduction of exotic fish or animals or disturbance of habitat. If problems are discovered, the City will take appropriate action to protect salamanders and their habitat. Appropriate actions may include but are not limited to repairing damage from vandalism, removal of trash, and removal of introduced exotic fish.

Justification: Prompt identification and remediation of problems helps minimize or prevent detrimental effects on salamanders and their habitat. Based on experience accrued since the 1998 permit was issued, City biologists have determined that inspections four days per week are sufficient to quickly identify and respond to changed conditions. The presence of Pool staff during operational hours and high visibility of the habitat areas to park users likely to notify the City if unusual conditions are observed provides an additional level of surveillance. The reduction in site inspection frequency will enable City biologists to spend more time in monitoring, restoration, data processing and data analysis activities.

6.1.1.7 a. **The City will clean salamander habitat as necessary** to keep at least the upper 2-3 inches of habitat from becoming embedded with sediment. Easily observable or measurable characteristics of physical habitat (e.g., embeddedness, sediment depth or percent sediment cover) will be used as benchmarks for determining when to clean.

Justification: The cleaning described in this measure is designed to mimic some of the natural flushing that occurred during base flows and average flood flows before any impoundments of Parthenia, Eliza, and Old Mill Spring were built. Periods of high and low water flow are a natural characteristic of the Barton Springs/Barton Creek ecosystem. Shallower creeks have faster water velocity and consequently, greater natural power that creates the layer of clean, rocky substrate required by Barton Springs' *Eurycea*. In the present-day, dams cause deeper water and slower water flow in Barton Springs Pool, and prevent water from Barton Creek from passing through except during large floods. Thus, the dams inhibit the gradual beneficial flushing and redistribution of sediment and debris provided by un-impounded free-flowing water from both the spring and the creek. The amphitheaters surrounding Eliza and Old Mill springs also inhibit natural current velocity and contribute to excess sediment deposition. Thus, routine cleaning is necessary to maintain habitat that is suitable for occupancy by Barton Springs' *Eurycea*. In addition, cleaning that entails using spring water from Barton Springs ensures that potentially toxic contaminants present in drinking water (e.g., chlorine, chloramine) are not introduced into the aquatic habitat.

b. **All salamander habitats will be cleaned with the spring water of Barton Springs** at pressures not to exceed 30 lb/in^2 at the substrate and/or suspend rocks larger than 4 inches in diameter. Water for cleaning may be obtained by recirculation through submersible pumps, or other methods acceptable to the Service.

<u>Justification</u>: The previous HCP prohibited the use of "high-pressure hoses" in salamander habitat regardless of actual water pressure experienced by salamanders. The important factor in salamander protection during routine cleaning is the pressure of the water and consequent disturbance of substrate, not the type of hose. Acceptable water pressures for cleaning are those that protect salamanders from injury and keep habitat sediment free, regardless of the type of hose used. The limits on water pressure and particle size in this measure are based on methods used by the City that have resulted in no observed salamander mortalities and very few observations of live salamanders disturbed by cleaning (< 10 since 2004). The water pressure criterion of 30 lb/in^2 (approximately 0.06 ft^3/s) is based upon the maximum water pressure produced by the 1 horsepower, submersible pumps used by the City since 2003. The particle-based criterion for identifying suitable water pressure allows for incorporation of variation in water depth, discharge, distribution, and future observations of effects on salamanders, into choice of cleaning methods and equipment.

6.1.2 The City will minimize the entry of anthropogenic pollutants detrimental to salamanders or their habitat into Barton Springs Pool and Eliza, Old Mill and Upper Barton Spring.

6.1.2.1 The City will reduce loadings of petroleum hydrocarbons, heavy metals and sediments to Barton Springs from current development and other activities located within the Barton Springs Zone in areas subject to the City's jurisdiction. This reduction in loadings will be achieved through the measures set out in the City's Stormwater Management Plan as required by the City's Texas Pollutant Discharge Elimination System (TPDES) storm water permit. The City's TPDES Stormwater Management Plan includes specific monitoring and protection measures for the Barton Springs Zone to protect the water quality of Barton Springs.

6.1.2.2 The City will control local surface water runoff around Barton Springs Pool, Eliza Spring, Old Mill Spring, and Upper Barton Spring to the maximum extent practical. Runoff of storm water can carry sediment and potential pollutants directly into Barton Springs Pool and adjacent springs, which could adversely affect aquatic life. Stormwater may be diverted away from Barton Springs Pool or treated using structural best management practices prior to entering Barton Springs Pool. Runoff protection improvement projects will not have adverse effects on salamanders or their habitat. These controls do not include storm water runoff collecting in Barton Creek that causes basin-wide flooding that can inundate the springs.

<u>Justification:</u> One of the primary threats to Barton Springs' *Eurycea* is degradation of water quality resulting from actions that occur within the Plan Area and in the watershed that feeds Barton Springs. Urban development and other anthropogenic activities can

carry pollutants into storm water that enters the aquifer and creeks in the Barton Springs Zone and travels to Barton Springs. Therefore, protection of water quality adjacent to and within the Plan Area, and in the watershed that feeds Barton Springs is a critical component of salamander conservation. The City monitors and reduces pollutant loads in storm water to the maximum extent practicable according to a Storm Water Management Plan associated with a Texas Pollutant Discharge Elimination System stormwater discharge permit. The Storm Water Management Plan describes various methods to control degradation of water quality from urban development; operation and repair of roadways; application of pesticides, herbicides, and fertilizers; flood control projects; illicit and improper discharges; and pollutant spills. In addition, the City implements Best Management Practices to control quality of storm water runoff from areas adjacent to the springs.

6.1.3 The City will change operation and management procedures at Barton Springs Pool to restore and/or maintain as much as is feasible the natural flow regime of a central Texas spring-fed stream system for *Eurycea sosorum* and *Eurycea waterlooensis*. This will help maintain natural and artificial selection on these species favoring adaptive responses to current and future variation in surface water flows and disturbance. The natural flow regime includes variation in water depth, velocity, and turbulence within the channel associated with variation in aquifer discharge, surface water flood and base flows.

6.1.3.1 The City will restore and maintain more natural flow regimes in Barton Springs Pool, Eliza Spring, and Old Mill Spring by modifying, replacing or removing existing infrastructure. Restoration of free-flowing spring pools and overland streams at Eliza and Old Mill springs will improve and enlarge surface salamander habitat and improve habitat quality. Restoration of a more natural flow regime in Barton Springs Pool by modification and/or replacement of dams, modification of the bypass culvert infrastructure, and suitable changes in management activities will improve aquatic habitat quality and ecosystem stability, as well as provide maximum operational flexibility. The City will develop plans for these restoration projects and, with concurrence of the Service, implement restoration. Flow regime improvements will not compromise water quality during baseflow.

Justification: See HCP sections 2.3, 3.2, 4.8.1, and 4.9 for more information related to this measure.

6.1.3.2 The City will allow floodwater to pass through Barton Springs Pool as unimpeded as is feasible to restore or maintain a more natural disturbance regime, which includes increased water velocities that inhibit excess settling of sediment and debris within the Pool confines. This will also reduce the need for dredging or other removal of accumulated flood debris from the Pool, thereby reducing potentially detrimental impacts of such projects on salamanders or their habitat. Some floodwater may continue to flow around the Pool in the bypass culvert. Prior to opening the gates in the downstream dam in preparation for potential flooding, Pool staff will confirm with

City biologists that Eliza Spring is properly prepared according to the Drawdown Plan. In the event of a flash flood or potential flash flood, Pool staff will prepare the Pool grounds for flooding and coordinate with City salamander biologists in conducting flood-related drawdowns. The City may open dam gates for all floods according to procedures described in the Drawdown Plan.

Justification: Flooding is a naturally occurring event in Barton Creek and Barton Springs Pool (See HCP section 2.3). Currently the dams and bypass culvert inhibit floods of less than 500 ft^3/s from naturally passing through Parthenia Spring and associated salamander habitat. Allowing the rapidly-flowing floodwater to move through Barton Springs Pool would mimic natural disturbance regime. Disturbance is an important feature of streams and rivers (Resh *et al*. 1988, Poff and Ward 1989, Gordon *et al*. 2004 and references therein), and was a natural characteristic of the Barton Springs complex prior to anthropogenic flow regime alteration. Restoration of disturbance that mimics historical natural conditions would be beneficial to salamander habitat by allowing suspended materials to flow through or settle more naturally. Allowing floods to flow more freely would also shorten residence time of floods within the confines of the dams of Barton Springs Pool. Some floodwaters will continue to flow around the Pool in the bypass culvert until feasible future modifications are developed and implemented with the approval of the Service. Safety issues associated with the bypass culvert in 2012 were addressed separately from this permit amendment.

6.1.3.3 The City, with concurrence of the Service, will develop and implement a plan for routine silt and gravel removal from the deep channel of the Pool downstream of Parthenia Spring that does not compromise the continued survival of covered species. The Pool is bounded by upstream (southwest) and downstream (northeast) dams across Barton Creek. These dams cause accumulation of aquifer-borne silt as well as flood-borne silt and gravel within the Pool confines, altering flow regime and natural geomorphic processes. Removal of this material from the deep channel of the Pool has been and will continue to be necessary until the dams are modified, replaced, or removed. The plan will describe when the removal of material will occur and focus on vacuum dredging or other minimally invasive methods approved by the Service. The plan will be in place within one year of the issuance of this permit.

Justification: The presence of dams causes excess deposition of sediment, rock, and other materials in the deep channel of Barton Springs Pool near the downstream dam. Removal of this material is a necessary component of restoring a more natural flow regime because it restores the natural geomorphology of the channel. Although improvement of flow regime through modifications of the dams is a goal of the amended HCP, implementation is not expected in the near future. Removal of flood debris will continue to be necessary in the near future. More frequent, smaller dredging projects using low intrusion methods are preferable because they impose less short-term anthropogenic disturbance of salamander habitat, while fostering long-term improvements in flow regime (HCP Figure 15). Smaller intrusions can be accommodated by the ecosystem more easily than large intrusions. A written plan allows the proposed methods to be reviewed and revised by the Service and the City.

6.1.3.4 The City will maintain a Drawdown Plan, which will provide standard operating procedures for use when Pool water elevation is drawn down. This plan requires the approval of the Service and will be in place at issuance of permit. The Plan will be updated periodically with concurrence of the Service.

6.1.3.5 The City will not conduct a full drawdown of the water level in Barton Springs Pool if the combined discharge of the Barton Springs complex is less than 54 ft^3/s without consultation and verbal or written concurrence of the Service. This measure is intended to prevent dewatering of surface habitat of Eliza Spring. When discharge is equal to or greater than 54 ft^3/s, water can be maintained in surface habitat of Eliza Spring during a full drawdown, based on current substrate elevation. The 54 ft^3/s threshold can be revised with the approval of the Service if habitat restoration or changes in substrate elevation allow maintenance of wetted surface habitat at lower discharges.

6.1.3.6 Approval from a City Salamander Conservation Program salamander biologist is necessary before the water level in Barton Springs Pool may be drawn down under any flow conditions.

6.1.3.7 When water level in Barton Springs Pool is drawn down for cleaning and maintenance, trained and permitted City salamander biologists and staff under their direct supervision **will visually inspect all exposed habitat for stranded salamanders** before cleaning and maintenance activities in those areas begin. Any stranded salamanders will be moved to permanent water. Water level in Eliza Spring will be inspected to ensure that water is retained in surface habitat of the spring pool.

6.1.3.8 A minimum of two City salamander biologists will be present when a full drawdown is conducted for cleaning and maintenance, and a minimum of one City salamander biologist will be present when a partial drawdown is conducted for cleaning and maintenance.

6.1.3.9 The City may conduct 4 full drawdowns per year exclusive of floods, when the combined Barton Springs complex discharge is at least 54 ft^3/s at the time of drawdown. Exposed habitat will be kept wetted with spring water or creek water while staff searches for stranded salamanders. The City will maintain water over the fissures area during drawdown for cleaning in order to minimize the stranding of salamanders. After the fissures area has been searched for stranded salamanders, the area may be allowed to dry and be cleaned.

