Biological Assessment
Barton Springs Bypass and Dam Repairs
Austin, Texas

Prepared for:
U.S. Army Corps of Engineers
Ft. Worth District Office

Prepared by:
City of Austin
Watershed Protection Department

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Executive Summary

The City of Austin is proposing to undertake two projects in Barton Springs Pool: repair of the concrete bypass culvert along the northwest bank of the Pool and minor repairs to the downstream dam. The City holds U.S. Fish and Wildlife Service 10(a) permits (10(a)1(A) #TE833851-2 and 10(a)1(B) #PRT-839031) in conjunction with a Habitat Conservation Plan for protection of the endangered *Eurycea sosorum*, the Barton Springs Salamander. The U.S. Fish and Wildlife Service has informally determined that these permits are also protective of candidate species *Eurycea waterlooensis*, the Austin Blind Salamander, because it inhabits the same springs as *E. sosorum*. The City's 10(a)1(B) permit grants permission for Incidental Take (hereafter "Take") of *E. sosorum* resulting from maintenance, habitat restoration, and recreation in Barton and adjacent springs (USFWS 1998, pg.47). Since bypass and dam repair projects are not included in this permit, additional permission for one-time Take for each project is necessary to meet federal obligations to protect these species.

There are four springs in the Barton Springs Complex: three perennial springs, Eliza, Old Mill (Sunken Garden), Parthenia in Barton Springs Pool, and intermittent Upper Barton Spring. Two salamander species are associated with these springs, the endangered *E. sosorum* (Barton Springs Salamander) and candidate species *E. waterlooensis* (Austin Blind Salamander). Both species are known to inhabit the three perennial springs; only *E. sosorum* has been found in Upper Barton Spring. Research and monitoring have greatly increased what is known about these species in the years since listing of *E. sosorum* and identification of *E. waterlooensis*. Since issuance of the 10(a) permits, average annual abundance of salamanders has reached record highs in all four springs, with the most dramatic increases occurring in Eliza and Parthenia Springs during periods of higher discharge. Although *E. sosorum* abundance has reached these record highs, it also fluctuates with changes in environmental conditions, particularly groundwater discharge. In general, salamander abundance decreases with periods of low discharge ("droughts"), and increases with periods of average or high discharge. Although abundance decreases during droughts, the data presented here suggest that the salamander populations in the Barton Springs Complex should have the capacity to weather the temporary disturbances associated with repair of the bypass culvert and downstream dam. Moreover, this capacity is greater currently than in 1997 and 1998 when *E. sosorum* was listed and the Habitat Conservation Plan implemented.

The U.S. Army Corps of Engineers requests a permit for one-time lethal and non-lethal Take for both projects. The total estimated maximum Take for both projects is 385 *E. sosorum* and 10 *E. waterlooensis*. The estimated maximum lethal Take is 39 *E. sosorum* and 1 *E. waterlooensis*; estimated maximum non-lethal Take in the form of harassment is 346 *E. sosorum* and 9 *E. waterlooensis*. The majority of Take is expected to be harassment because the City will be implementing numerous conservation measures to protect *Eurycea* salamanders during the two projects. These measures focus on selection of repair design, methods, materials, and sequencing that have the least potential for lethal and non-lethal detrimental effects on protected salamander species. They include daily onsite monitoring during construction by City of Austin Watershed Protection Department biologists authorized by the City's U.S. Fish and Wildlife

Service 10(a)1(A) permit. This monitoring will increase the likelihood of discovery and relocation of salamanders that may be within work areas, thereby preventing mortality. This includes a partial draw down of water level in Barton Springs Pool will be conducted for the duration of each project if discharge greater than or equal to 30 cubic feet per second (ft^3/s) and long-term weather predictions do not forecast a worsening drought. Consistent with the City's current Habitat Conservation Plan (PRT-839031), the drawdown will not be conducted if all of surface habitat in Eliza Spring would go dry. If these conditions are met and the project has begun, and discharge unexpectedly drops to less than 21 ft^3/s, the drawdown will be reversed. Construction will continue without a drawdown to minimize the length of the project and Take associated with repeated draw downs if construction were delayed. Although the salamander populations in Eliza and Parthenia Springs have improved since listing, repairs to the bypass and downstream dam will affect and may adversely affect *E. sosorum* or *E. waterlooensis.* Therefore, the Corps requests Formal Consultation with the U.S. Fish and Wildlife Service under Section 7 of the Endangered Species Act (1973).

1.0 Introduction

The purpose of this Biological Assessment (BA) is to address potential effects of the proposed construction at Barton Springs Pool and Eliza Spring on federally protected resources. These resources include an endangered species, *Eurycea sosorum* (the Barton Springs Salamander), and a candidate species, *Eurycea waterlooensis* (the Austin Blind Salamander), living in the Barton Springs complex, as well as several additional endangered species and species of concern that are found in the Austin, Texas area.

This Biological Assessment covers repairs to the bypass culvert along the northwest bank of Barton Creek and repairs to the downstream dam of Barton Springs Pool in Barton Creek. The City of Austin initiated investigation of damage to the bypass and design of necessary repairs in 2008. In April 2010, the City of Austin submitted an application to the Army Corps of Engineers for a Nationwide General Permit to repair the bypass repair in conjunction with removal of flood debris from Barton Springs Pool. After additional evaluation of the proposed repairs, the City withdrew the bypass project from the permit application on July 9, 2010, to investigate an alternative repair design. In December of 2010 after consultation with the U.S. Fish and Wildlife Service, the Corps granted a permit for (#SWF-2010-00012) removal of flood debris, which was completed in March of 2011. This document describes the alternative repair design for the bypass culvert chosen by the City, along with minor repairs to the dam.

The City, proposes to make repairs to the bypass culvert and the downstream dam. Design plans and construction drawings for these projects, produced by engineers licensed in the State of Texas, are provided in Appendix B. Construction will be contracted through normal City procurement processes, and repairs will be made through the City's contractors.

2.0 Project Description

The project addressed in this BA is under design by an international engineering firm with an Austin office but the project has not reached the contract bidding and award stage. Although this project will occur in and adjacent to salamander habitat, and will temporarily disturb habitat, there will not be any permanent alteration of designated habitat. The following sections describe the project, alternative methods considered, preferred project design, and proposed implementation.

In addition to repairing the bypass, minor repairs to the downstream dam are necessary to seal horizontal cracks on the northern end of the dam. There is no permanent alteration of endangered species habitat from this project. Dam repairs will be conducted simultaneously to minimize disturbance to salamander habitat.

2.1 Bypass Repairs

The bypass culvert was built to facilitate Pool maintenance for recreation but also serves two important functions for protection of aquatic wildlife and listed salamanders during base flow of Barton Creek. First, a toxic substance spilled into surface waters of Barton Creek upstream of the pool can be routed around Barton Springs Pool, thereby preventing direct contact with salamander habitat and avoiding potentially catastrophic effects on *E. sosorum* and *E. waterlooensis* in Parthenia Spring. Second, increasing urban development typically results in increased concentrations of pollutants in storm waters (Klein 1979; USEPA 1983; Schueller 1994), and impervious cover is increasing over time in the Barton Creek Watershed (City of

Austin 1997). The existing bypass can divert up to 500 ft^3/s of water, although larger volumes of storm water will overtop the upstream dam and flow through Barton Springs Pool. Repairs to the bypass are not only critical for maintaining the recreational quality of Barton Springs Pool, but also for protecting aquatic wildlife by allowing for diversion of detrimental pollutants.

2.1.1 History

In 1972 and 1973, Barton Springs Pool was closed for 77 days during floods and post-flood cleaning, resulting in loss of revenue and additional maintenance costs (Travis Associates 1974). In order to avoid such costs in the future, a plan to divert storm water from Barton Creek around Barton Springs Pool during "ordinary rainfall" was developed. The proposed solutions were to build a box culvert to divert storm water from average rainfall, and install mechanical gates in both the upstream and downstream dams and in the mouth of the bypass culvert. The free flowing openings in the upstream dam would be replaced with a mechanical gate connected to the existing skimmer drain that could divert up to 210 ft^3/s of storm water. The sluice plates in the downstream dam would be replaced by an electronically controlled gate system to allow medium and larger sized floods to "…pass through the dam virtually unobstructed, carry with it flood debris that would at present be trapped in the pool" (pg. 8, Travis Associates 1974). Finally, the underground outflow from Eliza Spring was to be re-routed from the beach area of the Pool to the inside of the bypass culvert. With implementation of these three structural changes, it was estimated that the City would save $27,000 per year in post-flood maintenance costs (in 1974 dollars).

In 1975, a concrete box culvert was constructed parallel to the north bank of Barton Springs Pool from upstream to downstream dam (Fig. 1). The top of the bypass serves as the sidewalk for the north side of the Pool. The culvert traverses the Balcones fault system and is adjacent to an 11,000 square-foot area, known as the beach (Fig. 1). This beach area became designated habitat for the Barton Springs Salamander with the listing of the species in 1998. Although the recommended solutions and original plans included installing new gates in the dams and bypass, actual construction did not include these structures. In addition, the openings in the upstream dam were filled with concrete.

2.1.2 Failure

On October 3, 2008, the top surface of the box culvert cracked and water depth in Barton Springs Pool began dropping, as did water depth in Eliza Spring. (An eyewitness account of failure is provided in Appendix C). Visual inspection of the inside of the culvert and the beach area of the Pool revealed that water from the Pool was moving under and into the culvert through holes in its concrete floor (Fig. 2). At this time, the drought had reduced groundwater emanating from Barton Springs to 22 ft^3/s, a condition where uncontrolled decreases in water depth in Barton Springs Pool can cause the surface habitat of Eliza Spring to go dry (Dries 2009; USFWS 1998). Following the suggestion of U.S. Fish and Wildlife Service staff (Austin Ecological Services Field Office), large limestone blocks were placed in the mouth of the bypass to allow water depth in the Pool and inside the culvert to equilibrate and stabilize water depth. The receding water depth in Eliza Spring was stopped before any surface salamander habitat was exposed. These temporary repairs made in October 2008 have stabilized conditions until permanent repairs can be made. Described below is the project encompassing repairs designed to increase the stability of the existing bypass culvert.

2.1.3 Bypass Repairs – Proposed Action

Analysis of the structure revealed that in addition to holes in the floor and leaking joints, the eastern 2/3 of the structure adjacent to the beach habitat (Figs. 1 and 2) was unstable. The structure is not sufficiently resistant to the potential for buoyancy, sliding, and overturning. This portion of the bypass is adjacent to the beach habitat. Repair designs focus on stabilizing the structure and strengthening it to increase its life span, protect the public, and minimizing site disturbance (terrestrial and aquatic) and risk to endangered species. The Pool is a very popular recreational resource and revenues contribute approximately $1,000,000 annually to the City's General Operating Fund. For these reasons, Pool closure is a factor in evaluating repair designs.
The repair concepts are discussed in the Preliminary Design Report by AECOM (February 15, 2011). The bypass repairs will include:

1. localized concrete repairs where reinforcing steel is exposed or concrete has cracked,
2. stabilization of the subgrade under the bypass
3. construction of new joints between the 13 concrete segments,
4. construction of a new concrete floor slab,
5. installation of rock anchors and soil tie-backs,
6. attachment of existing concrete structures to the bypass,
7. installation of new weep holes in the bypass wall,
8. rehabilitation of the deck drain system.

Construction will be conducted in three phases beginning with the upstream sections to reduce stress on the protected species and allow the Pool to remain open for recreation as much as possible during construction. The Pool will remain open for an estimated 4 weeks out of the estimated 5 month construction period. Construction inside the bypass will require re-directing creek flow, which may result in more surface water from Barton Creek temporarily flowing through the Pool than has occurred since the bypass culvert was built in 1974.

Phase I will occur mainly in the upstream section (segments 9-13; Fig. 3) of the bypass and address exterior expansion joints, interior of the joints in the upstream section of the bypass, stabilizing the subgrade and the floor. Phase II will mainly occur in the middle section (segments 5-8; Fig. 3) of the bypass and include interior and exterior joints, subgrade and holes. Phase III will focus on the lower section (segments 1-4; Fig. 3) of the bypass and include interior and exterior joints, subgrade, holes and valve installation. Preliminary construction plans including the detailed sequence and location of each task are provided in Appendix B. The following outlines the proposed construction sequence:

Phase I (segments 9-13) – 4 weeks (pool open)

- Staging and preparation
- Construct cofferdam to route creek flows around bypass and over upstream dam
- Construct Phase I coffer dam in pool to dry upstream segments
- Dewater and clean concrete surfaces
- Foundation stabilization as necessary
- Expansion joint wall repairs
- Miscellaneous concrete repairs
- New conventional concrete floor

- Expansion joint roof repairs
- Rehabilitate deck drains in segments 9-11
- Remove Phase I coffer dam

Phase II (segments 5-8) – 7 weeks (pool closed)

- Pool drawdown
- Preparation and water controls
- Construct Phase II coffer dam
- Dewater and clean concrete surfaces
- Foundation stabilization as necessary
- Install tiebacks
- Install rock anchors in segment 5
- Expansion joint wall repairs and cleaning pipe sleeves
- Miscellaneous concrete repairs
- New heavyweight concrete floor
- Expansion joint roof repairs
- Rehabilitate deck drains
- Construct new wall drain system
- Construct new weep holes
- Remove Phase II coffer dam

Phase III (segments 1-4) – 6 weeks (pool closed)

- Preparation and water controls including Eliza flow diversion
- Construct Phase III coffer dam
- Dewater and clean concrete surfaces
- Foundation stabilization as necessary
- Install rock anchors
- Expansion joint wall repairs and cleaning pipes sleeves
- Miscellaneous concrete repairs
- New conventional concrete floor
- Expansion joint roof repairs
- Rehabilitate deck drains
- Construct new wall drain system
- Construct new weep holes
- Install valves in bypass wall
- Remove Phase III coffer dam

Final Repairs – 2 weeks (pool closed)

- Deck waterproofing and crack repairs
- Cleanup and re-vegetate damaged construction areas as necessary

Primary access to inside the bypass and the upstream pool segments will be from the upstream, west end of the culvert (Fig. 4a) on an existing stabilized path. Light equipment (*e.g.*, Bobcat, small pickup truck) will access the top of the downstream half of the bypass on a temporary stabilized access path between Eliza Spring and the Pool (Fig. 4b). An existing stabilized path downstream of the Pool will be used on a limited basis to access the mouth of the bypass.

If there are no delays due to unforeseen circumstances, repairs are estimated to take 141 days or approximately 5 months to complete including cleanup and demobilization. Of this construction duration, the pool will be open to the public for approximately 4 weeks. However, floods and high creek flows could cause delays. A partial drawdown will be used to facilitate repairs but will not be conducted if spring discharges are below 30 ft^3/s and if long-term weather predictions forecast a worsening drought. The partial drawdown will not be permitted to dewater Eliza Spring. During construction, if spring discharge drops below 20 ft^3/s, the partial drawdown will be reversed although construction will continue. If spring discharge drops to below 20 ft^3/s during final design development, the project could be delayed until environmental conditions are more favorable.

2.1.4 Alternatives to the Proposed Action

City staff and its consultants evaluated a number of alternative conceptual designs to repair the bypass. Initially, three options were developed based on structural analysis, results of concrete core samples and inspection of the current conditions in the culvert, to address floor holes and global stability factors of sliding, buoyancy and overturning. Additional variations and options were also considered as described below.

2.1.4.1 Repair Option 1

This option involves addition of a new concrete bottom slab inside the existing culvert and the construction of a new concrete retaining wall and drainage system along the embankment side of the culvert (Fig. 5). The new bottom slab would be installed along the entire length of the existing culvert to protect, strengthen and seal the existing bottom slab which has moderate to heavy scaling, spalling and holes. The new concrete retaining wall and drainage system would be installed along the lower 2/3 of the culvert (approximately 600 ft). The retaining wall system would increase the resistance of the existing culvert structure to overturning, sliding, and buoyancy resistance of the existing culvert structure, and the drainage system would decrease these forces by lowering the water table at the embankment side of the culvert. The new retaining wall footing would also include a continuous key, embedded in limestone bedrock, to minimize water migration from the Pool into the embankment. Repair Option 1 would require a drawdown of the Pool and dewatering of the embankment for several months until construction of the new concrete bottom slab, retaining wall and drainage systems have been completed.

Variations on this option were also considered (Fig. 5). These include reducing the retaining walls and adding blocks on the Pool side of the bypass, moving the French drain system to inside the culvert and adding flow capacity to the top of the bypass deck under certain flood conditions. These options were not chosen due to significant disturbance of the embankment, risk to endangered species, constructability constraints and Pool closure issues.

2.1.4.2 Repair Option 2

Option 2 includes installation of a new PVC or HDPE pipe and high strength, non-shrink grout inside the entire length of the existing culvert and construction of a new concrete footing and drainage system along the embankment side of the culvert (Fig. 6a). Filling the annular space between the plastic pipe and culvert with grout would protect and strengthen the walls and top and bottoms slabs of the culvert. The new concrete footing and drainage system would be installed along the lower 2/3 of the culvert (approximately 600 ft). The new footing would increase the resistance of the culvert structure to overturning, sliding and buoyancy resistance of the culvert structure and the drainage system will decrease the overturning, sliding and buoyancy forces by lowering the water table at the embankment side of the culvert. The new footing also would include a continuous bottom key, embedded in limestone bedrock, to minimize water migration from the pool into the embankment. Repair Option 2 requires a drawdown of the pool and dewatering of the embankment to lower the ground water elevation for several months during construction until the new pipe, grout, concrete footing and drainage systems have been completed.

Variations on this option were also considered (Fig. 6a,b). These included larger diameter pipe, twin pipes, grouting the interior of the walls, floor and ceiling; and building new walls, floor, and ceiling with blocks on the Poolside of the bypass. These options were generally eliminated due to either excessive reduction in flow capacity of the bypass or the insufficient addition of strength to the structure.

2.1.4.3 Repair Option 3

This repair option is a variation of Option 2 with new walls, floor, and deck, and lacks the key into bedrock beneath structure. Option 3 has acceptable reduction in bypass capacity, less site disturbance and lower risk to protected species. Inside the bypass, the new walls and floor would be eight inch-thick concrete with two layers of reinforcing steel bars. The new top deck would consist of approximately five inches of steel plates overlain by five inches of concrete with reinforcing steel bars. The new deck would be structurally tied into the new walls inside the bypass. The City of Austin evaluated using soil anchors in conjunction with the concrete to eliminate the need for steel plates and reduce the new top deck thickness from ten inches to eight inches. However the spherical anchors tested did not perform well in the rocky alluvial soil adjacent to the bypass and other types of soil anchors may be more effective. Anchors into rock could be used but only in the downstream-most segments of the bypass to reduce the potential for intercepting flow conduits in the underlying limestone during installation.

2.1.4.4 Repair Option 4

Option 4 consists of the removal and replacement of the existing culvert with a new concrete culvert and a new drainage system along the embankment side (Fig. 7). The new culvert would have large capacity than the existing culvert and consist of pre-cast concrete segments. After removal of the existing culvert, the subgrade below the culvert would be excavated down to competent limestone bedrock. The pre-cast new culvert segments would then be positioned and supported on pre-cast concrete blocks founded on limestone bedrock. The space between the bedrock and bottom of culvert would be grouted to minimize water migration between the Pool and embankment, and to provide for good resistance to sliding. A drainage system would be installed along the embankment side of the new culvert segments to reduce lateral embankment pressures. Repair Option 4 requires a drawdown of the Pool and dewatering of the embankment for several months until construction of the new culvert and drainage system has been completed. Advantages of this option include a totally new structure built on known site conditions and increasing bypass capacity. This option was not chosen because of significant disturbance to the embankment, increased risk to endangered species, constructability constraints, extended Pool closure and higher cost.

2.1.4.5 Repair Option 5
Option 5 consists of a pier system to stabilize the bypass without adding as much mass to the structure as the other options (Fig. 8). Fourteen- to twenty-four inch diameter piers would be drilled approximately ten feet into bedrock either adjacent to the bypass or through the bottom. It would require 60 - 70 piers to stabilize the lower 600 ft of the bypass. This option was not chosen because of high risk of damaging water conduits in the aquifer leading to Eliza Spring and constructability constraints.

However, variations to this option could be incorporated into the current design that would reduce costs and the mass needed for stability. These include helical soil anchors that could be drilled into the steep embankment soils, and shallow rock anchors drilled into limestone bedrock. Anchors combined with concrete would not bear the full forces acting on the bypass, and could therefore be smaller and less invasive than described in Option 4. Rock anchors might be used in the downstream segments of the bypass where City staff believes there is less risk of intercepting important conduits in the limestone and less soil on the embankment. Soil anchors driven at a low angle into alluvial soils could be used where the bypass crosses the Barton Springs Fault.

2.1.4.6 Preferred Repair Option
The preferred option for repair is the proposed repairs outlined in section 2.1.3. This option is minimally invasive into salamander habitat, does not alter designated salamander habitat permanently, is cost effective, can be completed in a timely manner with minimal impact to salamander populations and does not alter the appearance of the bypass or dam.