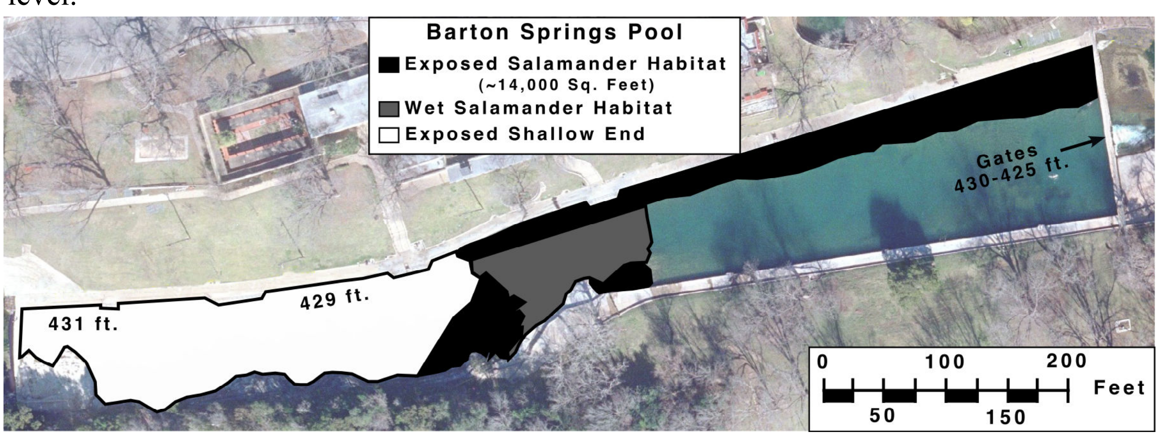
6.1.3.10 The City may conduct eight partial drawdowns per year exclusive of floods when the combined Barton Springs complex discharge is equal to or

greater than 54 ft^3/s. If the discharge is less than 54 ft^3/s, partial drawdowns will only be conducted in consultation with the Service. The water depth over the beach will be maintained at greater than or equal to 12 inches and surface habitat in the adjacent perennial springs (Eliza and Old Mill) would not be allowed to go dry. This measure will minimize the impact of low aquifer levels at the adjacent perennial spring sites.

<u>Justification for conducting drawdowns 6.1.3.4 – 6.1.3.9:</u> The goal of these measures is to minimize harm to salamanders or their habitat resulting from drawdowns of water level in Barton Springs Pool for routine or flood-related cleaning. The major potential short-term detrimental effect is stranding of salamanders due to repaid dewatering of surface habitat in Eliza Spring and the fissures of Parthenia Spring. The keys to avoiding this effect are recognizing the aquifer conditions appropriate for drawdowns, and controlling rate of water recession during a drawdown. Properly conducted drawdowns allow exposure of substrate in the shallowest areas of Barton Springs Pool for cleaning, while retaining water in deeper salamander habitat. Procedures for conducting drawdowns have improved considerably since the early 1990s.

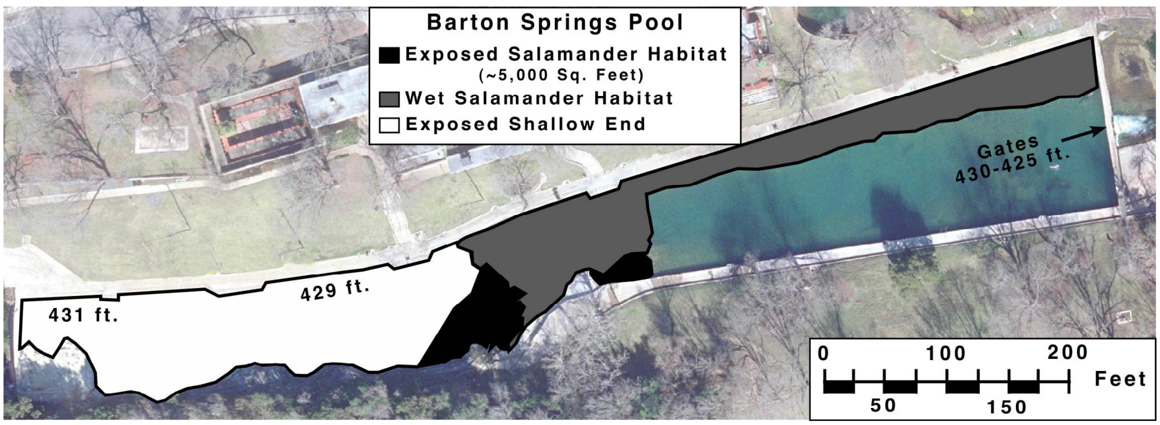
Prior to issuance of the previous HCP in 1998, weekly routine cleaning of shallow areas of the Pool was accomplished by conducting frequent (from daily to weekly), rapid, and full drawdowns of water level in the Pool. This was accomplished by removing the plates that blocked the rectangular openings in the downstream dam, which exposed shallow areas of the Pool (Figure B2, white and black areas) for cleaning. These plates could not be used to adjust the size of the openings and how quickly water was released through the dam. Unfortunately, these rapid drawdowns also stranded Barton Springs' salamanders (*E. sosorum*) in Parthenia and Eliza Spring as water receded from the areas of habitat that are higher in elevation than the bottom of the openings in the downstream dam (Figure B2).

Figure B2. Barton Springs Map of Areas Exposed During Full Drawdown Prior to 1998. Elevation of the concrete floor in Eliza Spring ranges from 432 – 433 feet mean sea level.



In 1998, data on the number of salamanders stranded in all spring sites during drawdowns were used to demonstrate take resulting from cleaning of Barton Springs Pool. These data underlie several measures in the previous HCP (6.3, 6.4, 6.6, 6.7, 6.8, 6.10, 6.11) designed to minimize stranding of salamanders. The measures limited the number of drawdowns, minimized the amount of salamander habitat exposed, and provided mechanisms for controlling drawdowns so that only the shallow end of the Pool would be exposed. The amount of salamander habitat exposed was reduced by lowering the elevation of the Beach to less than 425 feet above mean sea level and prohibiting drawdowns under aquifer conditions that would cause Eliza Spring surface habitat to go dry (Figure B3).

Figure B3. Barton Springs Map of Areas Exposed During Full Drawdown after 2000. Elevation of the concrete floor in Eliza Spring ranges from 432 – 433 feet mean sea level.



The measures in the previous HCP also suggested installation of water control devices to limit exposed area to the shallow end of the Pool. Adjustable gates were installed in the downstream dam and City staff tried to use temporary cofferdams across the Pool between the shallow upstream (Figure B2 white area) and deep downstream areas (Figure B2 gray area). The temporary cofferdams were not effective as they could not be anchored securely and the shallow end could not be de-watered without also opening the dam gates.

In contrast, judicious use of adjustable dam gates are an effective method for controlling magnitude and rate of water drawdown, and limiting exposed area to the shallow end of the Pool. Since the substrate in the Pool slopes downward from the upstream shallow end to the downstream deep end, when the dam gates are opened any amount gravity will drive the water from the higher shallow end to lower deep end and out through the dam. Since the dam gates are adjustable and can be opened slowly (at least 15 minutes to open all 4 gates), they could be used to expose variable amounts of the shallow end and to control occurrence and rate of water recession from downstream salamander habitat. In addition, partially obstructing the outflow from Eliza Spring could help retain water in surface habitat during drawdowns.

To determine how to use the adjustable gates to expose variable amounts of substrate in the Pool, City staff used data collected from 2004 – 2008 during full drawdowns and

Service-approved partial drawdowns associated with routine cleaning. All drawdowns were conducted when Barton Springs' discharge was ≥ 54 ft^3/s. Partial drawdowns were conducted monthly throughout 2004. During these partial drawdowns, gates were opened gradually until desired decrease in water level was reached (18-24 inches less than normal elevation). Approximately 1,500 ft^2 of salamander habitat in the fissures was exposed (HCP Figure 14), surface habitat of Eliza Spring did not go dry, and water depth in Old Mill and Upper Barton springs did not change (not shown).

Data were collected on the amount dam gates were opened (as measured by number of turns of threaded gate shafts), the resulting decreases in water level in Barton Springs Pool, and number of stranded *E. sosorum* in all of the spring sites (Table B1). Barton Springs' discharge data were provided by the U.S. Geological Survey. These data were used to develop an equation (Figure B4a) that estimates how much to open the gates in future drawdowns and still minimize stranding of endangered salamanders. They were also used to determine rate of water recession during drawdowns (Figure B4b). In 2005, the gates were re-seated in their slide brackets, which required collection of new data from to refine the previously determined equations.

Using these equations to guide use of adjustable gates and obstructing outflow from Eliza Spring has resulted in significantly fewer stranded salamanders during both partial and full drawdowns (Mann-Whitney $U = 29.0$ $z = -4.573$, $p < 0.0001$). Prior to installation of adjustable gates in 2001, the mean number of salamanders stranded during full drawdowns was 20 (± 10 s.e., N = 15). The mean for full and partial drawdowns after 2001 is 2 (± 1 s.e., N = 36). The mean time elapsed until desired extent of drawdown has increased significantly ($U = 39.5$, $z = -3.043$ $p = 0.0021$) from 80 minutes (± 13) before 2001, to 310 (± 150) after 2001. The mean rate of drawdowns since 2003 is 0.283 in/min (± 0.053 s.e., max = 0.703, min = 0.064). There are no data on rate of water recession prior to 2003, but, based on anecdotal information, the general rate was 48 inches in 80 minutes, or 0.6 in/min.

Figure B4. (a) Logarithmic linear regression of number of turns required to open dam gates to draw down the water level a desired amount, given a particular aquifer discharge. (b) Linear regression of water recession rate.

a.

b.

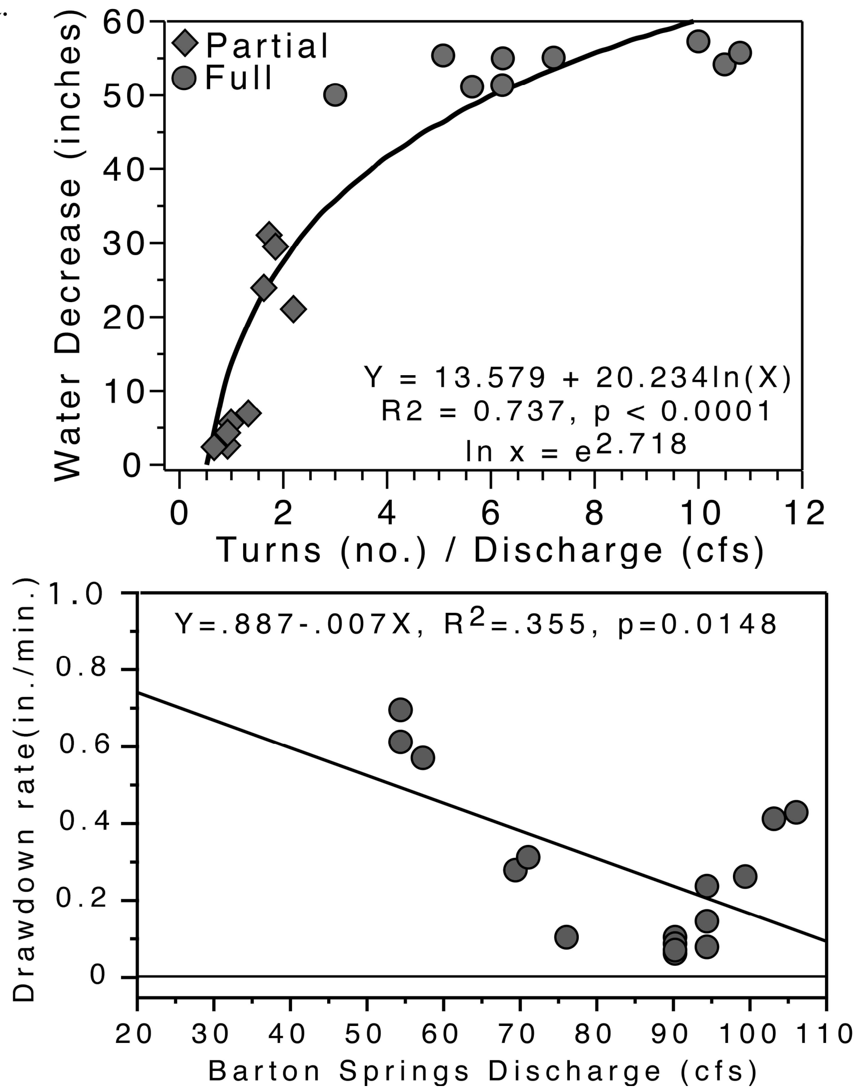


Table B1. Barton Springs' salamanders stranded during full and partial drawdowns associated with routine cleaning conducted from 2003 to 2008 using adjustable dam gates and obstructing outflow from Eliza Spring. Missing data are indicated by a dash (-). All salamanders observed were the Barton Springs Salamander (*Eurycea sosorum*) except where noted. An asterisk (*) denotes *Eurycea waterlooensis*.

Date	Site	Water Level Decrease	Aquifer Discharge U.S.G.S. (ft^3/s)	Number Stranded	Number Re-located	Number Collected Live	No. Died
Full Drawdowns							
10/28/04	BSP	46″	70	1	1	0	0
″	Eliza	?		0	0	0	0
2/28/05	BSP	48″	100	1*	0	1*	0
″	Eliza	0″		0	0	0	0
5/5/05	BSP	50″	103	0	0	0	0
″	Eliza	6″		0	0	0	0
8/25/05	BSP	55″	69	2	2	0	0
″	Eliza	?		0	0	0	0
10/6/05	BSP	55.5″	54	0	0	0	0
″	Eliza	6″		0	0	0	0
2/19/07	BSP	55.5″	65	0	0	0	0
″	Eliza	6″		0	0	0	0
5/4/07	BSP	54.9″	100	0	0	0	0
″	Eliza	10.5″		0	0	0	0
8/16/07	BSP	48″	106	0	0	0	0
″	Eliza	0″		0	0	0	0
3/3/08	BSP	55″	57	0	0	0	0
″	Eliza	22.6″	57	0	0	0	0

Table B1 (cont.). Barton Springs' salamanders stranded during full and partial drawdowns associated with routine cleaning conducted from 2003 to 2008 using adjustable dam gates and obstructing outflow from Eliza Spring. Missing data are indicated by a dash (-). All salamanders were the Barton Springs Salamander (*Eurycea sosorum*) except where noted. An asterisk (*) denotes *Eurycea waterlooensis*.

Date	Site	Water Level Decrease	Aquifer Discharge U.S.G.S. (ft^3/s)	Number Stranded	Number Re-located	Number Collected Live	No. Died
			Partial Drawdowns				
5/8/03	BSP	18″	102	0	0	0	0
	Eliza	-		0	0	0	0
6/19/03	BSP	20″	96	0	0	0	0
	Eliza	-	96	0	0	0	0
7/17/03	BSP	31″	89	1	0	1	0
	Eliza	-	89	0	0	0	0
3/3-3/8/04	BSP	9.5″	43	1	1	0	0
	Eliza	10″	43	0	0	0	0
4/29/04	BSP	31″	60	0	0	0	0
	Eliza	0″	94	0	0	0	0
7/8/04	BSP	31″	94	0	0	0	0
	Eliza	0″	94	0	0	0	0
7/22/04	BSP	4″	98	0	0	0	0
	Eliza	0″	98	0	0	0	0
7/29/04	BSP	2″	97	0	0	0	0
	Eliza	0″	97	0	0	0	0
6/9/05	BSP	23.75″	94	0	0	0	0
	Eliza	3.47″	94	0	0	0	0
7/7/05	BSP	22.52″	90	0	0	0	0
	Eliza	?	90	0	0	0	0
8/4/05	BSP	21″	76	0	0	0	0
	Eliza	0″	76	0	0	0	0
5/24/07	BSP	31.5″	99	0	0	0	0
	Eliza	3.18″	99	0	0	0	0
Total				8	6	2	0
Average				0.27	0.2		0

These results confirm that controlling the rate at which water level recedes is an effective means for reducing endangered salamander stranding and mortality. This is further supported by results from the March 2008 drawdown during which half of the surface habitat in Eliza Spring became exposed unexpectedly over several hours, yet no salamanders were stranded (Dries 2009). In this case, rate of water loss of 0.02 in/min was sufficient for salamanders to retreat to wetted areas with the receding water. In fact, at the end of the drawdown as the water level began to increase in Eliza Spring, City staff observed a Barton Springs salamander returning from subsurface to surface habitat through one of the holes in the concrete substrate.

The data and information presented here indicate that the adjustable dam gates provide precise and predictable control of drawdown magnitude and rate of water recession under a large range of discharge conditions. Moreover, their use has greatly minimized salamander stranding. These methods allow for more efficient routine cleaning in the shallow end of the Pool without causing additional incidental take of endangered salamanders. Thus, the adjustable gates are effective water-control devices that obviate the need for a permanent physical barrier in the shallow end of the Pool. Furthermore, permanent structures across the Pool would contribute to degradation of salamander habitat by altering the natural flow regime of a spring-fed stream (Cushing and Allan 2001, Spellman and Drinan 2001, Wetzl 2001, Giller and Malmqvist 1998, Leopold *et al*. 1992), as the existing dams do currently.

<u>Justification for increasing the total number of drawdowns:</u> Prior to approval of the previous HCP, the speed, frequency, and extent of drawdowns were directly detrimental to *E. sosorum* and *E. waterlooensis*. The limitation on the number of full drawdowns, installation of adjustable dam gates, and lowering the substrate of the Beach of the previous HCP, along with the City's improvements in how drawdowns are conducted, have been effective in eliminating frequent direct harm to salamanders.

However, this approach fails to consider that drawdowns also have a beneficial effect on the aquatic environment and its resident flora and fauna. Barton Springs Pool is part of a flowing water system. The obstruction of water flow imposed by dams has shifted the aquatic environment in the Pool away from that of a creek. The long-term effects of flow regime alteration have now become apparent. The majority of the aquatic habitat resembles a pond rather than a stream, with expected increases in nuisance algae and unnatural sediment deposition. Drawing down the water level in the Pool restores some of the natural water flow of creeks and rivers. The increased flow velocities of creeks and rivers are the dominant feature that separates them from lakes and ponds (Leopold *et al*. 1992, see HCP Section 2.3).

Fortunately, the adjustable gates in the downstream dam provides the City with a tool to reverse this trend in the Pool. As summarized earlier, the City can use these gates to partially drawdown water level, while exposing a smaller amount of salamander habitat than during full drawdowns. Just as in full drawdowns, when the water level decreases during partial drawdowns, water speed increases, and water flow is drawn from upstream to downstream more strongly. Thus, it creates a more natural flow regime, which would improve the aquatic environment and foster increased salamander abundance (Appendix A Dries 2012)

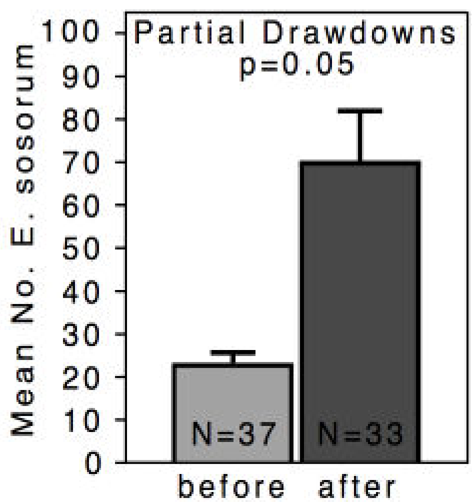
There is evidence suggesting partial drawdowns are beneficial. Barton Springs Salamander (*E. sosorum*) abundance in Parthenia Spring was significantly higher after monthly experimental partial drawdowns were conducted (2004 – 2006) versus before (1998 – 2003) (Mann-Whitney $U = 444$, $z = -1.959$, $p = 0.05$; Figure B5b). This result is consisted with an increase in *E. sosorum* abundance in Eliza Spring since flow regime reconstruction in 2003 (Figure B5a, Appendix A Dries 2012, City of Austin 2004, City of Austin 2005, City of Austin 2006). In 2003, stream-like habitat was reconstructed in Eliza Spring by excavating water inflow and outflow openings and lowering the water level. The result is a statistically significant increase in annual average *E. sosorum* abundance (Mann-Whitney $U = 78.5$, $z = -7.59$, $p < 0.0001$) and density (Mann-Whitney $U = 2.0$, $z = -3.487$, $p = 0.0005$) and statistically verifiable recruitment of juveniles (Spearman Rank $\rho = 0.502$, $z = 2.3$, $p = 0.015$) in to the adult population.

Figure B5. (a) Mean (± s.e.) annual salamander abundance in Eliza Spring from 1995 to 2008. (b) Mean annual salamander abundance from 2004 to 2006 in Parthenia Spring (BSP).

a) Eliza Spring

Year	Mean	s.e.
1995	23.0	5.6
1996	7.7	8.2
1997	25.8	12.5
1998	14.9	5.2
1999	6.6	4.0
2000	1.6	2.7
2001	4.1	2.4
2002	4.5	2.5
2003	39.8	44.2
2004	350.6	124.1
2005	345.3	192.7
2006	453.4	169.5

b) Parthenia Spring



The results in Eliza and Parthenia Spring clearly indicate how important flowing water is to the persistence and health of *E. sosorum*, and by inference, *E. waterlooensis*. Flowing water also fosters greater abundance and diversity of the invertebrate prey of these salamanders. It also inhibits accumulation of nuisance algae and sediment, and thereby reduces the amount of time Pool staff spend cleaning. Finally, a more natural flow regime fosters the return of a stable, resilient stream ecosystem that can support a diverse aquatic community and provide abundant salamander prey (Cushing and Allan 2001, Giller and Malmqvist 1998).

With the advances in controlling rate of drawdowns of the Pool and the demonstrated decrease in incidental take despite the addition of partial drawdowns, the City has the tools to improve flow regime for temporary periods of time using the existing dams and adjustable gates. Partial drawdowns are necessary to protect the aquatic environment and endangered salamanders while the City explores the potential to permanently improve the flow regime by improving current dams and other man-made structures at Barton Springs Pool. Therefore, conducting gradual, partial drawdowns of water level in the Pool more frequently, rather than relying on four full drawdowns annually, would improve habitat quality and would not impose incidental take above that already permitted.

Finally, a partial drawdown could also help mitigate the effects of a catastrophic spill that threatens to extirpate *E. sosorum* in the wild. The effects of entry of some contaminants into Barton Springs Pool could be mediated or minimized by opening the dam gates. This would reduce the water residence time within the Pool area and limit time of exposure to the contaminant. Even small openings in the gates would be of benefit at lower discharges when dilution is expected to be low and if the contamination precludes salamander rescue.

Therefore, conducting eight partial drawdowns annually, in addition to four full drawdowns, would improve habitat quality and would not compromise viability of the Barton Springs and Austin Blind Salamander or increase harm or harassment of salamanders residing in Parthenia and Eliza springs.

6.1.4 The City will restore and/or maintain more natural flow regimes in Barton Springs Pool, Eliza Spring, and Old Mill Spring to the maximum extent feasible by modifying, replacing or removing existing infrastructure. Restoration of free-flowing spring pools and overland streams at Eliza and Old Mill springs will improve and enlarge surface salamander habitat and improve habitat quality. The City will develop plans for these restoration projects with the verbal or written approval of the Service prior to implementing restoration. Flow regime improvements will not compromise water quality during baseflow (City of Austin 2011b).

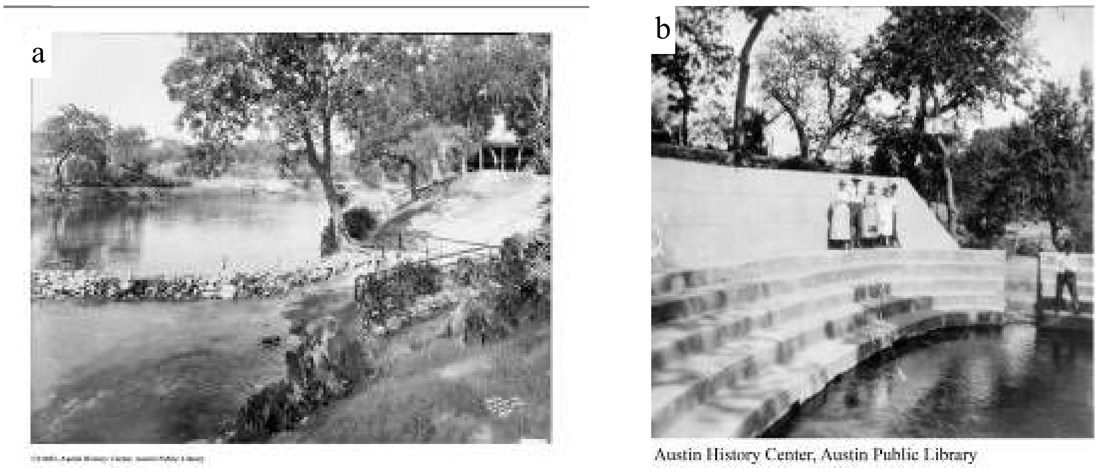
6.1.4.1 Eliza Spring flow regime improvement will be implemented to the maximum extent feasible to recreate historical salamander habitat by restoring the surface outflow stream. Presently, the outflow from the spring is routed through an underground pipe into the Barton Springs Pool bypass culvert and ultimately into Barton Creek downstream of Barton Springs Pool; there is no surface stream. The underground pipe is proposed to be "daylighted" and a natural surface stream created in its place. The new stream will be protected salamander habitat and access will be restricted. To fully recreate a free-flowing spring-fed stream system, the natural elevation and composition of the substrate in the spring pool will be restored to the maximum extent feasible. This will eliminate hindrance of aquifer flow to surface habitat, and provide wetted surface habitat during low aquifer discharge conditions and drawdowns without hindering outflow from the spring pool. A natural substrate will also provide abundant avenues for movement to and from subterranean habitat, reducing the potential for stranding salamanders during drawdowns. The current outflow pipe may be repaired as necessary until the stream is restored. All restoration activities will be submitted to the Service and receive verbal or written approval before implementation. The City will determine the feasibility of this restoration activity and submit an estimate of when construction activities may occur, if feasible, to the Service within 3 years of permit issuance.