2.1.4.7 No Action Alternative
If nothing is done, it is likely that the undermining and deterioration of the bypass floor will continue. With this alternative, staff would continue the current course of response to the deterioration, which includes maintaining limestone blocks in the downstream end of the bypass and plastic sheeting at the junction of the Poolside bypass wall and the beach substrate. The purpose of the limestone blocks is to retain enough water inside the bypass so that its mass counteracts destabilizing forces. The purpose of the plastic sheeting is to impede water flow from the Pool under and into the bypass. These solutions have several disadvantages. The materials have to be replaced whenever water pressure or flood flows dislodge or remove them. Moreover, it contributes to slow deterioration of salamander habitat in Eliza Spring and along the beach in the Pool. Retaining bypass water depth at $\geq$ 3 feet can be detrimental to the habitat quality in Eliza Spring because the Eliza outflow enters the bypass culvert. Greater water depth in the culvert decreases outflow velocity from Eliza, which will reverse much of the improvements from habitat restoration. In addition, the plastic lies on top of salamander habitat of the beach, obstructing light and inhibiting growth of natural flora and fauna upon which *E. sosorum* depends. The methods in the no action alternative provide no certainty of controlling water depths in the Pool and Eliza Spring. No action could result in uncontrolled draw downs of the Pool to unknown and unpredictable water depths, as occurred on October 3, 2008, when the current holes in the bypass floor erupted and began draining Pool water into the bypass. Uncontrolled, irreversible, rapid drawdown of water from Barton Spring Pool when discharge is below 54 cfs causes water to quickly disappear from surface habitat in Eliza Spring (Dries 2009;

USFWS 1998 PRT-839031 Environmental Assessment; City of Austin unpublished data). The immediate effects of dry surface habitat are mortality of stranded *Eurycea* salamanders and retreat of surviving salamanders to subteranean habitat for extended time periods. Extended retreat imposes additional stress on *E. sosorum* and *E. waterlooensis* as both species are forced to compete for limited resources in subterranean habitat. It is also problematic for management and use of the Pool as a recreational resource because maintaining water depths ensures safe swimming. Unless the proposed construction with mitigation measures would result in jeopardy of the salamander, the no-action scenario is an unacceptable alternative.

2.1.5 Repair Methods

As mentioned previously, repair options, methods and materials were chosen based not only on construction effectiveness, but also minimization of potential detrimental impacts on protected salamander species.

2.1.5.1 Construction Vehicles

Construction vehicles used adjacent to the Pool and Eliza Spring will be as light as possible to avoid damage to weak areas of the bypass or buried structures (e.g. irrigation or stormwater pipes, buried outflow pipe from Eliza Spring). These include bobcat-type loaders, light duty pickup trucks, small generators and small backhoes. Large vehicles, such as cement trucks, will be used only as needed and limited to staging areas only to the maximum extent possible.

2.1.5.2 Inlet Flow Diversion

Diverting the inlet flow from Barton Creek into the Pool or enclosed in a separate pipe within the bypass will provide dry working conditions within the bypass. A cofferdam will be constructed upstream of the inlet grate for the bypass, as seen in Appendix B (drawing C-1.1). Barton Creek flows less than 20 ft^3/s will be diverted through a 24 inch temporary pipe placed inside the bypass culvert. When Barton Creek exceeds 20 ft^3/s, additional flow would be pumped into Barton Springs Pool and filtered as necessary, with the exception of storm water that exceeds water quality criteria (Appendix E) that would not be diverted into the Pool unless upstream Barton Creek flows exceeded bypass capacity. Storm flows in excess of 500 ft^3/s will still flood the pool area as currently occurs. Diversion of Barton Creek flow will be managed to prevent back-up of Barton Creek water into Upper Barton Spring.

2.1.5.3 Eliza Flow Diversion

Eliza Spring flow will be diverted from the outlet pipe to the downstream side of the cofferdam at the bypass outlet. A pump, such as a self-priming pump, will be installed with the capacity to divert up to approximately 16.3 ft^3/s, the maximum discharge recorded at Eliza Spring. The pump inlet will sit within an open container and the entire structure will be surrounded with 1/6 inch mesh netting to prevent salamanders from entering the pump inlet (Figure 9). The pump will operate in conjunction with a level sensor inside the spring set at a height approved by City permitted biologists, assuring that habitat in the spring pool will remain wet at all times. The pump inlet will be in the Eliza Spring outflow pipe directly beneath the access grate approximately 10 feet downstream from the upstream end of the outflow pipe (Appendix B drawing C-4.3). Pumping of flow from Eliza Spring will not exceed the duration of Phase 3. Flow will be blocked in the outflow pipe using inflatable plug or equivalent method that is positioned to minimize potential to isolate or strand salamanders and will not damage the integrity of the outflow pipe.

2.1.5.4 Cofferdams and Dewatering Structures

Cofferdams or other approved dewatering structures will be used for maintaining dry work areas within Barton Springs Pool during each Phase (Appendix B drawings C-1.1 through C-1.6). Site-specific limitations, including but not limited to questionable structural stability of the skimmer system concrete pipe, width of the beach and vertical surfaces, will determine the type of dewatering structures suitable for each location. The contractor will develop dewatering methods with approval from City permitted biologists, recognizing that all dewatering structures within Pool boundaries will be capable of retaining water at Pool full conditions, i.e. no drawdown. Salamander habitat affected by dewatering and associated structures for bypass repairs is not to exceed 11,000 ft^2 (the total area of beach habitat), including areas of overlap. This calculated area restricts dewatering structures from entering primary habitat, where salamander density is significantly greater than beach habitat. In addition, intrusion into salamander habitat i.e. vertical supports forced into any substrate) is prohibited. If additional support is needed for the dewatering structures in salamander habitat, alternatives to intrusions into substrate must be identified by the contractor and approved by City permitted biologists. Any coffer dam or dewatering structure will be cleaned and disinfected with bleach or other suitable detergent and thoroughly rinsed and dried prior to use to prevent introduction of amphibian pathogens into Barton Springs Pool and Eliza Spring.

Disassembly of the cofferdams will begin once the project or phase has been completed. Dewatering of the work area will subside and water pressure will equalize on both sides of the cofferdam. It is presumed that when water re-enters the dewatered zone it will suspend particles making the water turbid. The City will require that suspended particles be allowed to settle out of the water column before resuming disassembly of the cofferdam.

2.1.5.5 Containment Booms / Silt Curtains

Turbidity barriers and containment booms will be installed inside the pool around the dewatered areas to confine turbidity in the water column to a particular area, limiting habitat disturbance. Any containment boom or turbidity barrier that is reusable will be cleaned, disinfected with bleach or other suitable detergent and thoroughly dried prior to use in Barton Springs Pool. An example of a sufficient turbidity barrier is a curtain floating barrier. They are dropped into the water with weighted bottoms to hold the curtain vertically. There are three main parts to these barriers — the float, the curtain and the ballast. Specifications are dependent on weight of the curtain. For the bypass project, a lightweight curtain, ideal for calm waters or water with little current, will most likely be sufficient. The float is a 6-inch expanded polystyrene log that fits in the upper hem of the curtain. The curtain is a polyester reinforced vinyl high visibility yellow material connected to each 55 ft section by lacing through a series of grommets and bolting together load lines. The ballast is a 1/4-inch galvanized chain secured in the lower hem (Fig. 10). These turbidity curtains are less invasive than similar curtains requiring substrate anchors. The lower hem of the curtain containing the ballast will gently rest on the substrate in salamander habitat. It is not necessary to disturb substrate material to anchor the curtain.

2.1.5.6 Concrete Cleaning and Preparation

Throughout this project, a number of repairs require concrete cleaning and preparation. Concrete preparation may require sand blasting and shot blasting, which will be contained to minimize airborne migration of fine particulate matter. Commercially available, non-toxic biodegradable detergents may be used to wash the surface of the concrete as necessary. Any wash water used from cleaning the concrete will be collected and disposed of in compliance with the Storm Water Pollution Prevention Plan (Appendix B) and City of Austin Codes.

2.1.5.7 Floor Holes

Holes in the bypass culvert floor have the highest pressure, velocity and volume of water flowing through them. Fortunately, several products can be used in flowing water. A foam polymer, cementitious grout and bentonite grout are the three most viable options and are discussed below. In considering the alternatives, an important goal of stabilizing the gravel and spaces beneath the culvert is to reduce its potential for sliding.

2.1.5.7.1 Methods for Bypass Subgrade Stabilization

Immediately prior to filling voids beneath the existing floor slab, a non-destructive survey will be completed to establish void locations. Impulse Response Technique (IR) is the proposed survey method. It uses a plastic hammer to vibrate the concrete at its natural frequency, sending a stress wave through the concrete. A geophone (small device that sits on the floor of the bypass) records the wave as it bounces back and determines the stiffness of the slab. The relative stiffness of the slab is less in areas with spaces beneath the floor. These variations in stiffness will be used to map the location and size of gaps beneath the bypass floor.

Once the IR survey is completed, the voids for each phase can be repaired (after dewatering along the pool side of the bypass) based on relative size and location, each of which is approached differently. Large spaces beneath the bypass will be filled with crushed limestone gravel (Appendix B drawing S-6.5) through access holes in the floor and gaps along the poolside wall. Large spaces under the southeast half of the bypass will be filled through gaps between bypass and poolside salamander habitat. Access to large spaces beneath the northwest half of the bypass floor and will require cutting holes (Appendix B drawing S-6.5) through the floor. If poolside gaps along the bypass wall do not provide sufficient access, holes will be cut through the southeastern half of the bypass floor. After gravel is placed in the subgrade, access holes will be patched with fast-setting, high strength mortar cement. Spaces or gaps along the poolside will not be patched.

After large gaps have been filled, small interstitial spaces between subgrade gravel will be stabilized with grout injected through a grid of ports (1 – 1.5 inches in diameter) through the bypass floor (Appendix B specification SS01045). The injection rate of the material will be adjusted to prevent migration of material into subterranean or adjacent salamander habitat, and Barton Creek.

2.1.5.7.2 Subgrade Stabilization Materials – Rock

Washed crushed rock is the primary material for subgrade stabilization because it fills spaces and forms the base around which grout forms a solid mass. While most rocks would be suitable for this project, the City has chosen to use only limestone. Limestone is the naturally occurring rock that forms the Edwards Aquifer and it serves the important geochemical function of buffering groundwater, maintaining the natural neutral pH.

2.1.5.7.3 Subgrade Stabilization Materials - Grouts

Option 1: Uretek 486 Star Polymer Joint Compound

Uretek 486 Star is a high density expanding polyurethane used to fill gravel voids. In this project, it would be used under the bypass tunnel to fill voids and create a watertight layer of material between the substrate and underside of the culvert floor. The product has two components, polymeric diphenylmethane diisocyanate and patented polyurethane polyol blend. The polymeric diphenylmethane diisocyanate is not a toxic compound, but one component (≥ 1% plasticizer) of the polyurethane polyol blend is highly toxic (Baysystems 486 STAR material safety data sheet). The plasticizer has a theoretical biological oxygen demand (ThBOD) of 2,300 mg/g. Laboratory experiments have shown that the material is lethal to *Pimephales promelas*, (Fathead Minnow) at a 96-hour LC50 of >1.55 mg/L. It causes indirect detrimental effects on *Daphnia magna* (Water Flea) at an EC50 of >1.46 mg/L. The LC50 threshold concentration would be met if the plasticizer is 1% of the product, and 155 mg of the product is used. Direct contact with this component of Uretek at this concentration would be expected to exert some detrimental effects on fathead minnows and water fleas. (MSDS information in Appendix D.)

While un-reacted plasticizer is toxic, the properties of Uretek and the application method could mitigate potential detrimental effects. The polymeric diphenylmethane diisocyanate and patented polyurethane polyol blend are combined in a 1:1 ratio in an injection gun. The two parts mix as they are released from the gun, and begin to react upon contact. The reaction is complete in 10 – 120 seconds, depending on water or air temperature. The reaction proceeds more slowly at lower temperatures. The reaction is exothermic, releasing both heat and carbon dioxide into the water. The product will expand 20 times the original volume in 25 seconds. Within 15 minutes, the product will cure to 90% compressive and tensile strength. Once fully cured, the solid foam product is inert. The final product is inert, but may erode with time and exposure to flowing water. This product has only been in use for 15 years so its longevity is unknown. Since Uretek 486 Star is liquid prior to and during reaction, it is possible that water flow beneath the bypass could carry it away from the injection site. This can be partially controlled by *in situ* adjustment of injection method and pressure, and use of protective barriers.

Option 2: Cementitious Grout

The alternative methods that could be used for filling the voids below the bypass floor include pressure grouting and low-pressure cement slurry grouting. Pressure grouting involves the injection of a liquefied, cementitious material under pressure, into large voids, void spaces between soil particles, cracks, or even between the subsurface bearing materials and an existing structure. This technique is used to apply pressures on adjacent soil formations or building structures as in floor or foundation leveling. The process further requires that the grout gel or solidify within the areas treated. In the case of the Barton Springs Pool bypass, large voids under the floor would need to be completely filled with an aggregate material capable of bonding with the grout, and pressurized grout would need to be injected into the stone matrix of the channel beneath the bypass culvert.

Conventional cement or slurry grouting is the pressurized injection of flowable particulate grouts ("flowable fill") into open cracks, voids and expanded fractures. Other applications of this technique include injection into abandoned pipelines, pressure-injected anchors, stabilization of gravels and shot rock, rock foundation treatment for dams and, under proper conditions, confinement of plumes resulting from hazardous waste spills. The materials composing slurry grouting include finely ground slag or Portland cement, dispersants and large quantities of water to form a slurry mixture capable of penetrating fine gravel or finely cracked rock. Where the mass of floor has to withstand applied hydraulic/water pressure, such as a harbor or a dam wall, either a quicker setting cement or marine grade grout is required. It would be used on this project to fill voids and gravel substrate beneath the bypass culvert. Although the pressure exerted by Pool and ground water inflow to the bypass channel will be minimized during construction, this unknown factor makes grouting a considerable risk. Loss of grout through dissolution in flowing water would likely result in a plume of water with a high concentration of suspended solids being transported downstream. This plume would likely also have a high pH as most grout materials can be extremely caustic. This could have negative impacts on *E. sosorum* and *E. waterlooensis* and other subterranean fauna if they come into contact with this material.

Methods of administering grout differ between contractors and application, but generally the amount of grout-fill and pressure of application is kept low, as too much wet-fill administered with an excess head of pressure can easily push the substrate apart. In cases where the floor is very unstable, it is sometimes necessary to introduce mechanical ties or formwork to bond the floor together first. Then, once the floor is stabilized, poor gravel is removed, holes are filled with clean aggregate and the affected area is carefully grouted. From the lowest point the nozzle can reach through the floor holes or drilled holes, pressure as low as that from pouring the grout through a watering can is used, while carefully monitoring the conditions of the floor opening and amount of wet liquid poured. When employing the above tentative approach, achieving a reasonable flow of grout that also limits the migration of material into sensitive habitat is difficult.

Preferred Option: Bentonite Grout -- Bentogrout

Bentogrout is composed of bentonite, a natural clay material (Christidis and Huff, 2009), and mixed with water to form a thick, injectable slurry (CETCO Bentogrout, 2011). Once set, Bentogrout creates an inert, flexible, impermeable barrier. Bentogrout is applied at approximately 2 in/s, but pressure and viscosity will be adjusted for environmental conditions and monitored by the contractor. As injection occurs, poolside gaps will be observed to assure excess material is not seeping into and solidifying in salamander habitat. (MSDS information in Appendix D.)

2.1.5.7.4 Rationale for Selection of Bentogrout

The Uretek sealant has several concerning toxicological and chemical properties, but it has the advantage of being hydrophobic and inert once placed. It also has the advantage that as a foam, it can penetrate further into the substrate and seal water passages that have caused the most damage to the floor of the bypass. Cementitious grout has more familiar properties and less potential toxicity. However, it is more likely to dissolve in moving water and be carried beyond the immediate floor area during construction. Any loss of material in moving water under the bypass has potential to reach salamander habitat. Bentogrout has a controlled penetration and containment and is the least toxic material reviewed; therefore this product was selected for application.

2.1.5.8 Tie Backs

A maximum of 30 Manta Ray and Stingray Tieback anchors will be installed in segments 6 through 8. Holes will be drilled through the north wall of the bypass at an angle and the tiebacks will be installed (Fig. 11). Tiebacks will extend approximately 10 ft into the embankment and will terminate above bedrock, based on soil boring data collected near these segments (AECOM report, 2010). The tiebacks will then be anchored to the bypass wall using steel bearing plates and the holes through the concrete plugged with cement. Installation will follow S-4.5 through S-4.8, S-6.2, and SS05120 in Appendix B.

2.1.5.9 Rock Anchors

A maximum of eighty hollow-core spin-lock type anchors will be used in Segments 1-5.5 (Fig. 12; Appendix B drawings S-4.1 through S-4.5), with restricted use to the eastern portion of Segment 5 due to the estimated location of the Barton Springs Fault. Each anchor will be attached to the bedrock approximately 3.5 ft beneath the surface of the bedrock. A PVC casing around the anchor will extend from the surface of the existing bypass floor to approximately 1 inch into bedrock (Fig. 12) and will prohibit the flow of grout material into any void space beneath the bypass. Steel bearing plates sitting atop the bypass floor will help ensure proper function of rock anchor support and weight distribution on existing floor. All rock anchors will be tested prior to grouting in place to ensure proper function. Rock cores will be taken to assess competency of bedrock. Rock anchors will only be used where the bedrock is competent and lacking macropores. If the bedrock is not competent or if the rock anchor fails, the hole will be filled with bentonite, a naturally occurring clay. If a flowing void is punctured, the hole will be abandoned and the void will be filled following the same USFWS approved protocol designed for rock anchor testing in August 2010 (Fig. 13; Appendix F).

Cementitious grout is recommended for filling between the casing and the rock anchor. The amount of material used per anchor will not exceed the amount of material required to fill between the casing and the anchor. Grout leaking from the casing into void space would have an immediate, direct effect on any salamanders present around the casings.

2.1.5.10 Expansion Joints

Expansion joints that are severely deteriorated with large concrete spalls or delaminations at either side of the joint will be repaired by one of four methods. The first two methods were suggested in a 2006 assessment of the bypass (PKA), the third method was suggested during preliminary engineering for the proposed project (PKA), and the fourth method was recommended by AECOM in the 2011 60% design submittal.

2.1.5.10.1 Expansion Joint Repair Option 1

Repair Option 1 consists of carefully removing 2 ft of concrete and exposing the existing rebar on either side of the joints. Extra care must be used to avoid damage to the existing culvert structure and cutting of the existing reinforcing steel. The joint can then be reconstructed with class "c" (3,600 psi) concrete with a 9-inch ribbed PVC center-bulb water stop. Prior to the concrete placement, the exposed concrete surface of the existing culvert would be coated with a concrete bonding agent, followed by installation of a Synko-Flex Waterstop. Acceptable concrete bonding agents include Sika Armatec 110 EpoCem manufactured by Sika Corporation and Slow Set Bonding Agent manufactured by Unitex Corporation. Where voids exist below the bottom slab, they would be filled with concrete as part of the reconstruction process. Voids in the embankment would be filled during backfilling operations. (MSDS information in Appendix D.)

2.1.5.10.2 Expansion Joint Repair Option 2

Repair method Option 2 consists of cutting the existing dowels across the culvert expansion joint and installation of a strip and seal system around the interior surface of the culvert expansion joints. This strip and seal system consists of a 12-inch wide Hypalon sheet adhered to the concrete surface(s) of the joint with an epoxy material. The system would be protected and covered by a 3/8th-inch galvanized steel plate anchored to one side of joint. The system can accommodate irregular surfaces and cracks or spalls up to eight inches wide and withstands large movements in the joint. Acceptable products are Sikadur Combiflex (for the Hypalon sheet) and Sikadur 31, Hi-Mod Gel for the epoxy paste adhesive, all manufactured by Sika Corporation. Both Sikadur Combiflex and Sikadur 31, Hi-Mod Gel are potable water approved products. Where large spalls or delaminations exist, the concrete would require removal down to sound concrete. The areas would then be built-up using SikaTop 123 Plus to provide a surface satisfactory for installation of the strip and seal system. On the Pool side of the south wall, delaminations and spalls at the joints would be repaired using this same material. Voids below the bottom slab would require filling by pressure grouting prior to installation of the strip and seal system. Voids at the exterior side of the north wall will be filled by use of flowable fill or pressure grouting as discussed below under 2.1.5.6. (MSDS information in Appendix D.)

2.1.5.10.3 Expansion Joint Repair Option 3

Option 3 is a modification of Option 2, and consists of cutting the walls at both sides of the joint, and reconstructing the walls and joints, with dowels connecting new concrete with existing walls.

2.1.5.10.4 Expansion Joint Repair Preferred Option

Repair option 4 consists of carefully removing 3ft 10 in strips of concrete centered on expansion joints and exposing the existing rebar on either side of the joints. Extra care must be used to avoid damage to the existing culvert structure and cutting of the existing reinforcing steel. New reinforcing steel, non-slip dowel bars will be epoxy-grouted in place and bulb-centered waterstop strips will be installed as described in Appendix B (drawings S-6.3 through S-6.5). On the north side of the bypass, a steel plate will be inserted between the embankment and the bypass wall to provide support when pouring concrete. The south side of the bypass in Barton Springs Pool and within the bypass will have temporary shoring, bracing, and forms to provide support when working on expansion joints. Roof repairs will be performed in a similar manner, but completed after the new floor slab is completed.

2.1.5.11 Transverse Cracks

Transverse cracks will be injected with a urethane crack repair material. A surface seal material will be applied to the surface of the crack prior to grout injection to prevent flow of the grout material from the crack. Two 45˚ holes will be drilled on either side of the crack to intersect the crack midway (refer to SS03705 and S-5.1). The grout will be mixed with potable water and injected into the ports at rates specified by the manufacturer of the grout. After the grout has cured, the surface seal will be removed and the face of the crack finished.

Acceptable products with potable water activators are ”SikaFix HH” by Sika Corporation and “Scotch Seal 5600 Chemical Grout” by 3M Company. They are both one-component epoxy-based surface seal materials that are applied with automated pressure-injection equipment (MSDS information in Appendix D). It can be applied to dry or damp concrete surfaces, but not to surfaces with standing water. Special care must be used in preparing the surface to meet manufacturer's recommendations.