Justification: Eliza Spring is a natural spring fed by the Barton Springs segment of the Edwards Aquifer. The original geomorphology of Eliza Spring was a shallow spring pool where water emerged from the aquifer through limestone bedrock, cobble, and gravel. A flowing stream carried water from the spring pool into Barton Creek, approximately 300 ft downstream of Parthenia Spring (Figure B6a). Since the early 1900s, the natural flow regime of Eliza Spring has been successively altered with construction of an amphitheater, diversion of the outflow stream into a buried pipe, and addition of a concrete floor into the amphitheater (see HCP sections 2.3, 2.8, and 3.2.1.2 for more information). The amphitheater allowed for the pre-existing outflow stream to follow its natural course (Figure B6b) and joining Barton Creek downstream of Parthenia Spring. When the permanent dams creating Barton Springs Pool were constructed, the outflow was diverted into a buried concrete pipe that discharged directly into Barton Springs Pool. In the 1950's, a concrete floor was poured over natural substrate of the spring pool. From this point on, the only inflow from the aquifer into Eliza Spring has been through seven small round holes and 15 rectangular vents in the base of the riser to lowest bench of the amphitheater. With the construction of the flood bypass culvert along the north bank of Barton Springs Pool, the Eliza outflow stream was separated from the Pool and directed into the bypass (HCP Figure 10).

Flow regime restoration in Eliza Spring requires two separate projects, reconstruction the overland outflow stream and removing the concrete floor in the amphitheater. Reconstruction of the outflow stream is a type of environmental restoration has been termed, daylighting, which refers to projects that "deliberately expose some or all of the flow of a previously covered river, creek, or stormwater drainage" (Pinkham 2000).

Daylighting of buried streams has been effective in improving ecological integrity of aquatic habitat and typically consisted of reconnecting fragmented stream habitats for migratory fish (Jones 2001, Pinkham 2000). For example, Darbee Creek a tributary of the Darbee River in Roscoe, New York was diverted into an underground culvert, prevented upstream fish migration (Pinkham 2000). The culvert failed in 1996, requiring immediate emergency attention. The culvert was removed and the stream daylighted. After daylighting of the Darbee Creek, migration of hatchery-reared fish upstream of the previously culverted section was restored (Pinkham 2000). A small section of the Spanish Banks Creek in Vancouver, British Columbia, was redirected through a culvert creating a barrier to migration of Coho and Chum salmon upstream to breeding sites (Jones 2001). In 2004, four years after daylighting the creek, salmon were documented spawning in the upstream reaches (Vancouver Board of Parks and Recreation 2004). Jenkins Creek in Maple Valley, Washington, was also daylighted and habitat reconstructed to restore salmonid migratory pathways to spawning habitat and improve upstream habitat quality (Pinkham 2000). In 2009, the City of Maple Valley reported that salmon were spawning in the daylighted reaches of Jenkins Creek.

Figure B6. (a) Confluence of Eliza Spring outflow stream with Barton Creek. (b) Original amphitheater exit to overland stream.

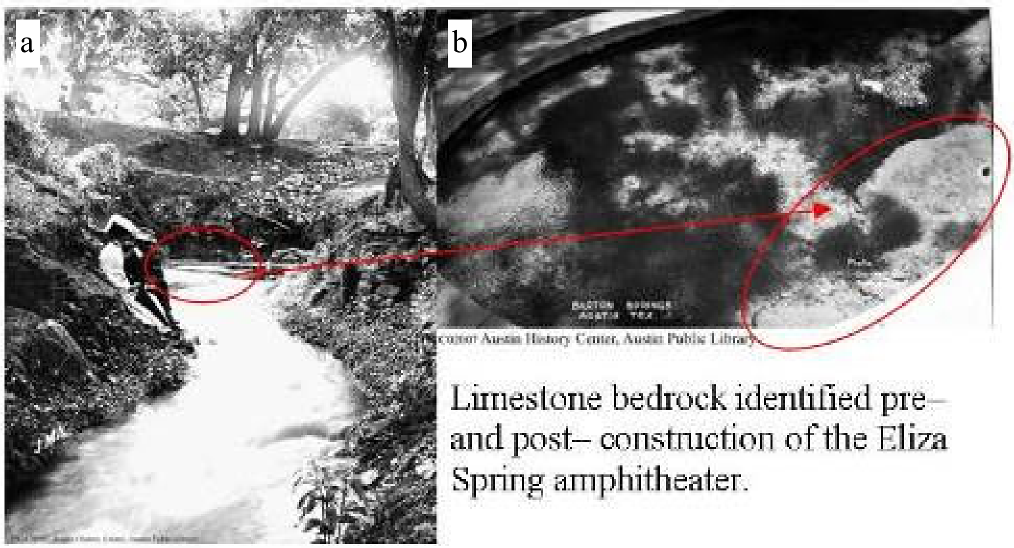


Daylighting the Eliza Spring outflow stream is a high priority for environmental and logistical reasons. It would help restore the natural flow regime and re-create additional suitable and protected habitat for the Barton Springs and Austin Blind Salamander species (*E. sosorum* and *E. waterlooensis*, respectively), both of which are goals in this amended HCP and in the Barton Springs Salamander Recovery Plan (USFWS 2005). A naturally free-flowing stream will improve habitat within Eliza Spring by decreasing water depth and increasing water flow velocity along the substrate. Stream daylighting will also reduce maintenance requirements by opening a currently confined stream path, eliminating the potential for rocks and/or roots to clog the inaccessible buried pipe. Although salamander abundance in this site has improved, reconstructing the outflow stream will be a significant contribution to restoring natural flow regime and fostering long-term recovery of the species.

In addition to daylighting the outflow stream, habitat reconstruction will also include removing the concrete floor in the spring pool, which will restore the natural substrate in surface salamander habitat and improve flow regime. The concrete of the floor is not suitable substrate for salamander residence. The suitable surface habitat is the clean interstitial spaces in the layer of rocks on top of the concrete. The localized inflow of water through the concrete floor limits suitable surface habitat in the spring pool to the areas around these points of inflow. The concrete floor also hinders salamander movement to subterranean habitat when water recedes or for courtship and breeding. Beneath the concrete floor is a natural substrate of limestone bedrock, cobble and gravel (Figure B7). Although this natural substrate is presently laden with sediment it can be easily cleaned once the concrete is removed providing abundant interstitial space for salamander occupation.

The concrete floor also restricts flow of aquifer water into the spring pool and its elevation requires that elevation of water level in Eliza Spring be maintained at approximately 433 feet msl at a minimum. The elevation of water in Barton Springs Pool is maintained at approximately 433.4 feet msl (SAM 2009). Removal of the concrete floor will lower the elevation of the substrate and allow for lower elevation of water in surface habitat. If the elevation were lowered, the hydraulic head between Eliza Spring and Barton Springs Pool would equilibrate or be reversed requiring less pressure to maintain wetted salamander habitat in Eliza Spring. Removal of the concrete floor will

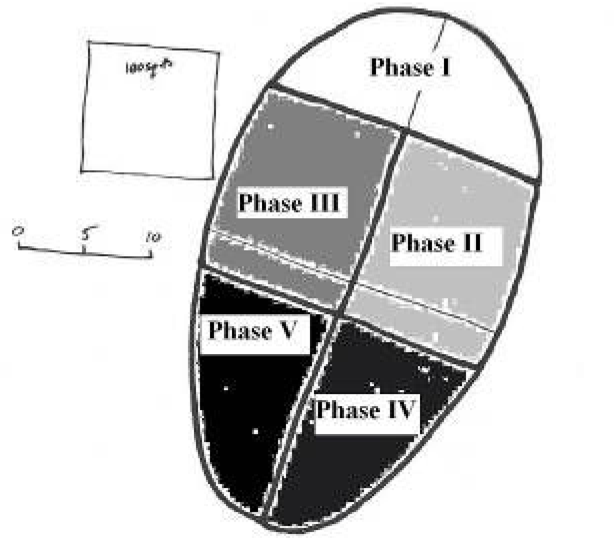
Figure B7. (a) Natural substrate of Eliza Spring shown in the 1890s before construction of the amphitheater, and (b) in the 1940s before installation of the concrete floor.



make surface habitat more resilient to changes in water elevation in Barton Springs Pool, allowing for drawdowns in a wider range of aquifer conditions without exposing surface habitat in Eliza Spring.

Concrete removal would be a phased project (Figure B8) to localize the potential detrimental impacts on resident salamanders to particular areas of the spring pool. The project could progress from upstream to downstream, shallowest to deepest water, and highest velocities to lowest velocities at the substrate directly in front of vents (Figure B8). The phases could also progress from downstream to upstream. The goal is for each section of substrate exposed by removal of concrete to be cleaned and allowed to transition into suitable salamander habitat before continuing to the next project phase.

Figure B8. Aerial diagram of the spring pool of Eliza Spring showing the footprint of each phase of concrete floor removal if conducted upstream to downstream.



Ideally, removal of the concrete floor would be conducted after the surface outflow stream is reconstructed simply because the stream would provide suitable surface habitat into which salamanders can retreat from activities within the spring pool. However, removal of the concrete floor is an important component of habitat reconstruction independent of stream reconstruction. The improvements in habitat in the spring pool and resilience to variation in water depth in Barton Springs Pool are significant benefits that do not rely on overland stream flow. Concrete floor would be removed even if the outflow stream cannot be reconstructed.

6.1.4.2 Old Mill Spring habitat restoration will be implemented to the maximum extent feasible to eliminate permanent, immovable obstructions and hindrances to free outflow from the spring pool to its stream. Infrastructure associated with the plugged outflow pipe on the Tier 1 stone wall (immediately surrounding the spring pool) will be removed within 3 years of permit issuance. The elevation of the outflow streambed may be lowered to ensure free water flow from the spring pool to its stream. A community of native aquatic vegetation will be established, which will help mitigate effects of low spring discharge by releasing oxygen into the water. Canopy cover vegetation will be maintained or increased to provide shade over the spring pool and stream, which will help mitigate increased surface water temperature during seasonal periods of high air temperature. Remaining stone walls of the amphitheater outside of aquatic salamander habitat and the supporting riparian habitat (Tiers 2 – 4) may be rehabilitated or stabilized as necessary to ensure safety in publicly accessible areas. Plans will be submitted to the Service and receive verbal or written approval before implementation.

Justification: Old Mill Spring is a natural outlet of spring water from the Edwards Aquifer that is part of the Barton Springs complex (see HCP sections 2.8, 3.1.2.1.3). Habitat restoration in this site will consist of hand excavation of debris to reveal the natural geomorphology of the spring pool and removal of impediments to outflow from the spring pool. Photographs or drawings of this spring in its natural, untouched state have not been found. The construction of a mill in the 1800s and an amphitheater in 1937 altered the spring by almost completely impounding the water outflow (HCP Figures 9 and 16b), creating a pool of water with low flow velocity under most aquifer discharge conditions. The natural surface stream was buried beneath several feet of soil and its historic course is poorly known. The exact topography of the natural limestone underlying this site is not recorded; neither are the location and elevation of the natural fissures and caves from which groundwater is emitted to the surface. Currently, spring water percolates up to the surface through a deep layer of cobble, gravel, and sediment that is also littered with a thick layer of fragments of concrete and asphalt, broken glass, rusty metal, plastic, and other trash. Outflow from the spring pool is impeded by remnants of a buried concrete pipe and the unnaturally high elevation of the reconstructed streambed. Restoring that natural, unfettered water flow from the spring necessarily includes eliminating water impoundment structures.

Salamander habitat restoration activities since issuance of the permit in 1998 focused on restoring full surface water flow to the stream by preventing water from entering the buried outflow pipe and by lowering the streambed. While these efforts were partially successful (City of Austin 2005, City of Austin 2006, City of Austin 2007, City of Austin 2008, City of Austin 2009, City of Austin 2010), additional work is necessary to achieve the habitat restoration goals. Drastic alteration or elimination of existing amphitheater and old mill structures is not necessary to achieve this goal. A large part of the natural flow regime can be restored by removing the remains of the plugged concrete pipe that obstructs flow of water from the spring pool to the stream. If necessary, the streambed could be lowered to its historic elevation. Removal of material obstructing flow of groundwater from the aquifer into the spring pool will also help restore the natural flow regime and improve surface habitat quality. This restoration would be accomplished by gradual hand-excavation of rock and debris from the spring pool, which would minimize detrimental effects on resident salamanders. Because of the presence of historic landmarks, the Texas Historical Commission will be notified in advance of restoration activities at this site.

6.1.4.3 The City will restore and permanently maintain groundwater flow and light penetration to the maximum extent feasible in salamander habitat of the fissures of Parthenia Spring. The City will not artificially obstruct groundwater flow or artificially inhibit light penetration in the fissures habitat area. Restoration will include permanent removal of concrete in the natural fissures transmitting groundwater to the surface in Parthenia Spring. Small areas of concrete may be removed gradually using underwater hand tools. Large areas may be removed at one time during drawdown, which would allow use of larger construction tools and foster retreat of salamanders from work area. Removal methods will be chosen to minimize harassment of resident salamanders and subject to verbal or written approval of the Service.

Justification: There are long- and short-term negative consequences of using concrete, a material detrimental to salamander habitat and the aquatic ecosystem as a whole. The short-term negative effects are primarily a result of the lack of light penetration into the water and substrate beneath any hardened, solid material. Without light, no photosynthetic organisms, such as beneficial algae, moss and plants would survive. These organisms are building blocks of stable, diverse aquatic ecosystems because they are critical initial links in food webs (Elton 1927 as quoted in Ricklefs 1990 pg. 175) and therefore, important components of suitable salamander habitat (reviewed in Bolen and Robinson 1995).

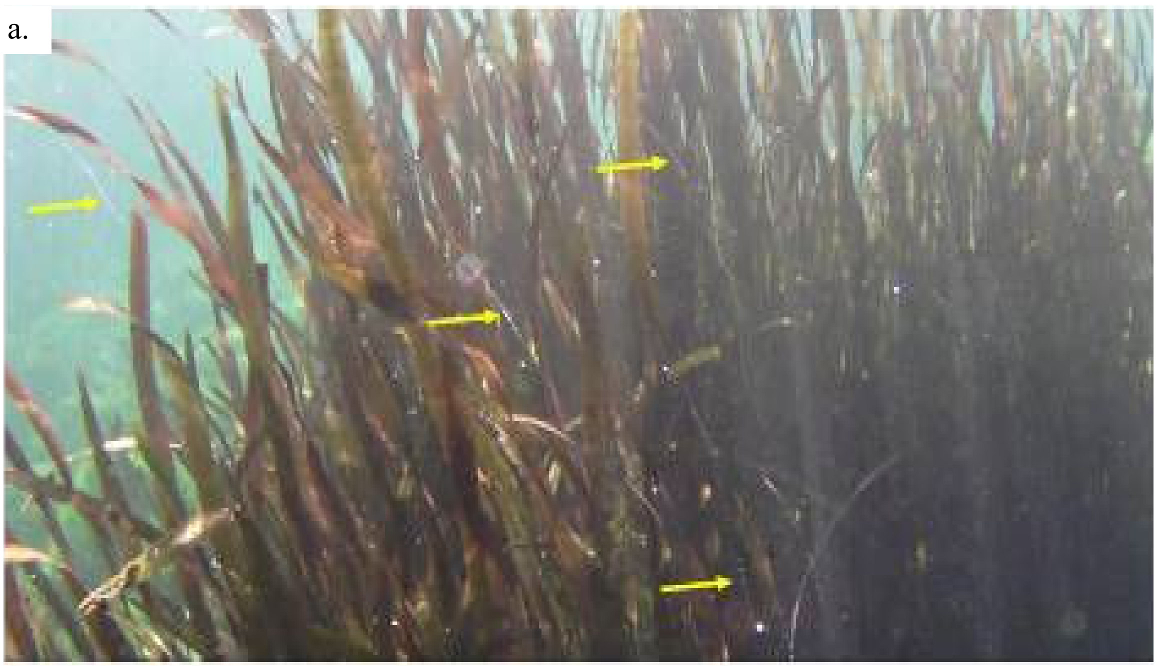
The long-term negative effects arise from the physical nature of concrete products. Because the typical structure of concrete includes pores and capillaries, it will deteriorate over time from exposure to the environment including constant water flow (Kay 1992). The aggregate concrete in the fissures of Parthenia Spring is at least 50 years old and is a visible example of this process. The abrasion from constant water flow in the fissures beneath the concrete, and water flow and underwater cleaning equipment on top, is eroding the existing concrete. This is releasing small sand and gravel particles that combine with fine silt creating heavier material that is deposited in fissures and on the substrate. This heavier sediment mixture plugs the interstitial spaces that comprise ideal salamander habitat and increases the rate of sedimentation beyond what water flow alone can remove. Thus, there are areas of the Pool that would be healthy parts of a stable aquatic environment and good quality salamander habitat if they had not been plugged with aggregate concrete.

6.1.6.1 The City may manually trim and remove aquatic vegetation (macrophytes, bryophytes and algae) as necessary. Vegetation management will not adversely affect habitat or compromise ecosystem health. Only City biologists listed under current federal Endangered Species Act 10(a)(1)(A) and state scientific permits are authorized to manage vegetation in salamander habitat areas.

Justification: Aquatic vegetation will be managed according to the Habitat Management Plans for each spring site. While one goal of these Plans will be creating and maintaining a diverse native ecosystem beneficial for the protected salamanders, Barton Springs Pool must also take into account human safety because the Pool is a public recreational facility. Maintaining aquatic vegetation in a public recreational facility may result in conflict between conservation based interests and recreation based interests (van Nes *et al*. 2002). Designated salamander habitat will be managed solely for the protected salamanders, while other areas of Barton Springs Pool will be managed for both human safety and ecosystem health.

Increasing aquatic macrophytes reduces turbidity, resuspension of sediments, current velocity, and available nutrients while increasing water clarity and depth of light penetration (Minckley 1963, Gregg and Rose 1983, Moeller and Wetzel 1988, Marshall and Westlake 1990, Madsen *et al*. 2001, Wetzel 2001). Macrophytes can out-compete phytoplankton and periphyton in low nutrient environments, and they release oxygen into the water column (Figure B9a, Wetzel 2001). Aquatic macrophytes are critical fish, macroinvertebrate, and epiphytic algae habitat (Killgore *et al*. 1989, Merritt and Cummins 1996, Randall *et al*. 1996, Graham and Wilcox 2000, Petr 2000, Wetzel 2001, van Nes *et al*. 2002, Wehr and Sheath 2003) and are, therefore, a critical part of a healthy ecosystem.

Figure B9. (a) Water Celery releasing oxygen in Barton Springs Pool. Photo taken by Karen Kocher. (b) Barton Springs salamanders in algae and moss in Eliza Spring.



Algae and bryophytes also have an important role in protected salamander habitat. Barton Springs and Austin Blind salamanders are known to feed on a variety of macroinvertebrates (Chippindale *et al.* 1993, Hillis *et al*. 2001, Gillespi*e* 2011) many of which feed on and reside in algae and bryophytes (Wetzel 2001, Gurtz and Wallace 1984, Suren and Winterbourn 1991, Merritt and Cummins 1996, Graham and Wilcox 2000). In addition, salamanders are occasionally found in algae and bryophytes (Figure B9b).

Appendix C. Recovery Plan Status

The Service (USFWS 2005) developed a recovery plan for *E. sosorum* in 2005. The stated goal of the recovery plan was to ensure long-term viability of the Barton Springs salamander in the wild to the point that it can be delisted. In order to reclassify the status of *E. sosorum* from endangered to threatened, the following actions must be implemented and shown to be effective so that *E. sosorum* populations become stable and self-sustaining. The City has made significant progress towards implementing these actions, and continues to address these actions with specific conservation measures described in this habitat conservation plan.

- ACTION: The Barton Springs watershed is sufficiently protected to maintain adequate water quality (including sediment quality) and ensure the long-term survival of the Barton Springs salamander in its natural environment.

  PROGRESS TO DATE: Urbanization and increasing impervious cover from development activities in the Barton Springs Zone has increased stormwater runoff pollutant loading and alters patterns of groundwater recharge to the aquifer. The City directly addresses the quality of stormwater runoff, including provisions to address contaminated sediment transport, with programs described within the City's jurisdiction through a Municipal Separate Storm Sewer System (MS4) permit issued by the Texas Commission on Environmental Quality under the Texas Pollutant Discharge Elimination System permit program.

  The City of Austin also protects the water quality of Barton Springs through the Save Our Springs (SOS) water quality development ordinance. The SOS Ordinance, applied throughout the City's jurisdiction in the Barton Springs Zone, requires non-degradation of water quality based on total average annual stormwater loading. The SOS Ordinance contains the lowest impervious cover limits in the State of Texas: 15% of net site area for all development in the recharge zone, 20% percent net site area for development in the Barton Creek portion of the contributing zone and 25% of net site area for development in the remaining portions of the contributing zone in Williamson, Slaughter, Bear, Little Bear and Onion creeks.

  The City and regional partners have cooperated to purchase an estimated 14% of the total land area of the Barton Springs Zone and to protect that area as permanent open space. An estimated 30% of the total recharge zone is now permanently protected open space which will not be developed in the future. The City continues efforts to permanently protect land from development by direct land purchase or acquiring conservation easements to limit development.

  The City has also implemented specific capital projects and best management practices to protect the quality of water entering Barton Springs Pool from overland flow or during flooding by overtopping of the upstream dam. In 2003, the City identified high concentrations of polycyclic aromatic hydrocarbons

(PAH) in Barton Springs Pool originating from coal tar-based pavement sealants. In 2005, the City banned the use of coal-tar based pavement sealants. A stormwater treatment control was constructed by the City to capture and remove contaminated sediments downstream of a coal tar-contaminated parking lot that was a probable source of PAH to sediments in the Pool.

The City conducts extensive public education and outreach throughout the City, including the Barton Springs Zone, thru the Grow Green program. A primary objective of the Grow Green educational materials is to limit the use of fertilizers and landscape chemicals that may contribute to water quality degradation.

The City maintains ongoing, routine chemical and biological monitoring of surface water and groundwater in the Barton Springs Zone to determine the effectiveness of City programs to protect water quality. The City also conducts specific research efforts to evaluate other potential programmatic and regulatory changes that could be more effective in protecting water quality in the future.

Many regional planning efforts that may mitigate impacts to the Barton Springs salamanders have been completed prior to and during the first permit period. Some of these efforts include components which are ongoing and could potentially be avenues for future City participation. However, most of the plans are weak in concrete methods for implementation and adequate funding. Regardless, they provide one method for administering beneficial infrastructure projects, regulatory changes and program improvements at coordinated state, county and municipal levels. Future regional planning efforts are also likely to provide opportunities for positively influencing the Barton Springs Segment of the Edwards Aquifer. The following is a summary of several existing regional planning efforts detailing the scope, internal and external partners, outcomes, benefits to the species of each, and potential for City participation in future implementation.

Consensus document on service for wastewater and water in the Barton Springs Zone (multi-jurisdiction task force)

In 1997, this effort created guidelines for restricting water and wastewater service by geographic area in the Barton Springs Zone. Participants included LCRA, City of Westlake, City of Rollingwood, the Austin Water Utility, and various citizen groups. The resulting policy document limited City of Austin retail service from extending service west of Loop 360. Specific infrastructure retrofits were identified in the document, and projects like the Barton Creek lift station replacement have been implemented. The Austin Water Utility continues to follow these guidelines when evaluating service extension requests.