2.1.5.12 Concrete Delaminations and Spalls
Partial-depth delaminations and spalls must be removed down to sound concrete, taking care not to damage existing reinforcing steel. Exposed reinforced steel will be cleaned of rust and prime coated with either "Zincrich Rebar Primer", by BASF Chemical Company or "Armatec 110 EpoCem" by Sika Corporation. Hook bars will be installed each square foot and epoxy grouted in place using HIT-RE500 (MSDS information in Appendix D). The repair area will be formed and patched using an acceptable mortar material. For full-depth repairs, straight steel dowels will be epoxy grouted into the existing concrete instead of hook bars.

Acceptable mortar materials are "LA/LA40 PMAC Repair Mortar", "EMACO S66-CR" and "HB2 Repair Mortar" by BASF Chemical Company, "Sto Flowable Mortar CR730" and "Sto Trowel-Grade Mortar with Cl" by Sto Corporation, and SikaTop 123 PLUS manufactured by Sika Corporation (MSDS information in Appendix D).

SikaTop 123 PLUS is a potable water approved, two-component, polymer-modified, non-sag, fast-setting mortar (MSDS information in Appendix D). It can be applied to vertical and overhead surfaces and is required to be applied to a surface that is saturated with clean water, but without standing water. Special care must be used in preparing the surface to meet the manufacturer's recommendations.

2.1.5.13 New Concrete Floor
A 10 in thick reinforced microsilica concrete overlay with a 150-pcf unit weight will be laid atop the existing bypass floor of segments 1-5 and 9-13. Sections 6-8 will be laid with a 10 in thick reinforced heavy-weight concrete overlay with a 250-pcf unit weight, using natural hematite aggregate. Hematite, with a density of 5.3, adds weight to the concrete. All holes and voids in the bypass floor will be patched prior to laying the floor. Tie backs and rock anchors will be installed and tested prior to pouring new floor. Temperature of concrete, as placed, is not to exceed 85˚F without approval of the Engineer. Although not anticipated, if the concrete is vibrated to help with consolidation, a frequency of up to 8000 v/min will be provided. Concrete finishing will be done by hand with a bullfloat or a darby.

2.1.5.14 Deck Drains and Weep Holes
New wall drains will be installed by excavating the embankment against the North wall of the bypass. Excavation per day will be limited to the amount of length of wall drain that can be completed per day to assure that excavated material is returned to the embankment before construction is completed each day. Wall drains will be an aggregate between 5/8 inch and 1 inch in size wrapped in a geotextile filter fabric, such as Webtec or Terra No. 4 Geotextile Fabric (Fig. 12). If void space exists beneath the wall drain, it will be backfilled with lightweight CLSM. Weep holes, 2 inches in diameter will be drilled from within the bypass tunnel to the wall drains. Deck drain boxes will remain accessible and 6-inch drain holes will be drilled for drainage from the deck drain boxes into the bypass tunnel (Fig 11). If the existing 12inch pipe remains in place, the ends will be grouted shut.

2.1.5.15 Valves

Valves will be installed along the bypass wall for increased flexibility in cleaning the beach area of Barton Springs Pool. One valve per segment along the beach area will be installed 1 ft downstream of the expansion joint and 1.5 feet above pool side substrate (Appendix A drawing S-6.4). Worcester Controls Three Piece Ball Valves with a 2-inch diameter are proposed with the valve installed on the bypass interior. A 2-inch stainless steel wall pipe will be placed horizontally through the bypass wall and will terminate flush with the poolside wall of the bypass. It will have a female thread on the poolside for optional attachment of hoses.

2.1.5.16 Deck Waterproofing

The concrete deck will be cleaned in preparation for membrane application (Appendix B specification SS07500). If any cracks, delaminations, or spalls are observed in the concrete after sand- and shot-blasting, they will be repaired prior to the waterproof coating application. All decking coats will be applied with appropriate squeegees using manufacturer specified application rates.

2.1.5.16 Equipment Cleaning

Any equipment used underwater at anytime in Barton Springs Pool, Eliza Spring, or Barton Creek will be cleaned, disinfected with bleach or commercially available detergent, and thoroughly dried prior to use in wetted area to avoid introduction of amphibian pathogens such as chytrid fungus. Such equipment will not be used for any other wetted sites during this project.

2.1.5.4 Leaking Pipe Connections

Connections around pipe inlets into the culvert that leak water, such as the skimmer pipe and the stormwater inlet, will be plugged with a fast-setting cement-based water stop or hydraulic cement. The following products are acceptable for the repair of leaking joints:

2.1.5.4.1 SikaSet Plug

SikaSet Plug is a fast-setting, Portland-cement water stop manufactured by Sika Corporation. When it is mixed with water, it becomes a mortar/grout that will stop pressure leakage and seepage. It can be applied to minor or large openings. (MSDS information in Appendix D.)

2.1.5.4.2 WaterPlug

WaterPlug is a portable water approved, fast setting, cement-based water-stop mortar manufactured by Degussa Building Systems. When mixed with water, it expands and sets to lock into place to stop running water. (MSDS information in Appendix D.)

2.2 Downstream Dam Repairs

Repairs to the downstream dam of Barton Springs Pool will occur concurrently to Phase III of the bypass repairs. While completing the projects concurrently, dam repairs are not to extend the time required for diverting Eliza flow. As mentioned previously, methods and materials were chosen based not only on construction effectiveness, but also minimization of potential detrimental impacts on protected salamander species.

2.2.1 Cofferdam or dewatering structure

Refer to section 2.1.5.4 for details on cofferdam selection and limitations. The extent of the cofferdam will not impede flow from any gates on the downstream dam. If dam repairs are done within Phase III of the bypass repairs, the cofferdam can be adjusted to incorporate workspace needed for dam repairs (see Fig. 3).

2.2.2 Sealing Cracks along Vertical Wall
Refer to section 2.1.5.11 for details on sealing cracks.

2.2.3 Sealing Cracks along Top of Dam
Cracks along the top of the downstream dam will be v-notched wider than 0.020 inches. Sealant will be installed as described in SS07500.

2.2.4 Waterproofing Membrane
Refer to section 2.1.5.16 for materials and application of the waterproofing membrane.

2.2.5 Physically Connecting Horizontal Cracks
Holes (1 in diameter) will be drilled at a downward angle, towards the dam center, into the dam from the upstream and downstream sides of the dam (Fig. 14). Hole depth with be approximately 3 ft long and depth will be centered on the horizontal crack. Stainless steel rods will be epoxy grouted into the holes with HIT-RE 500 (MSDS information in Appendix D).

3.0 Action Areas

This project will be conducted in Barton Springs Pool and equipment and supplies will be staged in two locations nearby (Fig. 4a,b). The action area includes the Barton Springs Fault, a portion of the Balcones fault system that feeds Parthenia Spring within Barton Springs Pool and adjacent Eliza Spring. The action area of the project encompasses all of the surface and epigean habitat of *Eurycea sosorum* and subterranean habitat of *Eurycea waterlooensis* within and between Parthenia, Eliza, and Upper Barton Springs. It also includes the entire aquatic environment of Barton Springs Pool and the riparian habitats within the action area (Fig. 15).

In description of the resources affected by the proposed project, the physical attributes of Barton Springs are provided along with the biological attributes supporting the ecology of the springs and thereby the support of the two imperiled salamander species.

3.1. Physical Attributes

The Barton Springs complex is located in Zilker Park near the center of Austin, Texas. Barton Springs consists of Parthenia (Main) Spring in Barton Springs Pool, Eliza (Concession or Elks) Spring, Old Mill (Sunken Garden, Zenobia or Walsh) Spring, and Upper Barton Spring. In Barton Springs Pool, there are additional references to local spring outlets where salamander surveys are conducted. These include Side Spring, Little Main Spring and the Fissures area.

Barton Springs are the largest natural discharge points for the Barton Springs segment of the Edwards Aquifer (BSEA). The BSEA is located south of the Colorado River at the City of Austin, Texas, and extends south to the Buda and Kyle areas, east to Interstate 35 (IH35) and west to FM 1826. The portion of the aquifer segment south of the Williamson Creek watershed is a federally designated sole source aquifer (EPA 1988). The Recharge Zone of the Barton Springs segment is 98 square miles in size in Travis and Hays Counties (Smith and Hunt 2002). The Contributing Zone is 254 square miles in size in Travis, Hays and Blanco Counties (Slade et al. 1986). The Edwards Aquifer generally overlies the less permeable upper member of the Glen

Rose Formation in the Trinity Group. The less permeable Del Rio Clay Formation overlies and confines the aquifer.

The Edwards Aquifer is a karst aquifer. A karst aquifer develops within relatively soluble rock where appreciable groundwater flow occurs through the dissolved openings (Maksimovich 1963; Aley 2000; Field 2002). Karst landscapes commonly contain sinkholes, losing streams, caves, and springs. Dissolution by recharging chemically undersaturated waters progressively enlarges openings in the limestone and dolomite host rock creating an integrated network of conduits. Recharge waters enter the aquifer through point features such as caves, sinkholes or solution-enlarged fractures in six major creek channels of Barton, Williamson, Slaughter, Bear, Little Bear and Onion Creeks that cross the outcrop of the Edwards Aquifer (Slade et al. 1986). Additional recharge occurs as direct infiltration through upland soils and bedrock surfaces, leakage from adjacent aquifers and some small amount from urban infrastructure. Large openings enable large volumes of water to rapidly enter the aquifer and migrate down gradient toward wells and springs.

The majority of the water that recharges the Barton Springs segment originates as rainfall runoff in the Contributing Zone west of the outcrop of the Edwards Aquifer (Slade et al. 1985; Barrett and Charbeneau 1996). Tracing studies have documented rapid travel rates, ranging from 1 mile/day to 4 mile/day (Hauwert et al. 2004). These rates are dependent on water levels in the aquifer. Under high water table conditions, recharging water may first reach Barton Springs over time periods ranging from several hours to a few days depending on distance. When the water table is low, recharging water can take weeks to reach Barton Springs from distinct recharge points.

The long-term average spring flow of Barton Springs is 53 ft^3/s from 1917-1995 (City of Austin compilation analysis of USGS Water Resources Data). The lowest flow measurement recorded for Barton Springs was 9.8 ft^3/s in 1956 (Brune 1981) near the end of an extended drought (local drought of record). Discharge from Barton Springs sustains flow in the lower portion of Barton Creek and contributes to Lady Bird Lake on the Colorado River.

The largest of the perennial springs is Parthenia, which historically was a part of a large and at times powerful, free-flowing central Texas creek. During floods, surface water mingled with spring water and flowed downstream, naturally scouring the creek channel. Sediment, rocks and woody debris were carried down into the Colorado River, and ultimately to the Gulf of Mexico (Leopold et al. 1992). Currently, Parthenia Spring is contained with Barton Spring Pool, a man-made impoundment of Barton Creek, consisting of upstream and downstream dams (Fig. 15). These dams and a bypass culvert divert creek flows up to approximately 500 ft^3/s around the Pool. Larger flows overtop the upstream dam and travel through the downstream dam into the remaining stretch of Barton Creek. With the presence of dams, material carried with water flow over the upstream dam is captured within the confines of the Pool and must be removed. The Pool bottom is a mix of natural limestone bedrock and concrete in the upstream shallow end and bedrock and fluvial sediments (silt, sand and gravel) in the deeper downstream end of the pool. Water depths vary from a few inches to approximately 20 feet.

Barton Springs Pool is contained within the grounds of Zilker Park in central Austin and is visited by over 500,000 people annually. Areas immediately around the Pool are regularly maintained park grounds. Turf grass lawns are mowed during growing season and trees are periodically trimmed. New trees are planted to replace aging or dead trees. The management of the Pool has changed considerably since *E. sosorum* was listed as endangered and a Habitat Conservation Plan developed. For example, chemical cleaners are no longer used, pool draw downs are restricted and habitat areas are cleaned only by permitted biologists.

Smaller Eliza and Old Mill Springs are both surrounded by stone and concrete amphitheaters. Old Mill retains an overland outflow stream, while outflow from Eliza is directed underground to the bypass culvert and ultimately downstream into Barton Creek. Water depths range from 0.5 to 19 in Eliza and 5 to 40 in in Old Mill.

3.2 Biological Attributes

Barton Springs resides at the junction of two terrestrial biogeographic regions of central Texas, the Edwards Plateau to the west and the Blackland Prairie to the east. Historically the Blackland Prairie was dominated by tallgrass prairie upland and deciduous bottomland forest (Diamond and Smeins 1993), while the Edwards Plateau was a mix of savannah and riparian woodland (Bray 1904). These two regions host 331 species of flora (TPWD Species Lists), and over 500 species of fauna (Schmidly et al. 1993). The climate in the Edwards Plateau region of central Texas is generally arid and is characterized by episodic droughts and floods (Baker 1977). This cycle plays an integral role in the 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. Because this region has numerous perennial and intermittent springs (Brune 1981), it is a global hotspot for endemic karst species (Culver and Sket 2000).

The Colorado River and its tributaries, including Barton Creek and Barton Springs fall within the boundaries of the East Texas Gulf freshwater ecoregion (Abell et al. 2000). The fauna within the Colorado River basin are mostly transitional; and the river is the southern boundary of many species range (Abell et al. 2000). This ecoregion is home to over 100 fish species, few of which are endemic (Conner and Suttkus 1986). Many endemic spring and karst aquatic fauna are found where the Edwards Aquifer discharges within this freshwater ecoregion (Culver et al. 2000). The limestone of the Edwards Aquifer reacts with carbon dioxide and buffers the pH of the groundwater, keeping it at or near neutral, an environmental requirement for endemic freshwater species that are adapted to neutral pH (Pierce 1985 and references therein; Moyle and Cech 1988).

Barton Springs is part of a flowing water system. The increased flow velocities of creeks and rivers are the dominant feature that separates them from lakes and ponds (Leopold et al. 1992). Flowing water influences every part of the aquatic ecosystem (Giller and Malmqvist 1998; Wetzl 2001), from the amount of sediment (Nowell and Jumars 1984) and type of algae (Blum 1960; Reiter and Carlson 1986; Poff et al. 1990) to the community of invertebrates and vertebrates (Vogel 1994). Faster, unidirectional water flow naturally favors growth of tightly attached algae (Fritsch 1929; Korte and Blinn 1983; Stevenson 1983), favors a diversity of stream-adapted invertebrates (Hynes 1972), and helps maintain high water quality (Spellman and Drinan 2001).

4.0. Species and Habitat Considered

There are a number of federally protected species in the Austin area (Table 1 below).

City of Austin Watershed Protection Dept.
Barton Springs Bypass and Downstream Dam Repairs
USACOE #SWF-2011-0208
USFWS #21450-2010-F-0150 (issued Sep. 2011)

Table 1. Federally protected endangered species and species of concern in the Austin area are listed. Endangered status is denoted by E, concern status is denoted by C, threatened status is denoted by T, candidate status is denoted by D.

Species Name	**Status**	**Common Name**
Amphibia		
Eurycea sosorum	E	Barton Springs Salamander
Eurycea waterlooensis	D	Austin Blind Salamander
Eurycea tonkawae	D	Jollyville Plateau Salamander
Osteichthyes		
Micropterus treculi	C	Guadalupe Bass
Aves		
Dendroica chysoparia	E	Golden-cheeked Warbler
Vireo atricapillus	E	Black-capped Vireo
Haliaeetus leucocephalus	T	Bald Eagle
Grus americana		Whooping Crane
Mammalia		
Ursus americanus	T	American Black Bear
Plantae		
Philadelphus ernestii	C	Canyon Mock-Orange
Streptanthus bracteatus	C	Bracted Twistflower
Croton alabamensis var. texensis	C	Texabama Croton
Karst Taxa		
Arachnida: Pseudoscorpiones		
Tartarocreagris texana	E	Tooth Cave Pseudoscorpion
Tartarocreagris intermedia	C	
Arachnida: Aranae		
Neoleptoneta concinna	C	

Table 1. (continued)

Species Name	**Status**	**Common Name**
Neoleptoneta devia	C	
Neoleptoneta myopica	E	Tooth Cave Spider
Cicurina bandida	C	Bandit Cave Spider
Cicurina cueva	C	
Cicurina reddelli	C	
Cicurina reyesi	C	
Cicurina travisae	C	
Cicurina wartoni	D	Warton Cave Meshweaver

Eidmannella reclusa	C	
Arachnida: Opiliones		
Texella reddelli	E	Bee Creek Cave Harvestman
Texella reyesi	E	Bone Cave Harvestman
Texella spinoperca	C	
Coleoptera		
Texamaurops reddelli	E	Kretschmarr Cave Mold Beetle
Rhadine persephone	E	Tooth Cave Ground Beetle
Rhadine austinica	C	
Rhadine s. subterranean	C	
Rhadine s. mitchelli	C	
Diplopoda		
Speodesmus sp.	C	
Pseudoscorpionida		
Aphrastochthonius sp.	C	
Tartarocreagris sp.	C	
Tartarocreagris comanche	C	
Tartarocreagris reddelli	C	
Tartarocreagris intermedia	C	
Ostracoda		
Candona sp.	C	
Isopoda		
Caecidotea reddelli	C	
Trichoniscinae sp.	C	
Miktoniscus sp.	C	

The terrestrial karst taxa live in karst features within the Edwards Formation in the Austin area. None of these species are expected in the Action Area due to the lack of surface karst features. Some aquatic karst taxa may occur within Barton Springs. Although they are considered species of concern, none are protected by federal or state regulations.

Habitat for the two endangered neo-tropical migratory songbirds, *Dendroica chysoparia* and *Vireo atricapillus*, 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 Action Area is not occupied habitat due to urbanization (Balcones Canyonlands Conservation Preserve Lisa O'Donnell personal communication). Therefore, these species will not be affected by the project proposed here. *Haliaeetus leucocephalus* are known to occur in eastern Travis County but have never been recorded in the Action Areas.

Ursus americanus are known to have occurred in Travis County but have never been recorded in the Action Areas. *Micropterus treculi* is found within the action area. Conservation measures to protect *Eurycea sosorum* will also protect *Micropterus treculi*.

Habitat for *Philadelphus ernesti* includes the steep canyons and slopes of western Travis County (BAT 1990 as cited in BCP 2007). Habitat for the *Streptanthus bracteatus* includes thin clay soils blanketing limestone in oak-juniper woodlands. None of these plants occur in the managed landscapes of Zilker Park and Barton Springs.

4.1 Natural History of North American Salamanders

Salamanders are amphibians, which generally require moist or wet habitats to survive (Duellman and Trueb 1994; Petranka 1998). 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; Fig. 16). 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. 16).

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 (Fig. 17; Chippindale et al. 2000). There are numerous intermittent and perennial springs throughout the 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 region is generally arid, these springs and spring-fed streams are the only sites where presence of water is reliable. These conditions together are thought to have favored the evolutionary loss of metamorphosis and consequent dependence on epigean (surface) and/or subterranean spring-fed streams throughout the life span of central Texas *Eurycea* (Sweet 1977, 1982; Chippindale et al. 2000).

Edwards Aquifer spring-fed streams ebb and flow with the level of the water table (Brune 1981), and resident perennibranchiate *Eurycea* experience natural contractions and expansions of their aquatic habitat (Sweet 1982). This somewhat predictable variation in the water table and the size of epigean habitat is thought to play a role in the evolution of life histories of Edwards Aquifer *Eurycea* species (Sweet 1982; Shaffer and Breden 1989). To the extent that natural variation in epigean stream flow provides a reliable signal of impending contractions and expansions, it could influence a variety of characteristics in perennibranchiate *Eurycea* species from timing of reproduction to migration between epigean and subterranean habitat (Levins 1968; Schmidt-Nielsen 1975; Pianka 1983; Tumlinson and Cline 1997).

4.1.1 *Eurycea sosorum* and *Eurycea waterlooensis*

Federally protected species in the Action Area are endangered *Eurycea sosorum* and candidate *Eurycea waterlooensis*. *Eurycea sosorum* and *E. waterlooensis* are both solely aquatic perennibranchiate species that inhabit the Edwards Aquifer springs known as the Barton Springs complex (Chippindale et al. 1993). Both have two of the smallest ranges of any vertebrate in the United States (Chippindale et al. 1993; Hillis et al. 2001). The three perennial and single intermittent springs of this complex are located within a 400 yard radius circle and are associated with Barton Creek (Fig. 18). The small size of its range, threats to quantity and quality of water emanating from the springs, and harm imposed by cleaning and maintenance of Barton Springs Pool are the main reasons *E. sosorum* was added to the federal list of endangered species (USFWS 1997). *Eurycea waterlooensis* differs from *E. sosorum* in that it is primarily subterranean (Hillis et al. 2001). It was placed on the U.S. Fish and Wildlife candidate species list in 2002 because of threats to quality and quantity of water in the Barton Springs segment of the Edwards Aquifer.