Barton Springs Water Quality Protection Plan (BSWQPP) – A multi-jurisdiction effort to determine regionally implemented water quality and quantity protection measures.

Developed in 2005, the scope of the plan was to maintain or enhance the existing water quality of the groundwater and surface water within the Barton Springs Contributing and Recharge Zone by developing a regional water quality protection plan to implement local water quality protection measures. Stakeholders and consultants developed measures based on best available science and consensus building public meetings covering a sequential set of regulatory, programmatic, funding, and technical issues involved in drafting and implementing the plan. Partners included representatives from area cities, counties, groundwater conservation districts and a number of private entities and individuals. The plan proposed local watershed ordinance templates to implement water quality and quantity controls meeting the goals of the plan. Maintenance and improvement of water quality and water usage from the Barton Springs contributing and recharge zones have potential to benefit the discharge from Barton Springs necessary to the habitat of the species. Protective measures outlined under existing federal programs have been incorporated into the plan. During the public and agency comment process, the Service conducted a review of the water quality protection measures presented in this plan. Based on that review, the Service has determined that the measures recommended in the Plan, if implemented, will protect the Salamander and contribute to the recovery of its habitat. Continued participation of the City in implementation group promoting the plan through all jurisdictions will be an ongoing task. The Austin City Council approved a resolution supporting the plan and instructing the City Manager to use staff resources to make sure City programs, infrastructure, and regulations were consistent with the goals of the plan.

Region K Waterplan including results of BSEACD District Management Plan

This plan evaluates population projections, water supply availability and shortages, measures to ensure future water supplies while protecting the Region K (Lower Colorado) planning area. The planning area includes the recharge and contributing zones of Barton Springs. A major goal of the regional water planning process is planning for future water supplies while protecting the area's environmental, agricultural, and natural resources. The Austin Water Utility and representatives from the public, counties, municipalities, industries, agriculture, environmental groups, small business, electrical generating utilities, river authorities, water districts, water utilities, and recreation interests in the planning area participated. The latest update to the plan, which is revisited every 4 years, was conducted in 2011. Projections for future pumping from the aquifer are evaluated as well as water conservation and alternate supplies. Further curtailment and restrictions on pumping from the aquifer and implementation of water conservations measures in the plan can benefit the species by protecting Barton Springs' flow especially during drought conditions. In addition, contributing creeks to the aquifer can be protected by the designation as ecologically unique to preclude a state agency or political subdivision of the state from financing the actual construction of a reservoir in a specific river or stream segment designated by the legislature as ecologically unique. The Region K

Water Planning Group did not recommend Barton Creek or any other segments contributing to Barton Springs for designation as ecologically unique despite data supplied by the City through the Clean Rivers Program managed by the Lower Colorado River Authority, citing need for further studies and environmental data. For the next update of the plan, additional environmental data can be obtained by the City to support and justify designation of the contributing creeks as ecologically unique. The Texas Parks and Wildlife Department would assist with the preparation of a recommendation packet as identified in T.A.C. §357.8 if the Water Planning Group proposed such designation for inclusion in the next plan update in 2015. In addition, the City has participated and will continue to participate in the stakeholder groups for the Region K Water Plan and the BSEACD

Barton Springs Salamander Recovery Plan

Although not a regional planning effort in itself, the recovery plan included multiple recommendations for regional planning including the possible development of a Regional Habitat Conservation Plan for the Barton Springs Zone. Preparation of the Recovery Plan was completed by the Service although input from the City and other existing regional planning groups was included. Nonbinding recommendations were made for regional plans to address water quality and quantity threats. Recommendations for a regional approach providing some guidance for development throughout the BSZ are also included. The recovery plan recommended "a single authority (that) could effectively adopt, implement, and enforce regulations over the entire Barton Springs watershed or relatively large portions of it. Alternatively, local jurisdictions within the watershed could jointly agree to regulate new development under similar regulations". Proposed land acquisition in the document would protect recharge water quality and quantity.

Hays County Transportation Plan

The Hays County Commissioners Court has authorized its transportation consulting company, Parsons Brinkerhoff, to move forward with developing a countywide transportation plan to update the County's 10-year-old plan. This is not a regional plan by design; however, it has potential to impact water quality and hydrology in the recharge and contributing zones of the Barton Springs Edwards Aquifer. A Citizen Advisory Committee for the Transportation Plan has been appointed, although no specific requirements were made for environmental groups regional agencies, or affected municipalities outside the county. A Technical Committee is also proposed that may offer additional opportunities for regional interests to engage. The development of the plan is on-going. Public meetings and review of the document may provide regional environmental concerns including those of the City to be considered and included.

CAMPO and AMATP Transportation Plans

Regional transportation planning includes population, employment, and traffic projections leading to prioritization of infrastructure projects to address capacity gaps. The prioritization matrix used in planning was developed considering locations of roadways in the Barton Springs contributing and recharge zones. The adopted 2035 plan included a 16 factor Environmental Sensitivity Analysis including location of threatened and endangered species including the Barton Springs Salamander. Special attention in the plan was made "through avoidance or through mitigation activities" for aquifer protection. The plan also states that "Particularly in already-developed areas, transportation projects can actually have a positive impact on the aquifer by incorporating water treatment features into their design". Transportation infrastructure provides a significant pollutant load, potential to cut off recharge features, and incentive for secondary development along roadway corridors and service areas. Proper measures to right-size and control infrastructure, alter routes to result in the least impact, and implement structural BMPs in roadway right of ways can benefit both water quality and quantity of recharge to Barton Springs. The City is an integral part of the CAMPO planning process and will be involved in each amendment and update of the plan. Coordination with the regional transportation planning groups in implementing CAMPO plans (especially where City permitting, funding, or environmental review is required) is the primary City future participation.

Imagine Austin Comprehensive Plan

The Comprehensive plan for the City was developed though a consensus building process including stakeholder involvement and coordination with regional partners. Although the plan is limited to the City limits and ETJ, Austin provides leadership in the region and specifically invited regional partners to collaborate on solutions to transportation, water resources, development, environmental protection, climate change and economic issues. One of the policies endorsed by the Imagine Austin plan is to "Promote regional planning and increased coordination between municipalities to address major land use and transportation challenges". Another is to "Integrate citywide/regional green infrastructure to include such elements as preserves and parks, trails, stream corridors, green streets, greenways, and agricultural lands and the trail system into the urban environment and the transportation network". These policies implemented are to be implemented citywide including the Barton Springs Zone. Policy directive in the draft plan includes "CER 2. Conserve Austin's natural resources systems by limiting development in sensitive environmental areas that include Edwards Aquifer and its contributing and recharge zones and endangered species habitat". By limiting development, both water quality and quantity of Barton Springs are protected which will benefit the species. In addition, other policy directives include: "Expand regional programs and planning for the purchase of conservation easements and open space for aquifer protection, stream and water quality protection, wildlife habitat conservation, as well as sustainable agriculture" and "Expand and improve regional collaboration and coordination in preserving Central Texas' natural environment". These policies also have potential to further protect Barton Springs water quality and quantity. Implementation of the plan will be the primary future participation of the City. A priority action of the plan is the create a regional task force to address interjurisdictional environmental sustainability issues. Another priority action is to Collaborate with regional water providers to identify and reduce service overlaps and coordinate access to main water sources, including groundwater.

- ACTION: A plan is implemented to avoid, respond to, and remediate hazardous material spills within the Barton Springs watershed such that the risk of harm to the Barton Springs salamander is insignificant.

  PROGRESS TO DATE: A catastrophic spill response plan has been developed and implemented by the City to avoid and remediate any hazardous material spills that threaten the covered species. City staff are continuously on call to respond to any environmental pollution incidents. The City continues to conduct groundwater flow path tracing activities by dye injection and recovery monitoring to refine and improve knowledge of groundwater flow and refine the spill plan. The City actively maintains programs like the Storm Drain Discharge Permitting program to encourage good housekeeping measures at area businesses to avoid the potential for spills or contaminated stormwater runoff of hazardous materials. The City also conducts public education and outreach citywide to encourage individuals to practice environmentally-responsible disposal of hazardous materials. The spill response plan will be continue to be maintained as specified by the conservation measures in this plan.

- ACTION: An Aquifer Management Plan is implemented to ensure adequate water quantity in the Barton Springs watershed and natural springflow at the four spring outlets that comprise Barton Springs

  PROGRESS TO DATE: The City has no authority over groundwater withdrawal from the Barton Springs Segment of the Edwards Aquifer, and thus cannot implement this action directly. Permitting of groundwater withdrawal is administered by the Barton Springs Edwards Aquifer Conservation District (BSEACD) as authorized by state law. The BSEACD is currently pursuing their own habitat conservation plan to address the impacts of their permitting activities on the covered species. As specified by the conservation measures in this plan, the City will continue to participate in all regional planning efforts and will directly work with BSEACD to ensure sufficient quantity of spring discharge to maintain salamander populations over the proposed term.

- ACTION: Healthy, self-sustaining natural populations of Barton Springs salamanders are maintained at the four spring sites

  PROGRESS TO DATE: The cumulative objective of the specific conservation measures in this plan and all other related City activities to protect the covered species is to ensure self-sustaining salamander populations in the wild. Based on the most recent analysis of salamander monitoring data (Bendik and Turner 2011), the populations of *E. sosorum* in the wild are currently stable. Populations of *E. sosorum* have significantly increased (see Section 3) in the plan area during the time period when the City implemented the conservation measures described in the first habitat conservation plan (1998 – 2010) relative to conditions prior to *E. sosorum* being listed as an endangered species by the Service (1993-1997). Habitat restoration efforts appear to have significantly increased salamander abundance. The City continues to improve and refine conservation measures and habitat restoration activities to ensure continued survival of the covered species as described by this habitat conservation plan.

- ACTION: Surface management measures to remove local threats to the Barton Springs ecosystem have been implemented.

  PROGRESS TO DATE: The City has implemented benign cleaning measures and modifications to the operation and maintenance procedures of Barton Springs Pool to reduce local threats to salamander habitat. Eliza Springs and Old Mill Springs have been closed to the public to reduce human disturbance to surface habitat areas. Habitat restoration efforts have been conducted to increase the quality and quantity of available surface habitat plan areas. The City will continue to control local threats to the covered species through multiple specific conservation measures described by this plan. The City will submit habitat management plans for the plan area for approval by the Service as a specific conservation measure in this plan.

- ACTION: A captive breeding population has been established and a contingency plan is in place to ensure the survival of the species should a catastrophic event destroy the wild population.

  PROGRESS TO DATE: The City has implemented a fully-functional and dedicated captive breeding center and the necessary funds to maintain operation. The City will continue to operate the captive breeding facility for the proposed term as a specific conservation measure in this plan. Additionally, the City has committed to developing a plan that once approved by the Service will allow for release of captive individuals to the wild as a specific conservation measure in this plan.

  The primary goal of the program is to maintain a population in captivity that represents the genetic diversity of that found in the wild, while minimizing collections from the wild. Additional goals include obtaining life history information and refining husbandry techniques, as well as developing a system to track individuals in order to utilize population management software to explore potential long-term management strategies designed to maintain a genetically diverse population over time while minimizing collections from the wild. Program staff also utilizes information gained on the species in education and outreach opportunities.

- ACTION: Develop and implement an outreach plan.

PROGRESS TO DATE: The City maintains a facility dedicated to hosting educational exhibits about the Edwards Aquifer and the covered species at the SPLASH! Exhibit in Zilker Park as well as educational signage near salamander habitats and other outreach programs. Continued funding for the SPLASH! Exhibit to support public education efforts is a specific conservation measure of this plan.

- ACTION: Monitor the current salamander populations and the results of the recovery effort.

  PROGRESS TO DATE: The City has implemented a successful routine monitoring program of all salamander habitat areas. Data from salamander population surveys is included in annual reports to the Service and is available to the public by automated query of the database storing the counts via the City's website. The City will continue regular salamander population monitoring as a specific conservation measure of this plan.

Appendix D. Community Involvement with this Plan

The City actively promoted public participation in and awareness of this habitat conservation plan. Initial briefings were presented individually to the City of Austin Environmental Board and Parks Board in August 2011. These briefings introduced the need for the new habitat conservation plan and the process by which the City planned to develop the new plan.