The presence of two *Eurycea* species in a single spring complex is not unique to Barton Springs. There are two other perennial spring complexes south of the Colorado River that harbor *Eurycea* species pairs, San Marcos and Comal Springs. Each of these also contains an epigean, surface-adapted species and a subterranean, cave-adapted species (Fig. 17). Epigean *E. nana*, *E. sosorum* and *E. neotenes* are syntopic with the subterranean *E. rathbuni*, *E. waterlooensis*, and undescribed *Eurycea* sp., respectively. The subterranean species form a separate evolutionary group (Hillis *et al*. 2001; Bendik 2006). In contrast with other Texas *Eurycea* from intermittent habitats, these epigean and subterranean *Eurycea* are distinct species adapted to their respective microhabitats. Evidence that these subterranean and epigean species remain distinct is provided by published genetic and morphological information (Chippindale et al. 2000; Hillis et al. 2001). A recent genetic survey of a small region of mitochondrial DNA from a very small number of *E. sosorum* revealed some similarity with sequences from *E. waterlooensis* (City of Austin, unpublished data). However, most wild *E. sosorum* and *E. waterlooensis* do not exhibit intermediate morphologies. Characteristics are typically consistent with either surface (e.g. dark pigmentation) or subterranean dwelling (e.g. reduced eyes). Furthermore, there is evidence of partial overlap in diet composition and egg deposition sites of *E. sosorum* and *E. waterlooensis*, which is indicative of selection for ecological niche-partitioning to reduce competition (Vrijenhoek 1979; Pianka 1983). These factors likely maintain genetic divergence between these species as is known for a variety of other species.

4.1.1.1 Morphology

Eurycea sosorum and *E. waterlooensis* share some morphological similarities. Adults of both species are roughly 1.5 to 3.5 inches in total length (TL) and typically have 4 toes on their forefeet and 5 toes on their hind feet (Chippindale et al. 1993; Hillis et al. 2001; City of Austin, unpublished data). Each salamander has 6 external gills, 3 on each side of the head, reduced, spindly limbs, and dorsoventrally flattened fin on the tail. The two species differ in a few key characteristics that appear to be adaptations to their respective microhabitats. 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, Hillis et al. 2001). While *E. waterlooensis* also has iridiphores, its background pigmentation is purple, lavender, peach, or brown overlying a layer of reflective connective tissue. The snout of *E. waterlooensis* is pronounced and shovel-like, while its eyes are reduced to spots beneath the skin. These salamanders do not have image-forming eyes but may detect light. These are characteristics of subterranean life where absence of light renders prey or predator detection by vision impossible and other sensory systems, such as olfaction, serve that function. In contrast, *E. sosorum* has fully developed eyes with image-forming lenses, a rounded snout and a smaller head, characteristics consistent with life at the surface where light makes vision useful.

4.1.1.2 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 rifles beetles, snails, and leeches (Chippindale et al. 1993; Gillespie 2011, COA unpublished data). *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.

Longevity data are currently only available for captive *E. sosorum* and *E. waterlooensis* (City of Austin, unpublished data). 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 14-year-old male that hatched in 1997. The oldest *E. waterlooensis* in captivity is 12.5 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; City of Austin, unpublished data). 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, respectively, in a clutch (City of Austin, unpublished data). The eggs are laid singly and this process can take 12 hours or more. 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 (City of Austin 2002). Hatchlings are about half an inch total length (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 total length) and grow to about 3 inches total length as adults. In captivity, *E. sosorum* has been observed reproducing to an age of at least eight years (City of Austin, unpublished data). *E. waterlooensis* become sexually mature at about 18-23 months (48-55 mm total length) and grow to 3.5 inches total length as adults. Wild-caught adults in captivity have reproduced to an age of at least 4.5 years (City of Austin, unpublished data).

4.2 Habitat

E. sosorum salamanders are found in streams and shallow pools where groundwater exits the aquifer (Chippindale et al. 1993; City of Austin 2004, 2005, 2006, 2007). The interstitial spaces are critical microhabitats for *E. sosorum* and other aquatic *Eurycea* species (Randolph 1978; Tumlison et al. 1990; Barr and Babbitt 2002; Bonett and Chippindale 2006). Adults and juveniles inhabit interstitial spaces of substrate where flowing water prevents accumulation of sediment. These areas provide protection from aquatic and terrestrial predators, and harbor abundant invertebrate prey. Water flow provides constantly renewing dissolved oxygen at concentrations which fluctuate with aquifer discharge levels. Excess sediment inhibits growth of algae, reducing occurrence and abundance of invertebrate prey. While salamanders have been found in aquatic moss, plants and leaf litter, recent data suggest that *E. sosorum* prefers clean areas beneath rocks. Since 2003, the majority of salamanders in Eliza and Parthenia Springs have been found beneath gravel and flat cobble even when alternative types of cover are available (City of Austin, unpublished data).

E. waterlooensis is predominately a subterranean species and is thought to spend most of its life in the aquifer (Hillis et al. 2001). This species has been found in surface habitats of Parthenia, Old Mill, and Eliza Spring; therefore, *E. waterlooensis* is assumed to inhabit the subterranean environment associated with these springs. Its appearance in surface habitats is uncommon, and is typically seen near spring outlets (caves and fissures) in habitat similar to that in which *E. sosorum* is found (City of Austin, unpublished data). It has not been found at intermittent Upper Barton Spring.

Primary salamander habitat of Parthenia Spring consists of three cave openings along the base of the submerged rim rock ledge that are the main outlets, and numerous fissures in the top of the rim rock ledge upstream of the cave (Fig. 19; City of Austin 2004, 2005, 2006, 2007). All of these areas include the openings where water flows from the springs. Surveyed areas are the rocky substrate just inside the mouth of each cave, Main, Little Main, and Side Spring, extending downstream. Main Spring is the northeastern cave, river right of the channel, with a survey area of 405 ft^2 (W15 ft. x L26.75 ft.). Abutting Main Spring to the southwest, in the center of the channel, is Little Main, with a survey area of 800 ft^2. (W 20 ft. x L 40 ft.). Abutting Little Main to the southwest, river left of the channel is Side Spring, with a survey area of 1000 ft^2. (W25 ft. x L40 ft.) The fissures are a series of cracks and crevices scattered about an 1800 ft^2 area just upstream of the caves. The habitat of Main, Little Main, and Side Spring is always under 10 –20 ft of water except during draw downs of the Pool. The maximum decrease in depth possible is 5 – 6 ft. The substrate in front of the caves is bedrock sloping northeasterly, with an overlying layer of gravel, cobble, and boulder to variable depths. This substrate is largely free of moss, and, under favorable water flow conditions, has abundant interstitial spaces, attached periphyton, and scattered patches of aquatic macrophytes (*Vallisneria americana, Heteranthia dubia*, *Sagittaria graminea*, *Bacopa monnieri*). The fissures area is submerged under water varying in depth from 2 – 9 ft. The habitat generally consists of small gravel and rocks in the cracks and crevices with moss on the walls, and on the flat areas in faster flowing water. There are also a few aquatic macrophytes in this area. Salamanders found in this section are typically found in the cracks, rather than on the top flat surfaces.

Periods of high and low water flow are a natural characteristic of the Barton Springs/Barton Creek ecosystem (City of Austin 2004, 2005, 2006, 2007). In the present-day, the dams creating Barton Springs Pool inhibit the beneficial flushing of sediment and debris provided by shallower, free-flowing water from both the spring and the creek. Shallower streams and creeks may have stronger flow velocity depending on contributing drainage area size and consequently greater power to generate incipient motion of channel substrates and debris. 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 alteration by humans.

The majority of the aquatic habitat in Barton Springs Pool resembles a pond rather than a stream, with a predictable decrease in the diversity of stream species, increases in nuisance algae, increases in sediment accumulation and little improvement in salamander abundance (City of

Austin 2004, 2005, 2006, 2007; City of Austin, unpublished data). *E. sosorum* has been exposed to the alternation between increases and decreases of surface water flow, between flood and calm, over millions of years and presumably has adapted to co-exist with this cycle, if not flourish.

Protected salamander habitat within Barton Springs Pool consists of the springs and fissures areas and also includes an 11,000 square-foot area known as the beach (Fig. 1). The beach consists of a shallow gravel bench between the north bank of the Pool and the deeper original creek channel. The bypass culvert abuts the beach along its length, forming the northern wall of the aquatic environment in the Pool. The bypass sits on top of suspected subterranean habitat along the fault system between Parthenia and Eliza Springs.

Presently, much of the beach habitat is unsuitable for high densities of salamanders primarily due to sediment cover (City of Austin, unpublished data). Visual assessments of this habitat reveal decreasing quality with increasing distance downstream from the spring orifices. In general, 90-100% of the available substrate is covered by sediment that exceeds 1-2 inches in depth. Approximately 1,300 ft^2 of this habitat closest to the springs contains substrate with clean interstitial spaces in the gravel that could harbor salamanders. In the past, habitat may have been better in some aspects, but still did not harbor high densities of *E. sosorum* relative to the springs and fissures habitats. The beach habitat typically has low flow velocity, large areal percentage of sediment cover, deeper sediment depth, and little periphyton (Colucci 2009). Deeper sediment, greater percentage of sediment cover, and less periphyton are all factors associated with lower salamander abundance in Eliza Spring (see section 4.3.1). Since the lowering of the substrate in 1999, beach habitat has not improved and appears to have degraded in downstream areas. Plant cover has shifted from species found in more rapidly flowing water (e.g., *Ludwigia repens, Bacopa monnieri, Vallisneria Americana)* to dense stands of *Sagittaria platyphylla* and *S. graminea*, which prefer slow water flow. This is consistent with a reduction in flow velocity that would have occurred after increasing the water depth in the area in 1999.

Under average spring discharge, velocity of water flow along the substrate in beach habitat (<0.01 ft/s) is typically less than that necessary to keep interstitial spaces clean. Under low discharge (25 to 30 ft^3/s) from Barton Springs, velocity at the substrate in beach habitat is less than the detection limit of the Marsh McBirney flow meter commonly used in stream discharge measurement (Colucci 2009).

4.2.1. Subterranean Connection between Parthenia and Eliza Springs

Although the subsurface characteristics of the Barton Springs Fault are unknown, it is the most likely path for a subterranean connection between the source water of the two springs, Eliza and Parthenia. This would place any subterranean habitat and potential migration routes for the salamander below the bypass. Specific data are lacking with regard to the potential habitat for *E. sosorum* and *E. waterlooensis* underneath the bypass and in between Parthenia and Eliza Springs.

There are four pieces of evidence that indicate subterranean hydrologic connectivity between Parthenia Spring (the spring outlets within Barton Springs Pool) and Eliza Spring, and thus connectivity between designated habitats of *E. sosorum*. First, groundwater dye tracing has shown nearly identical aquifer pathways leading to Eliza and Parthenia Springs, and similar water composition (Hauwert et al. 2004). Second, stormwater constituents appear in Eliza Spring within minutes of their appearance in Parthenia (City of Austin, unpublished data). Third, there is an apparent re-direction of groundwater away from Eliza Spring when water level in Barton Springs Pool is lowered (City of Austin, unpublished data). The spring openings in Barton Springs Pool are roughly 15 feet below those of Eliza Spring (SAM 2009). When water depth in Barton Spring Pool decreases, there is a concomitant drop in Eliza Spring. Allowing Pool water depth to decrease reduces the hydraulic pressure exerted by surface water against the spring openings following Bernoulli's principle **(**Prasuhn 1938). Consequently, some of the groundwater previously exiting from Eliza Spring instead exits from the lower elevation openings of Parthenia Spring. This redirection of groundwater occurs until Barton Springs' discharge exceeds 80 ft^3/s (City of Austin, unpublished data) when presumably aquifer water levels are high enough that re-direction does not occur or is undetectable. Finally, Parthenia Spring emerges from the fault zone within the Pool. The main fault extends underneath the bypass (Hauwert 2009) and is directly in line with Eliza Spring (Fig. 19). Faulting across the Balcones Escarpment has had a large influence on the Edwards Aquifer by re-routing groundwater flow routes and compartmentalizing portions of the aquifer (Woodruff and Abbott 1979; Ogden et al. 1986; Hauwert et al. 2004). While faults can act as barriers to groundwater flow as well as conduits (Fetter 1988; Klimchouk and Ford 2000), the fault system in Barton Springs is likely a conduit from the aquifer to Parthenia and Eliza Springs and could serve as a migration pathway for salamanders between the two spring sites.

4.2.2 Use of Subterranean Habitat by *Eurycea*

Explicit patterns of subterranean migration in *E. sosorum*, *E. waterlooensis*, or other *Eurycea* have not been published. However, there is ample evidence to support the importance of subterranean habitat to *E. sosorum* and *E. waterlooensis* both from field observations and evidence from closely related species. Tumlinson and Cline (1997) observed that *E. tynerensis* possibly utilized subterranean corridors through bedrock-dominated springs and streams to move between habitats, especially when surface waters were dry. Strictly hypogean species, members of Typhlomolge, exclusively inhabit sub-surface waters and are only rarely observed at the surface, presumably as accidentals (e.g. *E. waterlooensis*) (Hillis et al. 2001). These species are cave specialists, exhibiting morphological characteristics typical of troglobitic organisms (Chippindale et al. 2000; Hillis et al. 2001). Thus, *E. waterlooensis* critical habitat is likely to include any subterranean passageways in and around Barton Springs.

Predominantly epigean central Texas *Eurycea* are also commonly encountered in caves and other subterranean habitat (Chippindale et al. 2000; Bendik 2006). *Eurycea tonkawae*, for example, depends on subsurface water to persist when spring flow is dry. Several headwater springs were dry for months during the drought of 2008 - 2009. As flow returned to the springs after the drought, so did *E. tonkawae* (City of Austin, unpublished data). Additionally, there are also several populations that appear to exclusively inhabit caves and recent evidence shows that they are genetically similar to surface populations (PT Chippindale, personal communication) as opposed to a distinct, unrecognized species. 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 subsurface waters as well as springs (Sweet 1978, 1984; Bendik 2006).

Field observations and data collected from *E. sosorum* abundance surveys also reflect the importance of subterranean habitat for this species, especially as a refuge during periods of low discharge from the aquifer (City of Austin 2004, 2005, 2006, 2007; City of Austin, unpublished data). During the drought of 2008 - 2009, lower than average discharge from Barton Springs was associated with smaller numbers of *E. sosorum* found during surveys without change in survey effort, particularly when discharge decreased below 40 ft^3/s for an extended period of time (see section 4.3). Whether this pattern was a reflection of a drastic increase in mortality or a shift to subterranean refuge (or some combination of mortality and movement) is unclear.

Although the extent of subterranean habitat that *E. sosorum* utilizes and under what conditions are uncertain, field observations, studies of closely related species and genetics indicate that it can be an important for survival and reproduction.

4.3 Salamander Abundance and Density

Eurycea sosorum abundance varies among the habitat locations within Barton Springs Pool (Fig. 20). From 1993 to the present, the largest proportion of salamanders occurred in and around the caves and fissures from which the groundwater emanates (Fig. 20) regardless of survey method. These proportions are largely independent of changes in density, and are not simply a consequence of greater or fewer salamanders in total. However, regular surveys have included only the upstream portion of the beach (Beach 1) or have not included the beach at all. Salamander abundance data for beach areas outside of regular survey areas are from experimental draw downs conducted from 1997 – 1998, and a single survey in December 2009. Nonetheless, these data also indicate that the majority of salamanders found on the beach are located in the upstream section near the springs and fissures (Fig. 20).

4.3.1 *Eurycea sosorum* Population Status and Trends

Assessment of the health and size of wild populations of *E. sosorum* is based on City of Austin abundance and density data from all four springs, perennial Parthenia (within Barton Springs Pool), Eliza, Sunken Garden/Old Mill/Zenobia and intermittent Upper Barton (City of Austin 2004, 2005, 2006, 2007). The period of record for these data is 1993 to the present, which includes data prior to federal listing in 1997. From 1993 to June 2003, data were collected for two size classes, juveniles (<1 in. Total Length, <0.6 in. Snout-Vent-Length; <25.4 mm TL, <15.3 mm SVL) and adults (≥ 1 in. TL). From 2003 to the present, the adult size classes are further divided into young adults at first reproduction (1-2 in. TL, 0.6 – 1.1 in. SVL; 24.5 – 50mm TL, 15.3 – 26.9mm SVL) and adults (≥ 2 in. TL). Status of salamander populations varies among spring sites because ecological conditions vary due to natural and anthropogenic factors. Analyzing salamander data from all sites combined would obscure the status of the salamander population in each spring site. Provided are assessments for each site because this provides a clearer picture of the salamander populations and habitat condition. Two factors that appear to have had differential effects in each spring site are habitat reconstruction and droughts. These are discussed below because they may provide some information on how the populations might be expected to respond in the future, and the potential effects of the proposed project on the status of the species as a whole.

Habitat reconstruction in Eliza Spring, an anthropogenic factor, resulted in an overall persistent increase in salamander abundance not seen in the other spring sites during the same time period. Another factor with variable influence among spring sites is drought. In the last five years, the

Barton Springs complex has experienced two periods when discharge remained below 40 ft^3/s for extended periods of time. In this document, we refer to these periods as droughts because this threshold is biologically relevant. When the discharge of the Barton Springs complex (all springs combined) is below 40 ft^3/s, surface habitat of Upper Barton Spring is dry, a condition that signifies natural habitat contraction that likely influenced the evolution of life history in *E. sosorum*. When Barton Springs' discharge is below 25 ft^3/s, dissolved oxygen in Eliza and Old Mill Spring drops to concentrations that likely affect salamander physiology. Based on data collected by the U.S. Geological Survey, during the drought of December 2005 through December 2006, groundwater discharge from the Barton Springs complex remained below 40 ft^3/s and dropped to a low of 21 ft^3/s. During the drought of June 2008 through September 2009, Barton Springs' discharge remained below 40 ft^3/s. During this period, it was below 25 ft^3/s for 12 consecutive months, dropping to a low of 13 ft^3/s, a level not seen since the drought of record in the 1950s (USGS, 1990; City of Austin, 2010; Smith and Hunt, 2010). At all three perennial springs of the Barton Springs complex drought conditions are magnified by dams and other impoundment structures (Giller and Malmqvist 1998). Although lack of rainfall feeding the aquifer is part of natural climatic variation, pumping of groundwater by humans is not. There are growing cities that draw groundwater from the Barton Springs segment of the Edwards Aquifer under all conditions. Therefore, we consider droughts that affect the Barton Springs complex semi-natural factors because their severity can be affected by this anthropogenic activity.

Both of these droughts also affected water quality; increases in water temperature and decreases in dissolved oxygen in surface habitats were the most notable changes in *E. sosorum* spring sites. These changes are predictable because decreases in discharge are associated with reduction in current velocity of surface spring water and generally causes decreases in dissolved oxygen in rivers and streams (Lampert and Sommer 1997 pg. 34; Giller and Malmqvist 1998 pg. 31-32; Wetzl 2001 pg. 151-164). In addition, the maximum concentration of oxygen that can be dissolved in water is inversely dependent on water temperature (Boyle's Law; Levine 1978; Wetzl 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.

Dissolved oxygen sustains animal life because it is used to convert food into metabolic energy (Eckert et al.1973). Both survival and reproduction depend on metabolic energy; its allocation to each depends on the amount available (Fig. 21) and the life history of the animal. For long-lived animals that reproduce more than once in a lifetime, such as *E. sosorum*, 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. Reproduction is delayed until environmental conditions improve. This gives rise to two predictions for *E. sosorum* that can be useful in predicting likely effects of drought. When dissolved oxygen is high, which occurs when discharge is higher, these salamanders are expected to reproduce, causing juvenile abundance to increase. Conversely, when dissolved oxygen falls below a reproduction threshold, juvenile abundance should decrease. Ultimately, when dissolved oxygen falls below the adult survival threshold, there should be a decrease in adult abundance. Thus, dissolved oxygen is likely one of the major indicators of salamander population status and trend and it is explicitly considered in this assessment. Similarly, when water temperature is lower, dissolved oxygen will be higher, also potentially promoting salamander reproduction and increases in juvenile abundance (Gillespie 2011).

Finally, of the four *E. sosorum* spring sites, the projects considered here will affect only Eliza and Parthenia Spring. Therefore, we provide site-specific assessments with emphasis on these two sites, which also have the largest salamander populations.

4.3.1.1 Eliza Spring

4.3.1.1.1 Abundance, Density, and Habitat Reconstruction

A census of the salamander population in Eliza Spring has been obtained roughly every month since 1995. These data suggest that this site has come to harbor the most robust population of *E. sosorum*. Abundance at this site likely provides the best information from which to infer population status because of two features. One, the smaller size of this spring (~ 800 sq. ft.) allows the entire surface habitat to be searched during every survey. Two, the presence of a concrete floor below surface substrate limits salamander access to the sub-surface, allowing for greater detection of salamanders if present.

There have been dramatic changes in abundance and density in this site due to anthropogenic and natural factors. The positive anthropogenic factor was habitat reconstruction of the spring pool in 2003 (City of Austin 2004). The changes in habitat included restoring more natural, shallow water depth, removal of rocks buried in sediment, and excavation of water flow paths along the substrate. These changes were followed by large increases in salamander abundance (Figs. 22, 23). Mean annual abundance from 1995 to 2002 is significantly lower than from 2003 through 2010, (Mann-Whitney $U = 150.5$, $z = -9.667$, $p < 0.0001$; Table 2). Increases in abundance and density of juvenile salamanders were followed by increases in young adults and subsequently, increases in adults (Fig. 24). Juvenile abundance is significantly positively correlated with young adult abundance three months later (Spearman Rank Correlation $\rho = 0.721$, $z = 5.395$, $p<0.0001$), and young adult abundance is likewise positively correlated with adult abundance two months later ($\rho=0.342$, $z=2.512$, $p=0.012$). Although it is possible that migration of salamanders of all size classes from other sites or between epigean and/or subterranean microhabitats contributed to the increases in abundance, the serial nature of the increases indicate the majority of this increase appears to be from reproduction and recruitment regardless of the source location of each size class.

Table 2. Mean, standard deviation (S.D.), and standard error (s.e.) of *E. sosorum* salamander abundance and density in Eliza Spring for each year of record are listed below. Minimum (Min.) and Maximum (Max.) salamander abundance are also listed. Density cannot be calculated for 1995 – 2002 because exact area surveyed is unknown.

Eliza	**Abundance (#)**						**Density (#/sq ft)**		
Year	**Mean**	**S.D.**	**s.e.**	**N**	**Min.**	**Max.**	**Mean**	**S.D.**	**s.e.**
1995	20.3	7.14	3.57	4	12	29	n/a	n/a	n/a
1996	7.7	8.19	2.47	11	1	23	n/a	n/a	n/a
1997	25.8	12.51	5.11	6	13	44	n/a	n/a	n/a
Before HCP 1995 - 1997	15.3	12.3	2.67	21	1	44	n/a	n/a	n/a
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
Before Reconstruction 1998 - 2002	6.3	5.78	0.87	44	0	23	n/a	n/a	n/a
2003	39.8	44.24	14.0	10	3	148	0.04	0.06	0.02
2004	350.6	124.1	46.9	7	233	601	0.44	0.16	0.06
2005	369.6	197.2	62.4	10	151	673	0.44	0.25	0.08
2006	453.4	169.5	53.6	10	216	738	0.57	0.21	0.07
2007	437.0	166.7	50.3	11	280	701	0.55	0.21	0.06
2008	703.4	347.4	100.3	12	231	1234	0.88	0.43	0.13
2009	163.6	114.3	36.1	10	35	405	0.20	0.14	0.05
2010	155.6	88.7	31.4	8	53	360	0.18	0.12	0.04
After Reconstruction 2003 - 2010	348.9	274.5	31.1	78	3	1234	0.43	0.35	0.39
After HCP 1998 - 2010	225.3	274.3	24.8	122	0	1234	n/a	n/a	n/a
All Years 1995 - 2010	194.5	264.0	22.1	143	0	1234	n/a	n/a	n/a

Physical characteristics in the spring pool after habitat reconstruction (7/2003 – 12/2009) confirm the importance of two factors to *E. sosorum*. Salamander density in Eliza Spring is significantly positively correlated with flow velocity, and negatively correlated with percent sediment cover and water depth (Table 3). Percent sediment cover represents the sedimentary layer overlying substrate and is positively correlated with water depth; as water depth decreases, percent sediment cover also decreases. Mean values of sediment and water depth after reconstruction are more typical of shallow, flowing streams (sediment = 0.6 in. ± 0.6 S.D.; water = 12.9 in. ± 3.1) in which the majority of *Eurycea* species are found (Wells 2007, Petranka 1998). These results support previous inferences (City of Austin 2004) that *E. sosorum* fares better in habitats with flowing water and less sediment-laden substrate.

Table 3. 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 Mean ± SD	Salamander Density 348.9 ± 274.5	Sediment Depth 0.68 ± 0.51 in.	% Sediment Cover 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	.

In Eliza Spring, the most detrimental "semi-natural" factor (as noted in 4.3.1) was the severe drought of June 2008 – September 2009. Its effects on the salamander population were statistically significant decreases in total salamander abundance and density relative to the 2003 – May 2008 period (abundance: *U* = 196.5, z = -2.253, p = 0.024; density: *U* = 201.5, z = -02.169, p = 0.030; Table 4). Juvenile and adult abundances were significantly lower during the drought (Juv.: U = 172.0, z =z –2.662, p = 0.0078; Adult: *U* = 131.5, z = -3.286, p = 0.001), while young adult abundance was not (*U* = 268.5, z = -0.960, p = 0.337) (Fig. 25).

The drought's effects on habitat were evident in the reduction of dissolved oxygen, increases in water temperature, and decreases in current speed. Mean water temperature increased from 69.8ºF (21.5ºC) to 70.7ºF (20.0ºC) during the drought, and mean velocity decreased significantly (U = 36.50, z = -2.960, p = 0.0031) from 0.851 ft/sec. (±0.168 s.e.) to 0.292 (±0.050 s.e.). Mean dissolved oxygen concentration was 4.3 mg/L (±0.124 s.e.), which includes values as low as 3.88mg/L (Table 4). The mean is below the 28-day LC_5 threshold (4.5 mg/L) for adult survival of *E. nana*, and below the 60-day threshold (4.44 mg/L) at which growth of juvenile *E. nana* is compromised (Woods et al. 2010).

The drought began to break with the rainfall and increase in groundwater discharge in October of 2009. Within two weeks, abundance of young adult and adult salamanders jumped from 27 and 14, to 139 and 134, respectively. No juveniles were found. November abundances showed increases in all size classes, 12 juveniles, 230 young adults, and 154 adults. Since reproduction, hatching, and juvenile development require more than two months, these increases suggest that some adults and young adults found places to take refuge from the effects of drought, and were not detected during monthly surveys. However, abundances have not increased to 2008 pre-drought highs of 256 adults, 535 young adults, and 568 juveniles. This represents a 98% decrease in juvenile abundance over 16 months, suggesting that drought was most detrimental to juveniles. The very small numbers of juveniles from October through December of 2010 also suggests that during the drought, adults did not reproduce, which is consistent with theoretical and empirical demonstrations (Pianka 1983; Harris and Ludwig 2004; Takahashi and Pauley 2010) of resource allocation for long-lived animals. 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). Based on the new information gleaned from the recent drought we expected this population to rebound as favorable environmental conditions continued through 2010. Yet, 14 months after the drought, salamander abundance and density have not increased significantly (stats). Salamander abundance and density during and after this drought are not significantly different for all size classes except juveniles (Table 5). Juvenile abundance and density are significantly lower after the drought (Table 5), while dissolved oxygen concentration is significantly higher after the drought. 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 higher discharge returns. It also suggests that there are other drought-related factors that affect salamanders. 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.

Despite the recent severe drought, Eliza Spring remains the best habitat and harbors the largest and most robust *E. sosorum* salamander population in the Barton Springs complex. This population likely has the best potential to weather adverse conditions. It provides our best opportunity to understand how the species responds to environmental change, both natural and anthropogenic, and therefore, how to best protect and foster recovery of *E. sosorum*.

Table 4. Mean, standard deviation (S.D.), and standard error (s.e.) of dissolved oxygen (DO) and *E. sosorum* abundance and density in Eliza Spring from 2003 – 2008 before the severe drought, and 2008-2009, during 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.

Eliza	**Abundance (#)**						**Density (#/sq ft)**		
	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

Eliza	**Abundance (#)**						**Density (#/sq ft)**		
	Mean	**S.D.**	**s.e.**	**N**	**Min.**	**Max.**	**Mean**	**S.D.**	**s.e.**
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
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

Table 5. Results of nonparametric Mann-Whitney U statistical tests comparing salamander abundance and density during (June 2008 through September 2009) and after the drought

(October 2009 through December 2010) are presented below. Probability values significant at $\propto = 0.05$ are indicated by an asterisk (*).

	U	Z-value	p-value
Abundance			
Total	57.0	-0.998	0.320
Adults	49.0	-1.442	0.149
Young Adults	46.0	-1.609	0.107
Juveniles	31.5	-2.413	0.016*
Density			
Total	53.0	-1.220	0.222
Adults	56.0	-1.054	0.291
Young Adults	44.0	-1.720	0.086
Juveniles	28.0	-2.607	0.009*
DO	0.0	-4.031	<0.0001*

__4.3.1.2__ __Parthenia__ __Spring__

The salamander population in Parthenia Spring (in Barton Springs Pool) has been monitored since 1993. This site has the largest area of potential habitat (~15,000 sq. ft.) composed of natural caves, crevices, and fissures (~4,000 sq. ft.), and the "beach" (USFWS 1998), 11,000 square feet of a manmade shelf of compacted caliche, gravel, and cobble. The size of potential habitat and human access to small cracks is limited and precludes conducting complete surveys of surface habitat as in the other sites of the Barton Springs complex. Since survey methods have varied in type, area surveyed, and survey effort (Fig. 26), the influence of systematic error on each sample of salamander abundance is likely greater in this site (Scheiner and Gurevitch 2001). Patterns of changes in abundance and density were examined to understand how the population responds to environmental changes and population status. The management of the aquatic environment of the Pool has changed considerably since listing of *E. sosorum* and implementation of the Habitat Conservation Plan associated with the 10(a)1(B) permit for Barton Springs (USFWS 1998). For example, chemical cleaners are no longer used, Pool draw downs are restricted, and habitat areas are cleaned by federally permitted biologists only. Therefore, included in the assessment below is an examination of whether changes in salamander populations are related to these changes in habitat management.

4.3.1.2.1 Abundance, Density, and Barton Springs' Discharge

From 1993 to the present, total abundance of salamanders is significantly negatively correlated with Barton Springs' discharge ($\rho = -0.262$, $z = -2.048$, $p = 0.04$) and density is marginally significant ($\rho = -0.261$, $z = -1.862$, $p = 0.06$). However, both are significantly *positively* correlated with discharge 6 months earlier (abundance: $\rho = 0.500$, $z = 3.042$, $p < 0.0023$; density: $\rho = 0.585$, $z = 3.359$, $p = 0.0008$: Figs. 27 a,b). The relationships between discharge and abundance, and density are statistically significant for juveniles (abundance <1": $\rho = 0.484$, $z = 2.947$, $p_{\alpha=0.0125} < 0.0032$; density: $\rho = 0.592$, $z = 3.400$, $p_{\alpha=0.0125} < 0.0007$) and adults (abundance ≥ 1": $\rho = 0.504$, $z = 3.067$, $p_{\alpha=0.0125} < 0.0022$). Young adults (abundance: $\rho = 0.467$, $z = 2.838$, $p_{\alpha=0.0125} = 0.0045$; density: $\rho = 0.549$, $z = 3.152$, $p_{\alpha=0.0125} = 0.0016$; and adults are significantly correlated with a six month lag in discharge from 2003 to the present (abundance $\rho = 0.422$, $z = 2.568$, $p_{\alpha=0.0125} = 0.012$; density: $\rho = 0.447$, $z = 2.566$, $p_{\alpha=0.0125} = 0.01$; Fig. 28), the period these classes were recorded.

4.3.1.2.2 Effects of 10(a)1(B) Permit Implementation

The status of the *E. sosorum* population in Parthenia Spring has improved since the species was added to the federal endangered species list in 1997 (USFWS 1997). Salamander abundance increased significantly after 1997 (PRT-839031) (U = 1,765.5, z = -3.281, p = 0.001;Table 6; Fig. 29 a), as did density (U = 1,062, z = -2.423, p = 0.015; Table 6). However, from 1993 – 1997 there is no significant relationship among juvenile abundance and adult (> 1in. TL) abundance 3 months later (ρ = -0.085, z = -0.583, $p_{\alpha=0.05}$ = 0.5596). This relationship is statistically significant after 1997 (ρ = 0.467, z = 2.723, $p_{\alpha=0.05}$ = 0.0065; Fig. 29). This indicates that juveniles have been better able to develop into adults since 1998, suggesting the status of this population has improved in the last decade.

4.3.1.2.3 Habitat Reconstruction

Concerted efforts to improve salamander habitat in Parthenia Spring were begun in 2004 based on the beneficial effects of similar changes in Eliza Spring (City of Austin 2004). The major goal of habitat reconstruction is to restore a more natural flow regime from Parthenia Spring and throughout Barton Springs Pool, as was done in Eliza Spring. Higher flow velocities of creeks and rivers are the dominant feature distinguishing them from lakes and ponds (Leopold et al. 1992). Flowing water 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, 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). The dams impounding Parthenia Spring have shifted the ecological character to a more lake-like condition less suitable for stream-adapted *E. sosorum*. Drawing down water level temporarily restores increased flow velocity, which could improve flow regime in salamander habitat. Hence, a series of experimental partial draw downs were designed to examine whether habitat quality would improve and salamander abundance would change.

A series of monthly partial draw downs were conducted from 2004-2005 (City of Austin 2005). Draw downs were coupled with manual efforts to reopen clogged spring flow paths by flushing sediment, small pebbles, and other obstructions from fissures and the mouths of the springs with gentle flow of re-circulated spring water. As of December 2006, there were statistically significant decreases in mean sediment depth in sections in front of two of the caves at the spring mouth, Little Main (U = 53.5, z = -2.329, p = 0.02) and Side Spring (U = 50.0, z = -2.309, p = 0.02). These reductions have persisted through 2010 despite bouts of floods in 2007 and 2010 (Little Main: U = 153.0, z = -2.730, p = 0.006; Side Spring: U = 158, z = -2.192, p = 0.03). Percent sediment cover was not significantly less in 2006 after habitat reconstruction (U = 51.0, z = -0.927, p = 0.35), although there is a marginally significant decrease by the end of 2010 (U = 202.0 z = -1.827, p = 0.07). This likely reflects the variability of sediment cover caused by periods when floods entered Barton Springs Pool.

Salamander abundance and density increased significantly by December 2006, after habitat reconstruction (Abundance: U = 2158.5, z = -2.871, $p_{\alpha=0.025}$ = 0.004; Density: U = 1131.0, z = -2.637, $p_{\alpha=0.025}$ = 0.008). These increases have persisted through 2010 (Abundance: U = 4328.5, z

= -4.520, $p_{\alpha=0.025} < 0.0001$; Density: $U = 2194.0$, $z = -3.033$, $p_{\alpha=0.025} = 0.002$; Fig. 29). Fewer salamanders are found and density is significantly lower in fissures and beach sections compared with sections in front of the spring mouths (abundance: $H = 213.18$, $p_{\alpha=0.05} < 0.0001$; density $H = 174.5$, $p_{\alpha=0.05} < 0.0001$). This is consistent with the sediment depth results; the sediment layer has not changed in the fissures, while it has decreased in two areas in front of spring mouths. There are no sediment data from beach sections prior to 2009 for comparison.

Adult abundance is positively correlated with juvenile abundance 3 months later ($\rho = 0.534$, $z = 3.291$, $p_{\alpha=0.025} = 0.001$; Fig. 30), suggesting conditions that favor increases in adults also favor reproduction. Juvenile abundance is significantly correlated with young adult abundance three months later ($\rho = 0.509$ $z = 3.135$, $p_{\alpha=0.05} = 0.0017$), indicating development and recruitment to the young adult stage. There is a significant positive correlation of young adult abundance with adult abundance two months later ($\rho = 0.507$ $z = 2.999$, $p_{\alpha=0.05} = 0.0027$). All of this indicates that under good environmental conditions, adult salamanders reproduce and juveniles are recruited into the adult population. The lags suggest that it takes roughly three months for juveniles (< 1" TL) to reach the young adult size (1-2" TL), and two months for young adults to reach adult size (≥ 2" TL).

Table 6. Mean, standard deviation (S.D.), standard error (s.e.), and sample size (N) of *E. sosorum* salamander abundance and density in Parthenia Spring for each year of record are listed below. Minimum (Min.) and Maximum (Max.) salamander abundance are also listed. Density could not be calculated for April 1998 – July 2003 because exact area surveyed is unknown.

Parthenia	**Abundance (#)**						**Density (#/sq ft)**			
Year	**Mean**	**S.D.**	**s.e.**	**N**	**Min.**	**Max.**	**Mean**	**S.D.**	**s.e.**	**N**
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
Before HCP	18.2	11.7	1.6	53	1	45	0.037	0.024	0.003	53
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	n/a	n/a	n/a	n/a
2000	17.7	14.1	4.7	9	3	42	n/a	n/a	n/a	n/a
2001	10.7	3.1	1.2	7	6	15	n/a	n/a	n/a	n/a
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
Before Phase I Reconstruction	32.3	25.6	3.3	62	3	127	0.025	0.021	0.005	17
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
After Phase I	86.2	95.2	14.0	46	1	447	0.034	0.039	0.006	46

Reconstruction										
After HCP	55.3	70.0	6.7	108	1	447	0.032	0.035	0.004	180
1993-2010	43.0	60.2	4.8	161	1	447	0.034	0.031	0.003	116

4.3.1.2.4 Drought

During drought conditions from June 2008 through September 2009, the aquatic environment of Parthenia Spring experienced changes similar to those in Eliza Spring. Mean dissolved oxygen concentration differed significantly before, during, and after the drought ($H = 23.99$, $p < 0.0001$). Dissolved oxygen was highest in the year following the drought and lowest during the drought, and (Table 7), although it did not drop as low as in Eliza and Old Mill Springs (Tables 4 and 10). There were no significant differences in salamander abundance and density before, during, and after the drought of 2008 – 2009 (abundance: $H = 0.825$, $p = 0.66$; density: $H = 3.78$, $p = 0.15$;Fig. 31), even though abundance and density reached record highs in this site in 2007.

Table 7. Mean, standard deviation (S.D.), and standard error (s.e.) of dissolved oxygen (DO) and *E. sosorum* abundance and density in Parthenia Spring from July 2003 – May 2008 before the severe drought, from June 2008 – September 2009 during the severe drought, and from October 2009 – December 2010 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.

Parthenia	**Abundance (#)**						**Density (#/sq ft)**		
	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
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
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

4.3.1.3 Old Mill Spring

Salamander abundance estimates have been obtained from Old Mill Spring (Sunken Garden) since 1995. A single sample was taken in 1995 and no samples were taken in 1996. In 1998, salamanders of a potentially different species were identified as *E. waterlooensis* was subsequently described in 2001 (Hillis et al. 2001). *Eurycea waterlooensis* abundance has been recorded separately from 1998 to the present; all salamanders found in 1995 and 1997 are identified as *E sosorum*. Until 2004, abundance of both *E*. *sosorum* and *E*. *waterlooensis* were generally higher in this site relative to the other three (City of Austin 2004, 2005, 2006, 2007).

Total *E*. *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: $H = 133.02$, $p < 0.0001$; Table 8; Figs. 32, 33). Based on data from 2003 to the present, when reproduction occurs in this site (Fig. 34), it is during non-drought periods. The number of juveniles is positively correlated with number of young adults three months later ($\rho = 0.663$ $z = 2.901$, $p_{\alpha=0.05} = 0.005$), as is number of young adults with number of adults three months later ($\rho = 0.669$ $z = 3.068$, $p_{\alpha=0.05} = 0.003$; Fig. 35).

4.3.1.3.1 Effects of 10(a)1(B) Permit Implementation

Comparison of *E*. *sosorum* abundance indicates a significant decrease after issuance of the federal 10(a)1(B) permit ($U = 980.5$, $z = -3.231$, $p = 0.0012$). However, this result does not accurately reflect changes in *E*. *sosorum* alone because prior to 1998 when *E*. *waterlooensis* was described, all *Eurycea* observed in this site before 1998 were classified as *E*. *sosorum*. Thus, data collected from 1995 – 1997 include an unknown number of *E*. *waterlooensis*. To make an appropriate, unbiased comparison of potential effects of implementation of the federal permit, numbers of *E*. *sosorum* and *E*. *waterlooensis* observed after permit issuance were combined (Table 9). Comparison of abundance and density of all *Eurycea* salamanders found in Old Mill Spring before and after issuance do not differ significantly (Abundance: $U = 180.5$, $z = -1.478$, $p = 0.14$; Density: $U = 174.5$, $z = -1.349$, $p = 0.18$). This suggests issuance of the permit has not been detrimental to abundance and density of resident *Eurycea*.

Table 8. Mean, standard deviation (S.D.), and standard error (s.e.) of *E*. *sosorum* salamander abundance and density in Old Mill Spring for each year of record are listed below. Minimum (Min.) and Maximum (Max.) salamander abundance are also listed. (See Table 9 for *E. waterlooensis*)

Old Mill	**Abundance (#)**						**Density (#/sq ft)**		
Year	**Mean**	**S.D.**	**s.e.**	**N**	**Min.**	**Max.**	**Mean**	**S.D.**	**s.e.**
1998	27.9	18.1	6.0	9	4	51	0.027	0.021	0.007
1999	5.9	4.4	1.5	9	0	13	0.004	0.003	0.001
2000	2.0	2.6	0.9	8	0	7	0.002	0.004	0.001
2001	27.6	17.6	5.6	10	8	56	0.031	0.023	0.007
2002	19.1	9.5	3.2	9	4	33	0.016	0.010	0.003
2003	27.6	18.8	5.9	10	1	52	0.021	0.014	0.004
2004	42.8	16.9	5.7	9	6	67	0.032	0.013	0.004
2005	13.4	6.7	2.4	8	7	23	0.007	0.003	0.001
Before Reconstruction 1998 - 2005	20.5	18.0	2.2	68	0	67	0.017	0.016	0.022
2006	0.8	1.3	0.4	9	0	3	0.001	0.001	0.0003
2007	6.5	4.4	1.8	6	1	14	0.005	0.003	0.001

2008	32.5	38.2	13.5	8	0	97	0.026	0.030	0.011
2009	0.9	2.1	0.6	12	0	7	0.001	0.001	0.0004
2010	1.5	1.2	0.4	11	0	4	0.001	0.001	0.0002
After Reconstruction 2006-2010	7.3	19.3	2.8	46	0	97	0.006	0.015	0.002
1998-2010	15.2	19.5	1.8	114	0	97	0.012	0.017	0.002

4.3.1.3.2 Habitat Reconstruction

Habitat reconstruction in this site 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 rock, trash, and accumulated sediment in the spring pool. These changes allow for greater flow velocities under all conditions, and more wetted surface habitat at low Barton Springs' discharge conditions. Despite the demonstrated benefits of similar habitat reconstruction in Eliza Spring and theoretical support for expected improvements, there is no evidence of a significant effect of these changes on *E. sosorum* abundance or density in Old Mill Spring (abundance: U = 388.5, z = -0.310, $p_{\alpha=0.05}$ = 0.756; density: (U = 376.50, z = -0.465, $p_{\alpha=0.05}$ = 0.641).