In August 2011, a dedicated email address, salamander@austintexas.gov, was created and publicized to provide a direct connection for citizen questions and comments on the habitat conservation plan. A webpage (http://www.austintexas.gov/department/salamander-management-guidelines) was launched in August 2011, which described the background for compliance with the federal Endangered Species Act, promoted upcoming public meetings and provided links to the draft documents as they became available. Drafts of the proposed conservation measures to be included in the new habitat conservation plan and a document linking the new measures to the measures in the current habitat conservation plan were posted to the website and available for download in October 2011.

An educational video describing the habitat conservation plan process was created by the City and posted on YouTube.com (http://www.youtube.com/watch?v=nAXGFifYP9A&feature=youtu.be). A link to the video was posted on the City webpage.

City staff met individually with members of the Friends of Barton Springs Pool on September 23, 2011, to discuss their specific concerns regarding the habitat conservation plan, and how volunteers may be able to assist with the management of the Pool. The City offered to conduct additional briefings or discussion meetings with stakeholder groups. Emails to a list of 57 individuals were sent on 4 separate dates, no other group requested a meeting. Thru December 2011, almost no public input has been received on the draft habitat conservation plan. Only 3 emails have been received to the dedicated email address.

A public meeting on the proposed process to renew the habitat conservation plan and answer questions on the proposed conservation measures was held on the evening of October 18, 2011, at Barton Springs Pool. Extensive media outreach was conducted to promote the meeting. Stories aired on the KXAN (http://www.kxan.com/dpp/news/local/city-seeks-new-barton-springs-permit), YNN, KTBC (http://www.myfoxaustin.com/dpp/video/Austin-Looking-for-Help-with-Salamanders-20111018-ktbcw#axzz1bEj5ezXc), KEYE and KVUE (http://www.kvue.com/news/City--132042383.html) television networks. Radio interviews were aired on KLBJ-AM and KUT-FM (http://kut.org/2011/10/habitat-conservation-plan-reconsiders-barton-springs-salamander/). Print media promoting the meeting included the Austin-American Statesman (http://www.statesman.com/blogs/content/shared-gen/blogs/austin/green/entries/2011/10/17/hearing_on_barton_springs_sala.html?cxntfid

=blogs_salsa_verde), AustinPost.org (http://www.austinpost.org/content/save-your-ability-swim-with-barton-springs-salamander), and Community Impact (http://impactnews.com/central-austin/293-recent-news/15320-city-starts-process-to-renew-barton-springs-permit-to-allow-cohabitation-of-swimmers-salamanders). Additionally, posters were displayed around the Pool and handbills were distributed to individual pool users by City staff. Representatives from the City, the Service and the Barton Springs/Edwards Aquifer District were available at the public meeting to answer questions. Four citizens gave their email addresses on the sign-in sheet, and were included on all future correspondence.

On November 3, 2011, the Austin City Council unanimously approved resolution #20111103-034 authorizing City staff to submit an application and negotiate with the Service for a new 10(a)(1)(B) permit. There were no citizens who spoke on this item at the meeting.

City staff briefed the Joint Subcommittee of the City of Austin Parks Board and Environmental Board on the status of the revision to the habitat conservation plan at a public meeting on February 6, 2012. There were no questions from the public about this habitat conservation plan at that public meeting.

A public meeting was held at Zilker Park inside of the grounds of Barton Springs Pool on November 14, 2012, to discuss public concerns and answer any questions regarding the daylighting of the Eliza Springs outlet pipe. The daylighting project is included in the covered activities of this permit amendment.

On November 24, 2012, the Austin-American Statesman newspaper published an article about the proposed federal rulemaking to list the Austin Blind Salamander as an endangered species, and the potential impact on the operation of Barton Springs (http://www.statesman.com/news/news/local/under-salamander-listing-zilker-park-could-see-add/nTD8Q/). A similar story was published in the Daily Texan newspaper (http://www.dailytexanonline.com/news/2012/11/28/austin-not-blind-to-nature-preservation).

On April 22, 2013, an article by April Reese was published in Greenwire entitled "Endangered Species: Austin, Texas seeks changes to salamander's habitat plan" discussing the amendment of the existing habitat conservation plan.

The City of Austin Environmental Board was briefed on the publication of the habitat conservation plan in the Federal Register, and process by which the public could submit comments on the plan, on May 1, 2013, at a regular meeting. The meeting was broadcast live on Channel 6 and is available for viewing via the Internet (http://www.austintexas.gov/edims/document.cfm?id=188354). An article by Charlotte Moore discussing the publication of the habitat conservation plan was published in InFact Daily on May 7, 2013, entitled "City staff working with feds to renew Barton Springs conservation plan."

A second public meeting to discuss the publication of the habitat conservation plan in the Federal Register was held at Barton Springs in the Beverly Sheffield Education Center on Saturday, May 18, 2013, from 10 to 11 am. Only two citizens were present to ask questions about the plan. The public meeting was covered by YNN (http://austin.ynn.com/content/292015/city-to-reapply-for-barton-springs-pool-swimming-permit) and KVUE television outlets.

Appendix E. Captive Refugium Population Management

In 1998, the City initiated a captive breeding program to fulfill Measure #41 of the Barton Springs Salamander Habitat Conservation Plan and Incidental Take Permit to establish a viable breeding population in captivity that could serve as a safeguard against extinction in the event that a catastrophic event were to cause the species to be extirpated from the wild. In addition, the captive breeding facility will function as a temporary refugium in the event that an emergency salamander collection must be conducted in response to an immediate threat (such as a contaminant spill) that could endanger the species in the wild.

Purpose and Goals

The primary goal of the program is to maintain a population in captivity that represents the genetic diversity of that found in the wild, while minimizing collections from the wild. Additional goals include obtaining life history information and refining husbandry techniques. In order to develop these goals, it became necessary to develop a system to track individuals in order to utilize population management software to explore potential long-term management strategies designed to maintain the genetically diverse population over time while minimizing collections from the wild.

Key components in the implementation of the program include the following: founders (including the ability to identify males and females), space and appropriate environmental conditions for wild-caught as well as the captive-raised individuals, knowledge of husbandry (including health, diet, working with each life stage), knowledge of life history, reproduction with surviving offspring, system to organize and track individuals, and software tools designed to explore strategies to meet genetic goals while minimizing collections from the wild.

A breeding program requires a long-term commitment of space and resources for the adults as well as the offspring, particularly given that individuals have been documented to live as long as 15 years. Adequate space is necessary to provide breeding opportunities for selected individuals as well as to provide space for offspring as well as the wild-caught population, which includes maintaining salamanders separately by spring site, reproductive group, size class (particularly small juveniles and eggs), and generation.

Program History

At the onset of the program, a permanent space of appropriate size and environmental conditions was not available to house the salamander tanks; as a result, the program was moved multiple times and established at three separate locations over the first ten years as the program grew and the needs expanded, before being moved to a permanent facility in 2008. The City watershed staff began working with the Barton Springs Salamander in captivity in 1997 in a small office space on the 16th floor of a downtown office building. The limited space and small surface populations in the wild as well as lack of information on the husbandry and life history of the species necessitated and warranted establishing a small population in captivity, initially. Salamander collections were kept to a minimum and were spaced out over time in order to minimize the removal of genetic material from the small surface populations at the springs. Being constrained in number of salamanders with which to work facilitated the opportunity to track and record information on individual salamanders with the advantage of utilizing software tools designed for managing captive animal populations. This also provided the opportunity to investigate the life history as well as the requirements in caring for/breeding the species prior to expanding the program with additional collections and the consequent risks of losing genetics by removing animals from the wild along with risking possible mortalities in captivity.

During the early years of working with the Barton Springs Salamander in captivity, staff discovered that there were actually two, not one, species of salamander in Barton Springs. In 1998, staff collected a small juvenile salamander, and, as it grew, it became clear the salamander did not have eyes with image-forming lenses, rather it had eye spots, a wider flatter head than the Barton Springs Salamander, and was purple in color. DNA analysis confirmed that this individual was, indeed, a different and previously undiscovered species, which was named the Austin Blind Salamander (add ref) and subsequently included in the captive breeding program.

In 2001, the program was moved to ~150 square foot space at the University of Texas at Austin; this larger space provided opportunities to expand the program and establish reproductive groups from each of the four spring sites. A further move in 2003 to a temporary site at a City Building Services facility allowed more expansion with more reproductive groups as well as additional space for offspring. Over the years, each location change presented the opportunity to expand the population as well as presented challenges regarding environmental conditions necessary to maintain and breed salamanders.

Current Facility

In 2008, the program was moved to a permanent facility designed for the program – the Austin Salamander Conservation Center (ASCC), a ~1100 square foot building at the Austin Nature and Science Center (ANSC). Since every previous location presented challenges related to the chilling and electrical systems critical to the survival of the salamanders in captivity during the hot Texas summers, the ASCC includes a backup generator and a chilled loop/heat exchange system, in addition to a well water system, a temperature and electricity monitoring system, and other building systems. Details on the current facility can be found in the ASCC Building Manual.

The current facility contains 14 tank stands consisting, primarily, of glass aquaria ranging in volume from 3 to 75 gallons. Each tank stand system is a discrete water system and equipment is maintained separately per each stand in order to minimize the potential of transmission of pathogens. The current water source for the salamander tanks is the ANSC well, which provides Edwards Aquifer groundwater similar in water chemistry to that of Barton Springs. The larger tanks, which are stocked with reproductive groups, are established for breeding, based on past successes, and provide space for a variety of habitat; however, reproduction does occasionally occur in the smaller tanks as well.

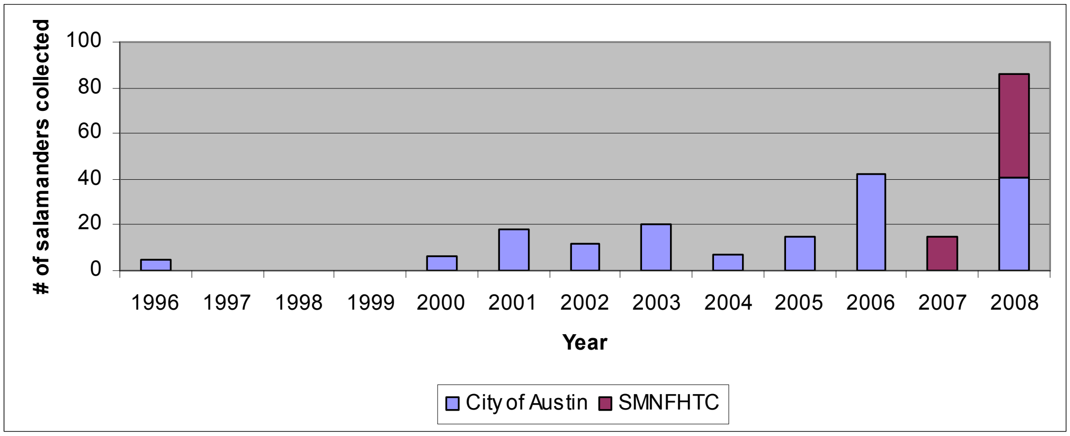
The City's existing Endangered Species Act10(a)(1)(A) scientific permit with the Service requires that Barton Springs' salamanders be maintained separately according to spring site and information on the tank/social group of each individual salamander is tracked. When a female oviposits, staff remove the eggs from the breeding tank and place them in a smaller tank so that, when the young salamanders hatch after ~3-4 weeks, the process of feeding the small animals appropriately sized food is efficient. In addition, staff track information on each clutch of offspring (oviposition date, dam/sire information, tank location). Juveniles are about 0.5" in total length when they hatch and grow to about 3" long as adults. To protect the animals, certain environmental conditions must be maintained. The temperature is generally maintained at 68-72 °F. In addition, the animals require flow of water with dissolved oxygen across their gills; therefore, water turbulence is provided (via aeration or water flow) in each of the tanks. The salamanders are also effective climbers and safeguards are taken to prevent the salamanders from entering pump systems or climbing out of the tanks. More details on the care of the salamanders can be found in the City of Austin's Barton Springs Salamander Husbandry Manual.

Collecting Founders, Individual Tracking

Wild-caught salamanders are necessary in order to maximize genetic diversity. Collections are conducted such that removing genetic material from the wild is minimized at any one time, particularly when the surface population is small or possibly stressed from environmental conditions, such as drought. Staff review the surface population size prior to determining an appropriate collection number. Generally, large juveniles/small adults are collected so that the age of the salamander can be estimated, which is useful information in tracking and analyzing the population in captivity. Also, this avoids collecting very old or very young individuals that may be susceptible to health problems in captivity. In an attempt to minimize the possibility of collecting siblings, collections are conducted over a range of locations at the spring. Once salamanders are collected, they are maintained separately by spring site of origin. Within the separate spring-site groupings, wild-caught salamanders are subdivided into reproductive groups.