4.3.1.3.3 Drought

The droughts of October 2005 to October 2006 and of June 2008 to September 2009 were accompanied by biologically significant decreases in dissolved oxygen and increases in water temperature, as well as lack of detectable flow velocity in the spring pool (City of Austin, unpublished data). The *E. sosorum* population in this site was affected more severely by the droughts than those in Eliza and Parthenia Springs. There were 6 and 11 consecutive months during the 2005 - 2006 and 2008 - 2009 droughts, respectively, where no salamanders were found (Table 10). Total *E. sosorum* abundance and density were significantly lower during the droughts (abundance: U=137.5, z=-5.088, p<0.0001; density: U=144.5, z=-4.999, p<0.0001). Dissolved oxygen was also significantly lower during droughts (U=447.5, z=-4.674, p<0.0001). Water temperature during the drought periods was significantly higher (U=802, z=-2.141, p<0.0001) than during non-drought. When D.O. is at or below 4.0 mg/L, number of adults is significantly positively correlated with number of juveniles three months later (ρ=1.000, z=2.000, $p_{\alpha=0.05}$=0.045). In other words, when dissolved oxygen is below 4.0 mg/L and adult abundance is at or near zero, juvenile counts are lower, compared to when adult counts are greater than zero. There is a correlation between adult and juvenile counts 3 months later under these conditions. When there are no juveniles, there is no opportunity for recruitment into the existing young adult population, so correlation is not significant (ρ=0.775, z=1.550, $p_{\alpha=0.05}$=0.147). This suggests that during the recent droughts no reproduction or recruitment were observed in this site despite efforts to augment DO in the spring pool after it dropped below 4 mg/L. Dissolved oxygen augmentation was accomplished by re-circulating water through a pump and allowing it to cascade back into the Pool, entraining additional oxygen in the water and increasing flow velocity. Measurements of dissolved oxygen during DO augmentation indicate this method was successful in general although warmer water temperatures during the day limited the total amount of oxygen that could be added to the water without creating unnatural supersaturation.

Table 9. Mean, standard deviation (S.D.), and standard error (s.e.) of abundance and density based on the sum of *Eurycea sosorum* and *E. waterlooensis* found in Old Mill Spring from 1997 through 2010. Minimum (Min.) and Maximum (Max.) salamander abundance are also listed. The sum of both species was used to compare effects of HCP issuance because prior the mid-1998 data do not distinguish between *E. waterlooensis* and *E. sosorum*.

Old Mill	**Abundance (#)**						**Density (#/sq ft)**		
Year	**Mean**	**S.D.**	**s.e.**	**N**	**Min.**	**Max.**	**Mean**	**S.D.**	**s.e.**
1995	3.0	n/a	n/a	1	n/a	n/a	0.002	n/a	n/a
1997	39.8	23.3	11.7	4	8	60	0.058	0.037	0.019
Total Before HCP 1995 - 1997	35.2	19.2	5.8	11	3	60	0.042	0.029	0.009
1998	28.6	17.5	5.8	9	6	51	0.027	0.021	0.007
1999	6.2	4.5	1.5	9	0	13	0.005	0.003	0.001
2000	2.5	3.3	1.2	8	0	9	0.003	0.005	0.002
2001	36.7	21.5	6.8	10	12	67	0.038	0.022	0.007
2002	28.4	12.7	4.2	9	5	46	0.023	0.013	0.004
2003	43.1	32.5	10.3	10	1	85	0.032	0.024	0.008
2004	51.4	20.6	6.9	9	6	83	0.039	0.015	0.005
2005	14.9	6.5	2.3	8	8	25	0.008	0.003	0.001
2006	1.2	2.0	0.7	9	0	5	0.001	0.001	0.0005
2007	6.7	4.5	1.8	6	1	14	0.005	0.003	0.001
2008	34.3	40.0	14.2	8	0	102	0.027	0.032	0.011
2009	0.9	2.1	0.6	12	0	7	0.001	0.001	0.0004
2010	1.6	1.3	0.4	11	0	4	0.001	0.001	0.0003
After HCP 1998 - 2010	18.7	24.5	2.3	112	0	102	0.015	0.020	0.002

Table 10 Mean, standard deviation (S.D.), and standard error (s.e.) of *E. sosorum* abundance and density, dissolved oxygen (DO), and water temperature in Old Mill Spring during non-drought and drought periods from July 2003 – December 2010. Totals and values for each size class are included. Minimum (Min.) and Maximum (Max.) salamander abundances, dissolved oxygen concentrations, and water temperatures are also listed.

Old Mill	**Abundance (#)**						**Density (#/sq ft)**		
	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

4.3.1.4 Upper Barton Spring

This spring site naturally flows intermittently, when Barton Springs' discharge drops below 40 ft^3/s, water at the surface of this site disappears. The site has no artificial impoundments and lies in the flood plain on the southeast margin of Barton Creek. Only *E. sosorum* has been found at this site; the first sighting occurred on April 1, 1997. The average size of the surface habitat at this spring is 493 square feet, and can be as large as 880 square feet under high aquifer conditions. Salamander abundance is typically low (Table 11; Fig. 36), but mean density is similar to that in Old Mill Spring. Mean annual salamander abundance in this site increased to a record high of in 2008. It is unknown where salamanders in this site go when surface habitat becomes dry but, apparently healthy *E. sosorum* have been found within a couple of weeks of return of spring water to the surface (City of Austin, unpublished data, L. Dries pers. obs.). Few juveniles have been found in this site (Table 12) and there is no statistical evidence of consistent reproduction if the relationship between adults and juveniles 3 months later is used as an indicator of reproduction. In this case, the number of adults is not correlated with number of juveniles three months later (ρ=0.053, z=0.268, $p_{\alpha=0.05}$=0.79). There is no statistical evidence of recruitment; number of juveniles is not correlated with young adults three months later (ρ=0.255, z=1.145, $p_{\alpha=0.05}$=0.25), neither is number of young adults correlated with adults three months later (ρ=-0.061, z=-0.311, $p_{\alpha=0.05}$=0.76).

Table 11. Mean, standard deviation (S.D.), and standard error (s.e.) of *E. sosorum* salamander abundance and density in Upper Barton Spring for each year of record are listed below. Minimum (Min.) and Maximum (Max.) salamander abundance are also listed. Density is number per square foot. Surface habitat in this spring site was dry from Sept. 1999 – May 2000, Nov. 2003 – Feb. 2004, Nov. 2005 – Jan. 2007, June 2008 to Oct. 2009.

Upper Barton	**Abundance (#)**						**Density (#/sq ft)**		
Year	**Mean**	**S.D.**	**s.e.**	**N**	**Min.**	**Max.**	**Mean**	**S.D.**	**s.e.**
1997	5.8	5.3	2.4	5	1	14	0.013	0.012	0.005
1998	1.9	1.3	0.4	9	0	4	0.004	0.003	0.001
1999	0.6	0.7	0.2	10	0	2	0.002	0.001	0.001
2000	1.9	3.2	1.1	8	0	9	0.011	0.008	0.004
2001	5.4	5.0	1.6	10	0	14	0.012	0.011	0.004
2002	5.0	3.6	1.1	10	0	12	0.011	0.008	0.003
2003	2.4	2.1	0.6	11	0	5	0.006	0.004	0.001
2004	5.8	5.1	1.6	10	0	14	0.016	0.010	0.004
2005	3.1	3.3	1.3	7	0	9	0.010	0.007	0.003
2007	4.8	5.1	1.6	10	0	13	0.010	0.010	0.003
2008	9.0	13.1	4.4	9	0	30	0.051	0.036	0.018
2009	9.0	9.9	7.0	2	2	16	0.013	0.012	0.009
2010	28.1	27.0	8.1	11	4	100	0.043	0.042	0.013
1997-2010	5.9	11.6	1.0	124	0	100	0.015	0.022	0.002

Table 12. Mean, standard deviation (S.D.), and standard error (s.e.) of abundance and density of juvenile, young adult, and adult *E. sosorum* salamanders in Upper Barton Spring for all years of record are listed below. Minimum (Min.) and Maximum (Max.) salamander abundance are also listed. Density is number per square foot. Data for young adult and adult size classes are a subset comprising 2003 – 2010.

Upper Barton	**Abundance**						**Density**		
Size class	**Mean**	**S.D.**	**s.e.**	**N**	**Min.**	**Max.**	**Mean**	**S.D.**	**s.e.**
Juvenile (<1" TL) (1997 – 2010)	1.7	6.5	0.6	124	0	62	0.004	0.012	0.001
Adult (≥ 1" TL) (1997 - 2010)	4.1	6.2	0.6	124	0	37	0.011	0.013	0.001
Young Adult (1-2" TL) (2003 – 2010)	5.4	7.1	1.1	43	0	34	0.010	0.013	0.002
Adult (≥ 2" TL) (2003 – 2010)	2.3	2.8	0.4	43	0	10	0.006	0.006	0.001

Although there is no evidence of recruitment in the *E. sosorum* population in Upper Barton Spring (Fig. 37), salamanders continue to be present and reproduce at this site.

4.3.1.4.1 Drought

Surface habitat of Upper Barton Spring is dry when Barton Springs' discharge drops below ~ 40ft^3/s. No live or dead salamanders have been found once surface water disappears, yet, salamanders are found when surface flow returns. Consequently, it is difficult to ascertain how drought affects this population. The fate of these salamanders when surface habitat is dry is unclear; they may die, remain underground, or migrate to another site during these periods. To begin to understand what happens to the resident salamanders during dry periods, City of Austin staff marked salamanders found in Upper Barton Spring from January 2007 through May 2008, while there was continuous water flow in surface habitat. During this period 48 *E. sosorum* in Upper Barton Spring were given a fluorescent elastomer mark by City of Austin staff. Nine of the 48 salamanders marked were recaptured at later dates (19% recaptured)(Table 13). Six salamanders marked in January and February of 2008 were recaptured in Upper Barton Spring 1 to 2 months later. Surface flow ceased in June of 2008, returned in November of 2009, and continued throughout 2010. Four salamanders marked in 2008 were recaptured in 2009 and 2010; one of these salamanders was recaptured more than once. No marked salamanders have been found at other spring sites. These data do not provide evidence of migration to or from Upper Barton Spring, but they do suggest that *E. sosorum* can survive dry periods, presumably by taking refuge in wetted subterranean habitat. All salamanders recaptured were young adult size (1-2 in. TL) when marked, and all but one had reach adult size (2 in. TL) when recaptured . No salamanders marked as adults were recaptured.

Table 13. Listed below are the number of captured-marked and recaptured *E. sosorum*. All salamanders were marked and subsequently recaptured in Upper Barton Spring. All animals were photographed when marked and recaptured. Pigment patterns on the dorsal surface of the head were used to match recaptured animals with mark date. Pigments patterns of three recaptured salamanders could not be matched to photographs and thereby date of initial capture and marking.

Mark Date	No. Marked	No. Recaptured	Recapture Dates
5/2/2007	8	?	
1/4/2008	6	2	2/28/2008, 3/4/2010,
2/28/2008	20	3	4/3/2008, 11/5/2009
4/3/2008	14	1	1/28/2010, 4/1/2010
Total	48	9	

4.3.2 *Eurycea waterlooensis* Population Status and Trends

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 reproduction and recruitment. Therefore, presented here is a summary of City of Austin data on *E. waterlooensis* encountered during monthly surveys of surface habitats. This species is most commonly found in Old Mill Spring (Table 14; Fig. 38); its abundance and density are significantly higher in this site relative to Eliza and Parthenia Springs (abundance: $H = 36.10$, $p < 0.0001$; density: $H = 32.96$, $p < 0.0001$). Since *E. waterlooensis* was not found regularly in Eliza Spring until after 2002, it is reasonable to ask whether its abundance in other sites also changed during this time frame. There is no significant difference in abundance of these salamanders found in Old Mill Spring after 2002 ($U = 1536$, $z = -0.082$, $p = 0.935$). Abundance in Eliza and Parthenia Springs are significantly higher since 2002 (Eliza abundance: $U = 1332.5$, $z = -3.950$, $p < 0.0001$; Parthenia abundance: $U = 2207$, $z = -1.855$, $p = 0.0005$). However, the statistical significance is likely due to the very small numbers of these salamanders found in Eliza and Parthenia before 2003 (Table 14), rather than large increases in abundance.

Table 14 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.) and Maximum (Max.) salamander abundance are also listed.

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

Table 14 (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.) and Maximum (Max.) salamander abundance are also listed.

Abundance (#)	Density (#/sq ft)

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

4.4 Salamander Behavior in Response to Environmental Stresses

Understanding natural responses of salamander to environmental stresses will enable reduction of harassment during construction of these two projects. In particular, understanding salamander response to noise and drying of habitat can be used to increase the effectiveness of proposed conservation measures.

4.4.1 Vibration, Sound, Noise

Aquatic vertebrates can detect and respond to sound vibrations underwater (Moyle and Cech 1988; Fay and Simmons 1999). Comparisons to more commonly studied vertebrates (mammals, reptiles and birds) regarding noise detection show that amphibians have a variety of unique adaptations and differ in complexity from other vertebrates. These adaptations include unique sound pathways and variability of receptor organs in the ear (Smotherman and Narins 2004). General structure of a vertebrate ear is split into three segments, outer ear, middle ear, and inner ear. The structure of the ear of an aquatic salamander is distinct from other amphibians (Hilton 1952; Monath 1965; Duellman and Trueb 1994). Unlike ears of anurans, the salamander outer ear lacks a defined tympanum (receives airborne vibrations), and the middle ear (tympanic cavity) and Eustachian tube (canal connecting middle ear to pharynx) are absent (Duellman and Trueb 1994). The salamander inner ear contains multiple fluid filled cavities and receptor organs, including the papilla amphiborium, which is a single patch of neuroepithelium that receives vibrations and is unique to amphibians (Duellman and Trueb 1994). In aquatic adult or larval salamanders, the operculum is attached to jaw-supporting bones, allowing vibrations to be transmitted through the jaw resting on the substrate surface (Fig. 39; Hilton 1952). In larval plethodontid salamanders, the operculum is fused with the columnella in the inner ear, which allows transmission of vibrations detected with the jaw to sensory nerves in the fluid filled cavities of the inner ear (Hilton 1952; Monath 1965; Duellman and Trueb 1994).

In addition to sensing vibrations through the ears, a lateral line system is also present in aquatic salamanders (Duellman and Trueb 1994 and references therein). The lateral line system is composed of neuromasts (mechanoreceptors) located along the head and body and ampullary organs (electroreceptors) located in reduced numbers on the head only. A series of cranial nerves are directly associated with lateral line organs in aquatic salamanders. Pressure receptors have also been identified as free nerve endings in the dermis of amphibians.

Studies assessing the impacts of noise on aquatic biota have generally been limited to fish and terrestrial amphibians (Haemmerle et al. 2009; Knudsen et al. 1994; Smith et al. 2004; Sun and Narins 2005; Warkentin 2005; Wysocki et al. 2006). Aquatic salamanders are identified as being sensitive to seismic vibrations (Smotherman and Narins 2004). Peak sensitivities in electrophysiological studies of aquatic *Notopthalmus viridescens* adults and *Ambystoma maculatum* larvae 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 dBa and 204 dBa in water), while salmonids exhibited behavioral changes. These studies suggest that aquatic amphibians may be less sensitive to noise than terrestrial amphibians or certain fish.

City of Austin data suggest that *E. sosorum* also detects and responds to sounds audible underwater (Clark et al. 1996). Areas in Barton Springs Pool outside of salamander habitat are cleaned weekly using power-washers, fire hoses and/or a bobcat, all of which generate noise detectable underwater (Clark et al. 1996). Salamander density in Barton Springs Pool during standard surveys is significantly less on cleaning days (Table 15; Fig. 40 a). Similar analysis of salamander density in Eliza Spring indicates no significant difference from 1995 – 2002, and significantly higher density on cleaning days after 2002 (Table 15; Fig. 40 b). This significant increase in density could have several interpretations. Since noise from cleaning equipment at Barton Springs Pool is not audible to humans underwater at Eliza Spring, the sound may also not be audible to *E. sosorum* at the surface in Eliza Spring. If the noise is audible in the subsurface habitat, an increase in salamander density at the surface may be a sign that salamanders are moving away from noise, which in Eliza Spring may be at the surface. If the noise is not audible in the subsurface habitat, the increase in *E. sosorum* at the surface in Eliza Spring may be unrelated to noise, and instead due to some other factor coincident with day of survey.

Table 15. Results of non-parametric Mann-Whitney *U* tests of change in densities of *E. sosorum* in Parthenia Spring (Barton Springs Pool, BSP) and Eliza Spring in response to noise produced during cleaning of Barton Springs Pool are presented below. Mean, standard error (s.e.), variance, (VAR), Mann-Whitney *U* test statistic (*U*), probability value (p), and sample size (N) are listed. Statistically significant probability values are based on $\alpha = 0.05$. Eliza Spring data were divided into periods before and after habitat reconstruction because variances differed by several orders of magnitude.

	Sample	*D*	**Salamander Density (#/sq ft)**							
Site	**Period**	*ay*	**Mean**	**S.D.**	**s.e.**	**VAR**	**U**	**Z**	**P**	**N**
BSP	1993-2010	Clean	0.037	0.041	0.005	0.002				65
		Other	0.048	0.037	0.005	0.001				67

							1586.0	-2.693	0.007	
Eliza	1995-2002	Clean	0.013	0.012	0.003	0.0001				20
		Other	0.011	0.012	0.002	0.0001				45
							393	-0.810	0.418	
Eliza	2003-2010	Clean	0.548	0.384	0.061	0.148				39
		Other	0.330	0.248	0.045	0.061				31
							482.5	-2.068	0.038*	

*Density of *E. sosorum* salamanders is significantly *higher* in Eliza Spring on BSP cleaning days.

<u>4.4.2 Retreating Surface Water</u>

There is also evidence that retreating surface water is a cue for another avoidance response in *E. sosorum* as well as other Central Texas perennibranchiate *Eurycea* (e.g. *E. tonkawae*). *Eurycea sosorum* inhabits perennial springs but also experiences regular contractions of surface habitat, either from natural variation in surface spring flow or during drawdowns of water depth in Barton Springs Pool (City of Austin 2004, 2005, 2006, 2007; Dries, 2009). During drawdowns from 2003 through 2009, only 8 salamanders have been observed stranded in Parthenia Spring (in Barton Springs Pool) and Eliza Spring combined. In the entire period of drawdown records, stranded or dead salamanders have only been found in the first day as water retreats (City of Austin 2004, 2005, 2006, 2007). Salamanders have been observed following the movement of water to and from the surface to the aquifer below (Dries 2009). There is no evidence that *E. sosorum* salamanders attempt to return to habitat while it remains dry. Thus, noise and retreating water stimuli, appear to be cues for salamanders to retreat to the confined spaces within the aquifer when they encounter adverse surface conditions and do not venture back to habitat until it is wet, noise is reduced or salamanders become habituated to increased noise levels.

5.0 Potential Impacts of Projects (Effects Analysis)

5.1 Cofferdams

Details of the cofferdams or dewatering structure can be found in Section 2.2.5.4 of this document. Type and size of cofferdam or other approved dewatering structure will be determined by the contractor and approved by City permitted biologists. The total amount of salamander habitat to be affected by cofferdams and dewatering structures, including liners and dewatered areas, will be 11,000 ft^2 and will be limited to the beach area of habitat (the total beach area). This will limit effects from cofferdams or dewatering structures to beach habitat where salamander density is significantly less than spring habitat. Intrusion into bedrock or salamander habitat anywhere within the limits of construction is prohibited. Effects of cofferdams and dewatering structures should be minimized by limiting where installation can occur and prohibiting intrusion into substrate.

5.2 Noise

Some protection from the impacts of these projects will be provided by natural salamander behavior in response to noise and retreating water. City of Austin data suggest that *E. sosorum* detects and responds to sounds audible underwater by retreating from surface habitat (see Section 4.4.1). Water transmits sound waves, particularly low frequencies (Hawkins 1993; Raichel 2006), while rock typically reflects sound (Raichel 2006). Therefore, we expect disturbance from noise generated at the surface will be muffled by the aquifer rock, resulting in less sound transmitted to subterranean habitat immediately beneath Parthenia and Eliza Springs. Subterranean habitat will most likely be a temporary refuge from the harassment introduced by noise from construction activities and equipment. Furthermore, ambient air noise of 60-70 decibels does not affect feeding or reproduction of captive *E. sosorum* and *E. waterlooensis* at the captive breeding facility. This suggests that these salamanders habituate to constant ambient noise and do not alter behaviors critical for survival and reproduction. Habituation to ambient noise is a common behavior response of many aquatic and terrestrial vertebrates (Sun and Narins 2005; Anderson et al. 2011). The potential effects of construction noise are expected to lessen as the project progresses through salamander habituation if noise remains a constant feature of the background. Conversely, multiple periods of noise interspersed with normal conditions would likely exert greater effects on salamanders through repeated bouts of stimulus response. This would require reallocation of energy from feeding and reproduction to retreat from noise. Once construction begins, it should most likely continue to completion if possible where not precluded by floods or other unforeseen events.

5.3 Subterranean Salamander Habitat

The proposed bypass repair project has the potential to affect subterranean salamander habitat and migration pathways along the fault system connecting Parthenia and Eliza Springs. If the fault follows a straight line between these two springs, proposed work on Segments 5 and 6 of the bypass have the greatest potential to affect subterranean habitat.