Figure E1 shows collection of founders from wild populations of the Barton Springs Salamander over the lifespan of the program. All of the collections in recent years have been conducted for research projects and the animals have subsequently been deposited in the program or at the San Marcos National Fish Hatchery and Technology Center (SMNFHTC), which also maintains a breeding program for the Barton Springs Salamander; funding for this program is federally required as mitigation by Longhorn Pipeline, which operates a gasoline pipeline across the recharge zone of the aquifer. As a safeguard against a possible disaster at any one facility, it is important to maintain salamanders in captivity at multiple institutions.

Figure E1. Total Number of Salamanders Collected for Captive Breeding Program 1996-2011

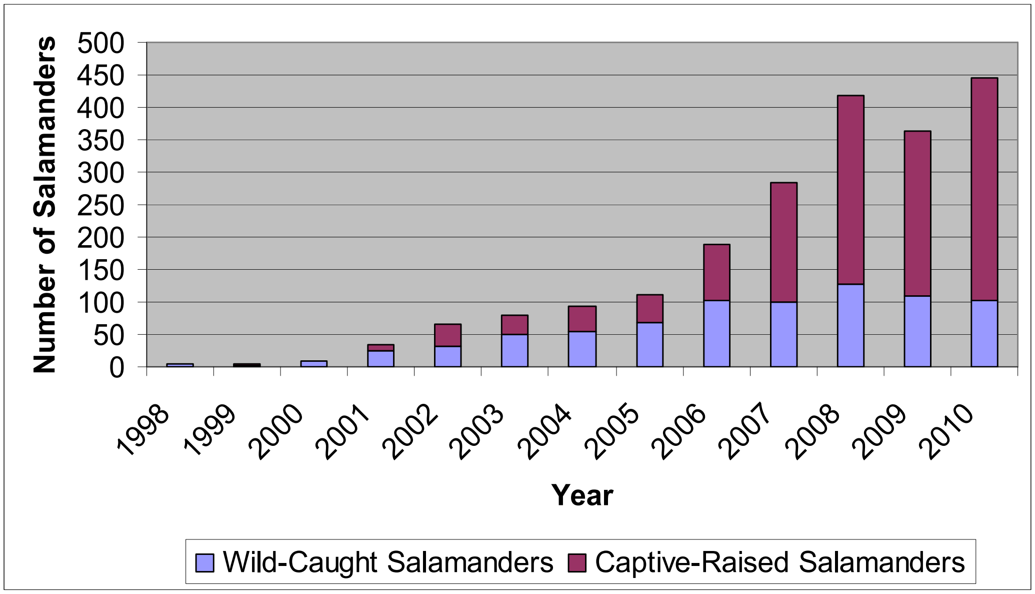


WPD staff utilizes AZA software tools, photographs, and clutch and tank information to track individuals. All wild-caught salamanders as well as captive-raised salamanders that have reached 6 months of age post-hatch are assigned studbook numbers. Wild-caught and older captive-raised individual salamanders are tracked over time by photographing the dorsal aspect of the head and matching melanophore/iridophore patterns with previous photographs taken of the individual. While using photographs to track individuals can be problematic in the field due to the fact that melanophore patterns have been found to change over time in this species, this is a useful method to track individuals in captive breeding tanks and photographs can be updated as necessary. Data on individuals have included collection/hatch date, estimated age based on size at collection, spring site of origin, dam/sire (or group of potential dam/sire) if captive-raised, death date, social group, sex, clutch information, as well as other information such as health problems. To determine whether an individual is male or female, staff examines the lower abdomen for the presence/absence of eggs (ova) or testes, which can be visible through the translucent skin of the ventral side.

Captive Population Description

As of November 2011, the population in captivity includes 447 Barton Springs salamanders (*Eurycea sosorum*) that are at least 6 months post-hatching. The larger facility has provided opportunities to establish additional breeding tanks, which has resulted in a larger captive-bred population (Figure E2). Breeding has occurred in every reproductive group that has been established and successful ovipositons have occurred with each of the species held in the program. For the purpose of this document, an oviposition is the process of laying a single clutch of eggs, which, given current information on the species, are deposited within 24 hours by a single female.

Figure E2: Barton Springs Salamander Population (> 6 Months of Age) in Captivity 1998-2011



A total of 232 Barton Springs Salamander ovipositions have occurred since the captive breeding program's inception in 1998 (Figure E3), with 60 ovipositions from captive-bred salamanders and 172 from wild-caught salamanders. Due to health problems, which developed soon after moving to the current facility, many salamanders were removed from breeding tanks and, therefore, the number of ovipositions decreased in 2009. Once the health issues subsided and were deemed to be non-life-threatening, salamanders were returned to breeding tanks and ovipositions resumed. Clutch sizes for all groups combined ranged from 1 to 52 eggs with a mean of 15.5 (Table E1). The mean hatch rate is 34.9% and 60.2% of hatchlings have survived to 6 months of age. Survivorship, which is the probability of a newborn surviving to a given age class (Table E2). As can be seen in the table, if an animal survives to 6 months, then that individual has a 71% chance of surviving to age 5 and a 44% chance of surviving to 10 years.

Table E1. Barton Springs Salamander - Hatching Success

Parameter	**Range**	**Mean**	**Standard Deviation**
Clutch Size	51 (1-52)	15.5	9.9
% Hatching	0-100%	34.9%	30.8
% of Hatchlings that Survive to 6 Months	0-100%	60.2%	38.7

Figure E3. Barton Springs Salamander Ovipositions in Captive Breeding Program

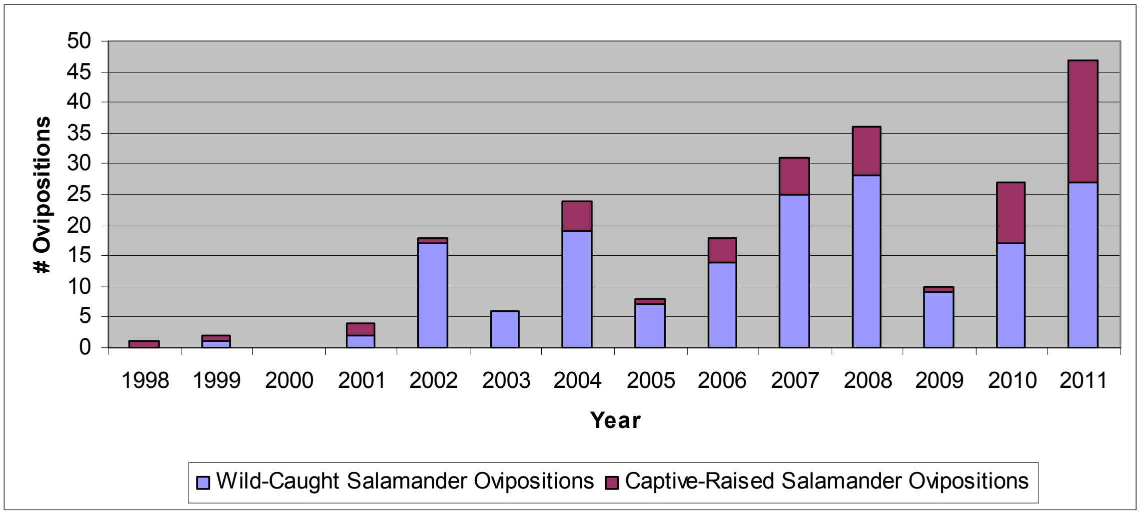


Table E2. Barton Springs Salamander Survivorship

Age (years)	Probability of survival to given age if individual survives to 6 months
1	0.930
2	0.837
3	0.787
4	0.747
5	0.710
6	0.675
7	0.654
8	0.582
9	0.547
10	0.438
11	0.438
12	0.438
13	0.166

Because Austin Blind salamanders are rarely found on the surface, a small number of animals have been collected. The current population in captivity includes 13 wild-caught, 33 captive-raised that are at least 6 months in age, and 26 juveniles that are less than 6 months in age. Seventeen ovipositions have occurred since 2003, with a mean of 16.1 eggs laid, a mean hatch rate of 28.8%, and a 58.1% survival rate to 6 months in age (Table E3).

Table E3. Austin Blind Salamander hatching success.

Parameter	Range	Mean	Standard Deviation
Clutch Size	36 (2-38)	16.1 (n=15)	10.3
% Hatching	26 (0-26)	28.8 (n=15)	35.2
% of Hatchlings that Survive to 6 Months	0-100%	58.1 (n=8)	34.0

With a history of a reproducing, surviving population in captivity of sufficient size that can provide a buffer in the event of unforeseen mortalities as well as provide individuals for reintroduction, the future direction of the program will be to focus on maximizing the number of wild-caught salamanders known to breed in order to maximize the genetic diversity and the value of the wild-caught salamanders. Further details on the population in captivity and the life history of both species can be found in the program's life history and captive breeding report.

Population Management

Animals are tracked and data collected includes date of collection/hatch, age, sex, current tank/social group, health conditions, sire/dam information, spring site of origin, death date, and information on ovipositions. Software tools are then utilized to model previous trends in a population projected into the future under various management strategies. While this can be complicated, particularly in working with a species that is difficult to study in the wild because it spends part of its life in the aquifer, the available information from captivity can be used to narrow down ranges of possibilities with which to analyze and model the population.

When an oviposition occurs, all of the possible dams are known. In some cases, the specific dam is observed ovipositing. In cases in which there is more than one male in a tank, it is not possible to determine the sire, although potential sires can be determined. This will include any male that had access to the female within the time-frame that the species has been documented to store sperm. Most salamander species can store sperm, some for a year or more (Houck et. al. 1985). In addition, some salamander species can store sperm from multiple males. In fact, plethodontid salamanders have complex spermothecae (Sever and Brizzi 1998), which has been found in some studies to facilitate the mixing of spermatophores, resulting in multiple paternity (Sever 2000) for a single clutch of offspring.

In cases in which the exact sire and dam are not known, the potential sires and dams are listed. Because of difficulties in determining the exact parentage, yet a broader set of the information is, in fact, known, "analytical" studbook/datasets are created using software tools Sparks 1.42, Poplink 2.1 to investigate and model strategies for two scenarios: one with a maximized genetic diversity and one with a minimized genetic diversity (Willis 1993). Given the current state of knowledge, when the exact sire and dam are not known, assumptions are made for the additional analyses using information on which males had access to females within the time-frame in which a female can store sperm and using information on which females were actually in the tank at the time of oviposition.

The “analytical” studbooks are then used for the modeling and breeding analyses of the captive population, which is conducted using software tools (Sparks v.1.42, Poplink 2.1, and PM2000 v.1.20) designed to assist in developing management strategies for captive breeding programs. A standard goal for managing a population of rare animals in captivity is to manage the population such that a genetic diversity of at least 90% over 100 years would be retained. Various strategies can be addressed and modeled; such strategies include collections (timing and number), increasing/decreasing generation time, increasing the number of wild-caught animals actually reproducing, increasing available space for offspring, population growth rate, and initial genetic diversity. Thus far, the modeling indicates that, while multiple strategies can be employed for maximum benefit, the single most effective strategy is to maximize the number of wild-caught salamanders actually reproducing. Although there are aspects of this that are somewhat complicated, one alternative is to collect additional salamanders from the wild, and, for a species with small surface populations, collecting large numbers could adversely affect the species diversity in the wild. Therefore, theoretically, each individual wild-caught individual should be represented in the genetics of the offspring found in the captive population. This will maximize the genetics of each of the wild-caught salamanders and help protect the survival of the species in the wild by minimizing the need for collections. More information on the breeding analyses and management strategies can be found in the Barton Springs Salamander Population Management Plan.

Outreach

In working with other facilities, the captive breeding program also provides opportunities for outreach and education. The program provides salamanders for the display tank at the Splash! Into the Edwards Aquifer exhibit at Barton Springs as well as provides information on the species for that exhibit and other educational outlets. The program also provides salamanders that are on display at the Fort Worth Zoo’s Museum of Living Art, as well as the Houston Zoo. Each of these facilities attracts large numbers of visitors and seeks to instill appreciation for the animals and their habitat that may translate into actions taken to protect the species/habitat/water quality. In addition, the City program benefits from partnerships with other institutions through the sharing of expertise and ideas on working with the species in captivity.

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