Aspects of Phase I, Stage 3 have the potential to adversely affect this subterranean corridor between the two springs both during and after the project. These activities are stabilizing the gravel subgrade below the bypass, sealing the holes in the bypass floor, and installing rock anchors into bedrock beneath the bypass. Segments 5-8 of the bypass culvert traverses the fault system, resting on a layer of gravel approximately six feet thick overlying limestone bedrock and overlying a general pathway of groundwater flow in the bedrock. The eruption of holes in the bypass floor allowed water from beneath and beside the culvert to flow into the bypass, which eroded gravel subgrade beneath and created large spaces where gravel has been washed out (not to be confused with subterranean voids in bedrock limestone). The extent of these spaces is unknown. The potential detrimental effects of filling them and sealing the undersurface of the bypass are partly dependent on the materials used; therefore, the toxicity and properties of sealant is an important consideration. However, eliminating all risk is not possible but the impact can be minimal to negligible if the appropriate mitigation measures are implemented. Filling subgrade spaces and stabilizing the substrate immediately beneath the floor of the culvert are critical for successful repair and long-term stability of the bypass.

Stabilization and sealing of the bypass floor will largely affect the gravel subgrade rather than underlying bedrock. Location and depth of subterranean conduits that salamanders might use is unknown. There is no detectable groundwater discharge immediately beneath the bypass and thereby, no evidence of conduits from beneath the bypass to subterranean habitat. Consequently, it is unlikely that salamander density beneath the bypass is greater than density in the adjacent Beach habitat. We do not expect stabilization of the subgrade beneath the bypass to have large effects on salamanders.

If salamanders are present in subterranean areas affected by the project, it is expected they would experience immediate, direct effects from filling large spaces in subgrade beneath the bypass with rocks and grout. However, there are no data on salamander abundance or migration or beneath the bypass, and therefore no direct method to assess potential Take. Nevertheless, detrimental effects must be considered. Therefore, for the purpose of this assessment, salamander density under the bypass is assumed to be the same as that of the adjacent beach area.

Use of soil anchors in the Barton Springs fault zone, rather than rock anchors, would not affect salamanders or their habitat because they will be installed into the alluvial soils of the embankment next to the bypass, and therefore, would not be expected to encounter salamanders. Use of rock anchors in the fault zone is less desirable because there is greater risk of intersecting conduits in the underlying limestone in this area.

5.3.1 Subgrade Stabilization – Filling Gaps and Spaces

Immediately prior to filling voids beneath the existing floor slab, a non-destructive survey will be completed to establish locations and sizes of gaps in the subgrade. Impulse Response Technique (IR) is the proposed survey method. IR uses a rubber tipped hammer to send a stress wave through the concrete and a geophone records the wave as it bounces back. Once the IR survey is completed, the gaps can be filled based on relative size and location, each of which presents unique concerns.

5.3.1.1 Large Subgrade Gaps North Side

Large subgrade gaps under the northwestern half of the bypass will require access holes to be drilled through the floor and crushed limestone gravel inserted into subgrade area. Drilling through the concrete potentially introduces noise and water turbulence that could be detected by *E. sosorum* and *E. waterlooensis*. Natural salamander avoidance behavior should reduce the impact of these activities (refer to section 5.2). Potential injury to salamander from insertion of gravel will be minimized because it will be packed by hand.

5.3.1.2 Large Subgrade Gaps Pool Side

Large subgrade gaps under the southeastern half of the bypass will be filled with crushed limestone gravel from the pool side wall abutting salamander habitat. No additional limestone will be added to substrate of salamander habitat. Any excess gravel for subgrade stabilization that is temporarily placed in salamander habitat will be removed before moving to the next section. Working within salamander habitat (the Beach) potentially introduces noise and vibrations that could be detected by *E.sosorum* and *E. waterlooensis*. Natural salamander behavior should reduce the impact of such activities (refer to section 5.2) in salamander habitat.

5.3.1.3 Small Gaps and Interstitial Spaces

Small gaps and interstitial spaces of the subgrade will be filled with Bentogrout injected through a series of ports drilled through the bypass floor. Viscosity of grout will be adjusted to ensure that the material does not move faster than 2 inches per second. Migration of the grout will be monitored by the contractor and City biologists. While the noise and water turbulence from drilling holes through the concrete floor could be detected by *E. sosorum* and *E. waterlooensis*, natural salamander avoidance behavior should reduce their impacts (refer to section 5.2). The amount of Bentogrout needed for void filling will be estimated prior to injection and not exceeded to prevent filling any flowpaths in bedrock beneath the bypass. Any large gaps visible along the poolside wall of the bypass will be monitored for emergence of Bentogrout into salamander habitat and injection stopped. Excess grout will be removed before it solidifies.

5.3.2 Subsurface Stabilization
Stabilization and sealing of the bypass floor will largely affect the gravel subgrade rather than underlying bedrock. Depth of conduits in the bedrock that salamanders might use is unknown. However, logically if the conduits were at the bedrock surface there would be groundwater discharge (spring flow). Since there is no evidence of groundwater discharge in these areas, the conduits are likely below the bedrock surface and therefore unlikely to be affected by stabilizing the gravel below the bypass.

If salamanders are present in subterranean areas affected by the project, it is expected they would experience immediate, direct effects from filling voids beneath the bypass. As previously stated, there are no data on salamander abundance or migration beneath the bypass, and therefore no direct method to assess potential Take. However, for the purpose of this assessment, salamander density under the bypass is assumed to be the same as that of the adjacent beach area.

5.3.3 Rock Anchors
Eighty rock anchors are proposed for Segments 1-5, adjacent to salamander habitat. Each anchor will be attached to the bedrock 3 ft beneath the surface of the bedrock, within a hole drilled 3.5 ft deep (Fig. 12). Drilling through the concrete floor of the bypass and into limestone bedrock will introduce noise, turbulence, and vibration as disturbances to *Eurycea sosorum* and *E. waterlooensis* and their habitat. Natural salamander behavior should reduce the impact of drilling noise, vibrations (refer to section 5.2), and turbulence. Rock anchors will only be used where the bedrock is competent and lacking macropores. The size of the salamanders limits their movement to macropore space (fractures, fissures, faults, etc). Despite the rock anchors being a permanent support for the bypass, they should not disrupt migration routes for *E. sosorum* and *E. waterlooensis* since they will not be placed in voids.

Cementitious grout is recommended for filling between the casing and the rock anchor. The toxicity of this type of grout suggests that excess grout leaking from the casing into an unknown conduit would have an immediate, direct effect on any salamanders if they were present. Therefore, the amount of material used per anchor will not exceed the amount of material necessary to fill between the casing and the anchor.

5.4 Tie-back Soil Anchors
Potential use of soil anchors would not affect salamanders or their habitat because they would not be constructed in habitat and would be completed into the alluvial soils overlying limestone bedrock and would therefore not be expected to encounter salamanders (Fig. 11). Rock anchors would be less desirable to use because of their potential to intersect conduits carrying water in the underlying limestone, especially in the area of the Barton Springs Fault.

5.5 Diverting Barton Creek into Barton Springs Pool
AECOM has proposed diverting Barton Creek (less than 20 ft^3/s) through a temporary pipe placed inside the bypass culvert. When Barton Creek exceeds 20 ft^3/s, additional flow will be pumped and filtered, as necessary, into BSP with the exception of storm water that exceeds water quality criteria. Based on COA and USGS data collected at Parthenia Spring in Barton Springs

Pool and Barton Creek above Barton Springs, parameters analyzed are not likely to have a negative effect on *Eurycea sosorum* or *E. waterlooensis*. For parameters where mean concentrations in Barton Creek was greater than the mean concentrations in Parthenia Spring, dilution of Barton Creek water by water in Barton Springs Pool are expected to reduce the concentrations to below levels of concern (see Appendix E). Dissolved oxygen and nitrate/nitrite are likely to improve with the addition of Barton Creek to Barton Springs Pool.

5.6 Diverting Eliza Stream Flow

During Phase 3, flow from Eliza Spring will need to be diverted from entering the bypass. The pump placed in the Eliza Spring outflow pipe will be capable of diverting 16.3 ft^3/s and will be controlled based on level sensors in Eliza Spring. The level sensor system will remove the potential dewatering of Eliza Spring due to pumping from the outflow pipe. Pumping water continuously for the duration of Phase 3 introduces noise and vibrations as a concern to *E.sosorum* and *E. waterlooensis*. Natural salamander behavior should reduce the impact of additional noise and vibration (refer to section 5.2) in salamander habitat. The inlet of the pump will sit within a structure designed to prevent salamanders from entering the pump inlet (Figure 9). The pipe will be plugged or dammed downstream from the pump inlet using either an inflatable plug or equivalent method located to prevent isolating or stranding salamanders. Pump will be electric powered from local connection or diesel generator located at a distance from habitat sufficient to prevent spill concerns. A condition assessment of the outflow pipe will be performed by contractor or City consulting engineers to evaluate plug or dam methodology and potential pump vibration effects on deteriorated portions of the pipe.

6.0 Conservation Measures

A variety of Conservation Measures will be used to minimize or eliminate negative impacts and take resulting from these projects on the Pool, the aquatic environment of Parthenia, Eliza, and Upper Barton springs, and resident endangered species. A listing and summary of Conservation Measures for both projects is provided below.

6.1 Bypass Repair

Bypass repairs will be phased such that disturbance of salamander habitat will occur in particular area for discrete blocks of time. Throughout the project and adjacent to each work area, there will be accessible, physically undisturbed habitat in which salamanders can take refuge. Activities that require disturbance of habitat on the beach and beneath the bypass will be conducted in linear order, from upstream to downstream. Construction methods, application techniques, and chemical properties of the product recommended to stabilize the subgrade below the bypass will substantially reduce risk of mortality endangered salamanders.

Use of cofferdams will provide a physical barrier between active work areas and undisturbed salamander habitat (Fig. 3). However, the dewatered habitat within cofferdams poses a threat of lethal Take should a salamander venture into the area. To reduce this possibility, permitted City biologists will be onsite to thoroughly search habitat disturbed prior to and during cofferdam assembly and de-watering. Observed salamanders will be captured and relocated in undisturbed habitat. It is possible that during de-watering some salamanders may try to retreat to subterranean habitat beneath the bypass. If so, these salamanders would be subject to potential detrimental effects of materials and activities associated with stabilization of substrate beneath the bypass and joint repair. To help prevent this and increase the chance that salamanders will be found and relocated, permitted City staff will place a plastic liner along the junction of Beach substrate and the Poolside wall of the bypass. This plastic will remain in place until the area is de-watered. City biologists will search work areas daily and capture and relocate any salamanders found. In Eliza Spring, lethal Take as a result of diversion of outflow water will be prevented by using protective barriers around intake structures of the pumps (Fig. 9). In addition, the pump inlet will be placed within the outflow pipe to maximize the amount of suitable refuge habitat upstream in the spring pool. Non-lethal Take in the form of harassment is expected only in quadrants III and IV because they are in closer proximity to pump inlets (approximately 15 feet upstream) and because noise from the pump motors will deter most salamanders from venturing into the outflow pipe of the spring pool.

6.1.1 Subgrade Stabilization

Methods and materials for stabilizing the subgrade beneath the bypass were chose to minimize potential immediate and long-term detrimental effects on protected salamanders that might be in that area but cannot be observed, captured, and relocated. Immediate effects will be reduced by de-watering the Beach before stabilizing the subgrade. Since protected *Eurycea* salamanders are solely aquatic, this will nearly eliminate the chance that a salamander remains in the dry or moist area immediately beneath the bypass. Should any salamanders remain while holes are cut in the bypass floor, the noise is expected to drive salamanders either deeper into wetted subterranean habitat or out onto the Beach where they can be captured and re-located. Potential long-term effects on salamanders will be reduced by using limestone rocks and Bentogrout. Ground water emanating from Karst aquifer systems is naturally supersaturated with carbon dioxide, yet have neutral pH because the geochemical reaction of limestone water buffers the effects of CO_2 (Klimchouk et al. 2000). To ensure this chemical characteristic is not altered, the rock used to fill spaces beneath the bypass will be limestone. Using Bentogrout to fill the remaining spaces between rocks will substantially reduce the chance that salamanders would die from contact because the material is non-toxic. Furthermore, its migration speed of 2 inches per second is slower than observed salamander swimming speed over short distances (~1 –2 feet per second; L Dries. pers. obs,). Thus, salamanders can escape from Bentogrout during injection. To avoid effects on salamanders that may be in subterranean habitat beneath the bypass, migration of Bentogrout beyond the targeted area will be limited the following way. The impulse response survey will detect location and size of spaces beneath the bypass. This information will be used to determine the maximum amount of Bentogrout to be injected in each area adjacent to Beach habitat, thus avoiding unknown migration of the material into fissures and voids in subterranean habitat.

6.1.2 Rock Anchors

Inserting rock anchors to stabilize the bypass requires drilling holes through the bypass floor and into the limestone beneath. This carries two risks. One, drilling could intersect conduits in the aquifer beneath Barton Springs, potentially altering flow paths and affecting spring flow from Eliza, Parthenia, and Old Mill Spring. Two, drilling will pass through potential habitat immediately beneath the bypass and could harm any salamanders present. To evaluate the first risk and the feasibility of using rock anchors, in August 2010 the City of Austin drilled three test holes to determine if rock encountered was strong enough to hold the anchors, if the elevation of bedrock beneath the bypass is higher than the deepest elevation at the spring mouths and if voids were present in the bedrock. The results from the test holes established the presence of limestone at acceptable elevations and thereby the depth limits for rock anchors, and the presence of voids in the fault zone. Based on these results, rock anchors will be used in areas downstream of the fault zone where no subterranean voids were encountered (~ segments 1 – 5.5) (Fig. 12). Rock anchors will not be used in the fault zone (~ segments 5.5 – 8) because a void was encountered during testing. Repair outside of the fault zone requires 16 rock anchors per segment if there are no drilling problems. Based on rock anchor testing in August 2010, no voids were encountered east of the fault zone and rock cores showed dense, competent limestone with no macropores (Appendix F). However, some of drilled holes may intersect voids precluding the use of rock anchors. Yet, the more holes drilled, the greater the chance of encountering problems. To limit the risks of drilling, the maximum number of holes drilled will be 80, 16 per segment. Furthermore, if voids are encountered or rock anchors fail in more than two holes within a segment, rock anchors not used will be replaced with soil tie-backs as deemed necessary by the engineers for stability. Voids will be plugged according to methods described in the Rock Anchor testing plan (Appendix F, Fig. 13).

The risk of harming salamanders in subterranean flow paths will be minimal because potential habitat immediately beneath the bypass will already have been filled with rock and Bentogrout eliminating the possible presence of salamanders. Once the drilling enters bedrock there will be nearly no chance of encountering salamanders because this is out of the fault zone and area of suspected conduit development.

<u>6.1.3 Salamander Habitat Protection:</u>

- Drawdown of water level in Barton Springs will be limited to 2 feet.
- Drawdown will not be done if Barton Springs' discharge is at or below 30 ft^3/s and climatic predictions suggest there will be no substantial rainfall during the project.
- Drawdown will be reversed if Barton Springs' discharge reaches 20 ft^3/s during the project.
- If Barton Springs' discharge reaches 20 ft^3/s, the project will continue with no drawdown to avoid additional Take from cessation and re-initiation of construction activities.
- Diversion of Barton Creek surface water flow upstream of Barton Springs Pool will not artificially inundate Upper Barton Spring; excess base flow will be diverted through Barton Springs Pool if necessary.
- Partial drawdown of water level in Barton Springs Pool will facilitate flow through of base flow from Barton Creek.
- Pre-construction briefings will be held with contractors on endangered species and general sensitivity of work area.
- Permitted City staff will be onsite during all repair activities that occur in *E. waterlooensis* and *E. sosorum* surface habitats to maintain compliance with City of Austin federal Section 10 permits.
- City biologists and hydrogeologists will be on call throughout project to respond to emergencies and monitor repair activities
- Permitted City staff will make daily checks of springs and include attention to signs of detrimental effects of project
- City staff will investigate anomalous signs in the springs, including water quality measurements if warranted.

- Construction notes will be included on plans to alert contractors that work will stop upon discovery of potential detrimental impacts to protected species, or their surface and subterranean habitats, or potential violations of the City's federal and state endangered species permits
- Construction notes will be included on plans to alert contractors that suspended sediment must be settled out to the satisfaction of COA staff prior to removing cofferdams.
- Emergency contingency plans will be developed for routing spills of hazardous materials in Barton Creek through the bypass if warranted.
- Pool may be closed for recreational use all or part of each day during Phase I.
- The Pool will be closed for recreational use during Phases II and III.

6.1.4 Salamander Protection and Monitoring:

- Salamander habitat will be surveyed before and during the installation of each cofferdam.
- Salamanders found within limits of construction will be relocated to other habitat within the Pool. Injured salamanders will be moved to the Austin Salamander Conservation Facility.
- Each cofferdam will be searched every morning to assure that no salamanders are present before work begins.
- The inside of the bypass will be surveyed before work begins.
- Bypass segments will be surveyed before they are dewatered.
- Each salamander observed and/or relocated will be documented as well as its apparent physical condition, size, and any other relevant characteristics.
- Monthly salamander surveys will continue as stipulated in the City's federal 10a1B permit for Barton Springs
- Barton Springs Pool will be closed during Phases II and III, eliminating harassment from recreational use.

6.1.5 Construction Methods

- Work will be phased so that adjacent, undisturbed salamander habitat is accessible at all times.
- There will be no permanent alteration of designated habitat from repairs.
- Cofferdams will be used to dewater work areas in salamander habitat to impede re-colonization of dry areas.
- Cofferdams will have no intrusions into substrate or bedrock.
- Cofferdam for Phase II will not extend beyond the limits of Beach habitat into primary salamander habitat.
- Non-invasive tie-backs into the embankment and heavy-weight concrete will be used in the fault zone; rock anchors will not be used in the fault zone.
- Heavy-weight concrete will be used for the bypass floor in segments 5-8 to reduce number of intrusions into bedrock for rock anchors.
- Aggregate for heavy-weight concrete will be hematite instead of magnetite, prohibiting the introduction of highly magnetized material near salamander habitat.
- If more than 2 rock anchors fail or if more than 2 voids are encountered during rock-anchor drilling in any segment, soil tie-backs will be used in place of failed rock anchors.

- Drill casing for rock anchor holes will be left in place to limit migration of cementitious grout.
- Amount of cementitious grout used around rock anchors will be limited to the volume of the casing
- Non-toxic materials will be used to stabilize subgrade under the bypass.
- Biodegradable vegetable oil will be used in hydraulic equipment.
- Any repair areas that require use of materials with known or unknown ecotoxicological effects will be fully surrounded with unused, environmental protection booms and absorbent materials. Any spilled material will be immediately removed and disposed of appropriately.
- All materials, equipment, and vehicles that will be inside the Pool will be cleaned and dry before initial use.
- All materials and equipment used inside the Pool will not be used in any other waterway during this project.

6.1.6 Precautions for Stabilizing Subgrade:

- Crushed limestone rock (gravel) will be used beneath bypass to maintain normal water quality
- Non-toxic Bentogrout will be used to fill subgrade under the bypass.
- Bentogrout will be injected one segment at a time.
- Bentogrout slurry will be viscous enough to limit migration to 2 inches per second.
- Volume of Bentogrout injected will not exceed calculated volume of space beneath bypass.
- Permitted City staff will visually examine Beach habitat and Eliza Spring for presence of excess Bentogrout during subgrade stabilization.

6.1.7 Containment Booms:

- Booms will completely surround any stationary gasoline/diesel powered equipment.
- Turbidity curtains will be placed in the water just inside the limits of construction.

6.1.8 Sediment Controls:

- Silt fences surrounding contractor staging areas and temporary spoils area will reduce runoff from entering the pool or Barton Creek.
- Stabilized construction entrances will reduce erosion of soil, protect tree root zones, and prevent soil compaction.

6.1.9 Noise Mitigation:

- Cofferdams will buffer noise generated within the areas to be de-watered.
- Equipment will be powered only when required – no idling.
- Ambient noise will not exceed City of Austin code limits (Chapter 9-2, Ordinance 20110210-029)

7.0 Determinations of Effects

As previously stated, there are a large number of protected species in Travis County. However, these two projects are not anticipated to result in Take of any songbirds, karst invertebrates, or other protected species. None of these species occur within or near the Action Area. The following analysis covers the two protected salamander species, *E. sosorum* and *E. waterlooensis*, that occur within the Action Areas.

7.1 Incidental Take Estimation

Because the City's 10(a)1(B) permit for *E. sosorum* does not include Incidental Take resulting from these projects, it is necessary to obtain permission for likely one-time Take. These estimates are based on available data and information, as well as mitigation and protection measures, which are related to habitat quality in the project areas.

Incidental Take can be quantified by area of habitat affected or by number of individual animals (USFWS and NMFS 1998). The approach taken here uses both of these methods for two reasons. One, activities for each project will affect particular areas of habitat sequentially, not simultaneously. So, using total number of salamanders in each spring would not accurately reflect the benefits of the Conservation Measures. Two, salamanders are unevenly distributed among habitat areas in time and space. Temporal and spatial variation can be influenced by natural environmental factors that can influence abundance and ability to detect salamanders on any particular sample date. Using a single sample value to estimate Incidental Take requires predicting the future environmental conditions, then, choosing a number from the dataset that corresponds with those assumed conditions. It is unknown what the exact environmental conditions will be at the time both the bypass culvert and dam repair projects occur, therefore take estimation could be un-quantifiably erroneous. Since, it is also difficult to know the exact number of salamanders occupying any area of habitat at a particular time, using simple statistics based on a set of data can provide an idea of what to expect on average, regardless of environmental conditions. These results will allow estimates of take to be more precisely assigned according to activity and habitat area affected. These statistics also provide quantitative estimates of variation and error.

These data also allow examination of potential effects of construction noise on salamander presence in surface habitat, specifically whether abundance and density of salamanders differs in the presence of loud noise generated during regular cleaning of Barton Springs Pool.

<u>7.1.1 Methods to Calculate Take</u>

Take for each species (Tables 20, 21) was calculated by multiplying the area of habitat disturbance times the density of salamanders present in that specific area of habitat (Tables 16-18). Methods used to calculate salamander density are provided in 7.1.2 below. Based on the scientific information presented here and discussions with U.S. Fish and Wildlife Service staff, the proposed Conservation Measures are expected to be very effective in reducing lethal Take. Therefore, final Take estimates (Tables 20, 21) assume lethal Take resulting from the projects will be reduced by 90% due to Conservation Measures. Non-lethal Take in the form of harassment is calculated by multiplying area of disturbance times salamander density of that specific area of habitat and subtracting calculated lethal take for that specific area of habitat. Harassment Take will be conservative because cofferdam liners will overlap areas of beach habitat (Fig. 3) and adjacent areas of non-habitat and the estimated harassment Take is calculated using the total area covered by the liners. For the bypass pass project, lethal and harassment Take are totaled by each of the three phases and rounded up to the nearest whole number when the value is greater than or equal to 0.1 and is shown is parenthesis. Total Take for each phase is calculated bysumming lethal and harassment Take values. The grand total of Take is calculated by adding Take for each project phase.

7.1.2 Methods to Calculate Salamander Density

Estimates of density for use in calculations of potential Take of *E. sosorum* resulting from these projects are based on all of the available data on abundance and occurrence in all habitat areas of Barton Springs Pool and Eliza Spring. Potential Take of *E. waterlooensis* from Eliza Spring is based on data from the date they were first encountered in 2002 through 2010 (Table 14). Very few individuals of this species have been found in Parthenia Spring (Table 14), and only one has ever been seen near habitat that will be disturbed by either project. Nevertheless, *E. waterlooensis* Take in the Pool and for the epigean area under the bypass is estimated using data from Parthenia Spring.

The dataset for Barton Springs Pool includes results from experimental drawdowns conducted in 1998 and surveys conducted from 1993 through 2010. Data from these experimental drawdowns were used to determine permitted Take for the City's 10(a)1(B) permit Habitat Conservation Plan issued in 1998 (USFWS 1998). The data listed in the HCP were double-checked with data sheets and field notes and minor errors subsequently discovered. The errors were corrected before conducting any analyses for this document (See Appendix G). Specific location data is not included in the dataset for 151 salamanders that were found on the beach. These salamanders were assigned to one of three beach sections based on the proportion of the remaining 89 salamanders found in specified areas of the beach. An example calculation is shown below.

Σ Beach 1, 2, 3 = 64+22+3=89
Proportion in Beach 1 = 64/89 = 0.72
Total Unknown Location = 151
Assigned to Beach 1 = 151*0.72 = 108.72 ≅ 109

Survey results are the other source of data for the Barton Springs Pool dataset. Although primary salamander habitat has been surveyed regularly since 1993, survey method and area searched have varied (Fig. 26). From 1993 to 2001, approximately 484 square feet of habitat were surveyed using transects across primary habitat and the Beach 1 section. From 2001 to June 2003, roughly defined, discontinuous areas of the runs in front of the caves (Main Spring, Little Main Spring, and Side Spring) were searched and fissures were surveyed for salamanders. From July 2003 to the present, regular surveys have included roughly 2,485 square feet of contiguous areas in front of the caves and 1,750 square feet of fissures habitat. Since 2002, the Beach was surveyed once in 2009 and 6 times in 2010. Consequently, much of the data on occurrence and abundance of salamanders in Beach habitat is from experimental drawdowns, including the largest number found on a single day (84). The entire dataset includes abundances from survey areas of differing size and survey effort. This variation was standardized by calculating densities for each section wherever possible. Densities for beach sections were calculated based on the sum of known and assigned numbers of salamanders. The data from 2002 to June 2003 do not include location and size of area surveyed, and therefore, were not included in density calculations. This omission is unlikely to have had a strong influence on density estimates because the largest abundances of salamanders ever found in Parthenia Spring occurred in 2007 and 2008.

The *E. sosorum* dataset for Eliza Spring includes survey results from 1995 through 2010. Eliza Spring is small, roughly 800 square feet, and thus, the entire spring can be searched in a single survey and provides a more rigorous estimate of salamander abundance than in the other sites.

Abundance in each habitat area was used to calculate the mean, standard deviation, and standard error in number of salamanders, and the percentage of the sum of all salamanders ever found. Density of salamanders per sample was used to calculate the mean, standard deviation, and standard error over the period of record. Mean salamander abundance was used to test whether the noise produced by cleaning equipment is related to variation in abundance in Parthenia and Eliza Spring.

7.1.3 Results

Abundance and density of *E. sosorum* in Parthenia Spring differs significantly among the survey sections of the spring mouths, the 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 (Fig. 20, Table 16). This habitat is typically higher quality salamander habitat of because, in general, they have the fastest water flow, the least sediment accumulation within the rocky substrate, and the greatest abundances of invertebrate prey. While the area known as the beach is 11,000 square feet, only a portion of the upstream 3,900 square feet (Beach 1 and Beach 2) currently has suitable habitat.

Table 16. Presented below are mean, standard deviation (S.D.), sample maximum (Max.), and sample minimum (Min.) for abundance and density (number per square foot) of *E. sosorum* in each section of Barton Springs Pool using data from 1993 – 2010. Also presented are the number of samples (N) and cumulative sums (Σ**)** of salamander abundance over all samples in each section. Statistics for the beach sections are based on the sum with assigned locations for 151 salamanders. Values used for Incidental Take calculations are in **bold** font.

Section	**Area (sq ft)**	**Mean**	**S.D.**	**Mean +1 S.D.**	**Max.**	**Min.**	**N**	**Σ**	**Σ w/ assigned**
				Barton Springs Pool					
				Eurycea sosorum					
Spring Mouths:	484 to 2485								
Abundance		15.0	37.0	52	412	0	412	6175	6175
Density		0.071	0.117	**0.19**	0.88	0	374	n/a	n/a
Fissures:	1900								
Abundance		2.3	3.8	6.1	23	0	196	445	445
Density		0.010	0.024	**0.034**	0.182	0	179	n/a	n/a
Beach 1:	1300								
Abundance		3.3	8.8	12.1	61	0	54	69	178
Density		0.003	0.007	**0.01**	0.047	0	54	n/a	n/a
Beach 2:	2600								
Abundance		3.2	5.3	8.5	21	0	18	20	58
Density		0.001	0.002	**0.003**	0.008	0	18	n/a	n/a

Beach 3:	7100								
Abundance		0.35	0.61	1.0	2	0	17	2	6
Density		0.00005	0.00008	**0.0001**	0.003	0	17	n/a	n/a
All Sections	484 to 15385								
Abundance		9.4	28.6	37.9	412	0	735	6711	6862
Density		0.044	0.095	**0.14**	0.88	0	651	n/a	n/a
				Eurycea waterlooensis					
Total	484 to 15385								
Abundance		0.181	0.613	0.794	5	0	160	29	29
Density		0.00007	0.0002	**0.0003**	0.001	0	115	n/a	n/a

Table 17. Presented below are mean, standard deviation (S.D.), sample maximum (Max.), and sample minimum (Min.) for abundance and density of *E. sosorum* in each section of Eliza Spring using survey data from 2003 – 2010. Also presented are the section area (in square feet) number of samples (N), and cumulative sums (Σ**)** of salamander abundance over all samples in each section. Values used in Incidental Take calculation are in **bold** font.

Section	**Area (sq. ft.)**	**Mean**	**S.D.**	**Mean +1 S.D.**	**Max.**	**Min.**	**N**	**Σ**
				Eliza Spring				
				Eurycea sosorum				
Quadrant I:	225 - 465							
Abundance		126.1	80.3	206.4	361	14	72	9079
Density		0.57	0.37	0.94	1.60	0.06	72	n/a
Quadrant II:	225 - 465							
Abundance		93.5	78.9	172.4	363	4	72	6733
Density		0.43	0.38	0.81	1.62	0.02	72	n/a
Quadrants I and II:	450 - 930							
Abundance		109.7	80.7	190.4	363	4	145	15906
Density		0.50	0.38	0.88	1.62	0.02	145	n/a
Quadrant III:	150 - 415							
Abundance		75.2	73.5	148.7	359	1	74	5565
Density		0.43	0.42	0.85	2.05	0.01	74	n/a
Quadrant IV:	150 - 415							
Abundance		84.3	66.7	151.0	286	0	73	6157
Density		0.48	0.38	0.86	1.63	0.0	73	n/a
Quadrants III and IV:	300 - 830							
Abundance		79.6	70.4	150.0	359	0	146	11628
Density		0.45	0.40	**0.85**	2.05	0.0	146	n/a

Table 18. Presented below are mean, standard deviation (S.D.), sample maximum (Max.), and sample minimum (Min.) for abundance and density of *E. waterlooensis* in each section of Eliza Spring using survey data from 2003 – 2009. Also presented are the section area (area in square feet) number of samples (N), and cumulative sums (Σ) of salamander abundance over all samples in each section. Values used in Incidental Take calculation are in **bold** font.

Section	Area (sq. ft.)	Mean	S.D.	Mean +1 S.D.	Max.	Min.	N	Σ
Eliza Spring								
Eurycea waterlooensis								
Quadrant I:	225 - 465							
Abundance		0.22	0.70	0.92	5	0	72	16
Density		0.001	0.003	0.004	0.02	0	72	n/a
Quadrant II:	225 - 465							
Abundance		0.26	0.86	1.12	6	0	72	19
Density		0.001	0.004	0.005	0.02	0	72	n/a
Quadrants I and II:	450 - 930							
Abundance		0.26	0.81	1.07	6	0	145	38
Density		0.001	0.004	0.005	0.03	0	145	n/a
Quadrant III:	150 - 415							
Abundance		0.55	1.54	2.09	11	0	74	41
Density		0.003	0.009	0.012	0.063	0	74	n/a
Quadrant IV:	150 - 415							
Abundance		0.25	0.62	0.87	3	0	73	18
Density		0.001	0.003	0.004	0.017	0	73	n/a
Quadrants III and IV:	300 - 830							
Abundance		0.38	1.16	1.54	11	0	146	56
Density		0.002	0.007	**0.009**	0.06	0	146	n/a
All Quadrants:								
Abundance		0.52	1.42	1.94	12	0	364	188
Density		0.002	0.005	**0.007**	0.06	0	364	n/a

Salamander abundance is significantly ~~less~~ more in quadrants III and IV combined (Mann-Whitney $U = 8861.5$, $z = -2.960$, $p = 0.0031$) than in I and II, combined (Tables 17, 18). Quadrants III and IV are approximately 15 feet upstream of the proposed location of the flow diversion pump in the Spring pool outflow pipe.

7.1.3.1 Potential Short-term Take

Lethal Take associated with this project is estimated with and without proposed Conservation Measures (see Section 6.0), including selection of construction methods and materials that afford the best level of protection for the salamanders, conducting the project in phases, and daily onsite monitoring of work areas. Conducting the project in phases allows only one area of salamander habitat to be affected, leaving other areas of available habitat undisturbed and accessible for refuge. The daily monitoring includes survey and relocation of salamanders by federally permitted City of Austin staff with experience in these activities before and during physical disturbances of habitat.

The potential lethal effects of these projects will be reduced by implementation of Conservation Measures that focus on use of least-invasive construction methods and on-site monitoring. These Conservation Measures are outlined in Section 6.0. *Eurycea sosorum* and *E. waterlooensis* salamanders are likely to respond to disturbance, noise, and transient changes in the surface water in and around their habitats by retreating to or remaining in epigean or subterranean areas of the aquifer. Not only will this keep salamanders in undisturbed wetted habitat, it will also buffer exposure to noise. Therefore, some of the potential impacts of these projects will be eliminated by natural avoidance behavior of the salamanders.

7.1.3.1.1 Rock Anchors

Potential Incidental Take of *E. sosorum* from use of rock anchors in bypass culvert repair is estimated below. Drilling of rock anchor holes through the bypass culvert floor will disturb salamander habitat between the floor and the bedrock below and potentially harm or kill protected salamanders in the work area. The approach to estimating Take from this activity is dependent on the expected density of salamanders in the work area and volume of potential habitat affected.

The amount of habitat disturbed is calculated based on the cylindrical volume of the hole necessary to install each rock anchor. Cylindrical volume of affected habitat depends on the depth of habitat between the bypass bottom and the top of bedrock, and the dimensions of rock-anchor holes. We estimated the expected depth to bedrock for segments 1 – 5 based on the actual elevations of bedrock determined during rock anchor testing and known elevation of the underside of the bypass floor (Table 19).

Table 19. Listed below are the elevations of the bottom of the bypass and underlying bedrock determined during rock anchor testing. Also listed are the dimensions of rock anchor cased access holes to be drilled. These values were used to calculate volume of potential salamander habitat affected, which was used to estimate expected Take from installation of rock anchors. Values in bold were used in Take calculations.

Elevations			Dimensions
Location	Elevation (ft.)	Depth to Bedrock (ft.)	Access Casing (ft.)
Bypass Underside	427.0		
Beneath Segment 2	419.2	**7.8**	
Beneath Segment 5	423.5	**3.5**	
Diameter			0.25
Radius (r)			**0.125**

The cylindrical volume of habitat affected was calculated as follows:

Volume = (Πr^2)(Depth from Bypass Bottom to Bedrock)

Volume Segments 1-3= Π(0.125 feet)^2(7.8 feet) **= 0.382 feet^3/anchor**

Volume Segments 4-5 = Π(0.125 feet)^2(3.5 feet) **= 0.172 feet^3/anchor**

Expected density of salamanders beneath the bypass culvert is based on the observed number of salamanders in a 1-foot long by 1-foot wide by 0.5-foot volume of Beach habitat adjacent to relevant bypass segments. We assume that the density of salamanders on the beach per cubic foot is double the density of salamanders on the beach per square foot. Put another way, the density of the salamanders on the beach per 0.5 cubic feet is equivalent to the density of the salamanders per square foot.

E. sosorum:

Beach 2: (0.003/1ft.L x 1ft.W x0.5 ft tall)(2) = **0.006 salamanders/ft.^{3}**

Beach 3: (0.0001/1ft.L x 1ft.W x0.5 ft tall)(2) = **0.0002/ft.^{3}**

E. waterlooensis:

Beach 2: (0.0003/1ft.L x 1ft.W x0.5 ft tall)(2) = **0.0006 salamanders/ft.^{3}**

Beach 3: (0.0003/1ft.L x 1ft.W x0.5 ft tall)(2) = **0.0006 salamanders/ft.^{3}**

Take is then estimated using the product of the salamander density in the Beach section abutting the relevant bypass segment by volume of habitat disturbed by each rock anchor casing, and the number of rock anchors.

E. sosorum

Take Segments 1-3 = (0.0002 sals./ft^3)(0.382 ft^3 habitat)(48 anchors) = **0.0037 salamanders**

Take Segments 4-5 = (0.006 sals./ft^3)(0.172 ft^3 habitat)(32 anchors) = **0.033 salamanders**

Total Expected Take *E. sosorum* from Rock Anchors = 0.0367 ~ 0.04 salamanders

E. waterlooensis

Take Segments 1-3 = (0.0006 sals./ft^3)(0.382 ft^3 habitat)(48 anchors) = **0.011 salamanders**

Take Segments 4-5 = (0.0006 sals./ft^3)(0.172 ft^3 habitat)(32 anchors) = **0.0033 salamanders**

Total Expected Take *E. waterlooensis* from Rock Anchors = 0.014 ~ 0.01 salamanders.

7.1.3.1.1 Partial Drawdown

Take from a partial drawdown is based on a decrease in water depth of 2 feet in Barton Springs Pool. This exposes 500 square feet of habitat in the fissures of Parthenia Springs and exposes no habitat in Eliza Spring at discharges ≥ 40 ft^3/s with no or partial blocking of outflow from the spring pool. Maintenance of partial drawdown from this project will be dependent on discharge and retention of water in surface habitat of Eliza Spring at discharges down to 21 ft^3/s. If Barton Springs' discharge is at or near 30 ft^3/s and climatic predictions indicate no rainfall in the subsequent year (e.g. a La Niña event), we could expect further decreases in discharge and a period of drought. Under these conditions, the project would be delayed until discharge returns to above average values. If Barton Springs' discharge is at or near 30 ft^3/s and climatic predictions indicate rainfall in the subsequent year (El Niño), the project would commence. If during the project Barton Springs' discharge decreases to 20 ft^3/s and/or surface habitat in Eliza Spring is in danger of going dry, the partial drawdown would be reversed and the project would continue. The logic for continuing the project despite drought is described in the cumulative effects section below. that once the project has started the harassment has already been imposed. Salamanders would have already retreated to subterranean habitat and experienced the decrease in reproduction associated with drought. Cessation and resumption of construction would subsequently impose harassment from the project during the post-drought period when salamander populations would begin to recovery. The most critical period for species persistence is the post-drought return of reproduction and recruitment.

Table 20. Presented below are estimates of *E. sosorum* Incidental Take from bypass culvert repair. Salamander habitat sections in Barton Springs Pool that will be affected by each activity are Beach 1 (B1), Beach 2 (B2), and Beach 3 (B3). Salamander density in each habitat section is the mean density plus one standard deviation (SD) (Tables 13 and 14). Take is estimated as the product of density and affected habitat area; Conservation Measures are assumed to be 90% effective in reducing lethal Take of all activities except Pool drawdown. Drawdown Take without conservation measures is calculated based on the area of habitat exposed during a full drawdown. Take with conservation measures is based on the area exposed during a 2-foot partial drawdown. These values were used to calculate total Take for each project phase and the entire project. An asterisk references Take calculations presented in 7.3.1.1 above.

Activity	**Area** ($ft.^2$)	***E. sosorum* Density + 1 SD** ($no./ft.^2$)	**Lethal Take** (no.)		**Harassment Take w/ Conservation Measures** (no.)	**Total Take** (no.)
			No Conservation Measures	**With Conservation Measures**		
Bypass Phase I						
Partial Drawdown (Fissures)	500	0.034	17	**1.7**	**15.3**	**17**
Bypass Phase II						
Cofferdam and dewatering segments 6.5-8.5 (B1)	1300	0.01	13.0	1.3	11.7	13.0
Cofferdam and dewatering segment 4.5-6.5 (B2)	2600	0.003	7.8	0.78	7.02	7.8
Subgrade gap fill 6.5-9.5 (B1)	2250	0.01	22.5 w/ Uretek	2.25 w/Bentogrout	20.25	22.5
Subgrade gap fill segments 4.5-6.5 (B2)	1500	0.003	4.5 w/Uretek	0.45 w/Bentogrout	4.05	4.5
Subtotal Phase II				**4.78**	**43.02**	**47.8**

Table 20. (continued)

Activity	**Area** (ft.^{2})	***E. sosorum* Density + 1 SD** (no./ft.^{2})	**Lethal Take** (no.)		**Harassment Take w/ Conservation Measures** (no.)	**Total Take** (no.)
			No Conservation Measures	**With Conservation Measures**		
Bypass Phase III:						
Cofferdam and dewatering segments 1-4.5 (B3)	7100	0.0001	0.71	0.07	0.63	0.7
Cofferdam and Dewatering Segments 4.5-5.5 (1/3 B2)	858	0.003	2.6	0.26	2.3	2.6
Subgrade Gap Fill Segments 1-4.5 (B3)	2625	0.003	7.9 w/Uretek	0.79 w/Bentogrout	7.1	7.9
Subgrade gap fill 4.5-5.5 (B2)	750	0.01	7.5 w/Uretek	0.75 w/Bentogrout	6.8	7.5
Rock Anchors Segments 4-5(B2)	*		0.0033 no grout containment	0.00033 w/grout containment	0.003	0.004
Rock Anchors Segments 1-3(B3)	*		0.0037 no grout containment	0.00037 w/grout containment	0.003	0.004
Eliza Outflow Diversion	350	0.85	297.5	29.75	267.75	298
Subtotal Phase III				**31.6**	**284.6**	**316.8**
Dam Repairs	1050	0.003	3.15	**0.32**	**2.83**	**3.15**
Total Take				**39**	**346**	**385**

Table 21. Presented below are estimates of *E. waterlooensis* Incidental Take from bypass culvert repair. Salamander habitat sections in Barton Springs Pool that will be affected by each activity are Beach 1 (B1), Beach 2 (B2), and Beach 3 (B3). Salamander density in each habitat section is the mean density plus one standard deviation (SD) (Tables 13 and 14). Take is estimated as the product of density and affected habitat area; Conservation Measures are assumed to be 90% effective in reducing lethal Take of all activities except Pool drawdown. Drawdown Take without conservation measures is calculated based on the area of habitat exposed during a full drawdown. Take with conservation measures is based on the area exposed during a 2-foot partial drawdown. These values were used to calculate total Take for each project phase and the entire project. An asterisk references Take calculations presented in 7.3.1.1 above.

Activity	**Area** ($ft.^2$)	***E. waterlooensis* Density + 1 SD** ($no./ft.^2$)	**Lethal Take** (no.)		**Harassment Take w/ Conservation Measures** (no.)	**Total Take** (no.)
			No Conservation Measures	**With Conservation Measures**		
Bypass Phase I:						
Partial Drawdown (Fissures)	500	0.0003	0.15	0.015	0.135	0.15
Bypass Phase II:						
Cofferdam and dewatering segments 6.5-8.5 (B1)	1300	0.0003	0.39	0.04	0.35	0.39
Cofferdam and dewatering segment 4.5-6.5 (B2)	2600	0.0003	0.78	0.08	0.7	0.78
Subgrade gap fill 6.5-9.5 (B1)	2250	0.0003	0.68 w/ Uretek	0.07 w/Bentogrout	0.61	0.68
Subgrade gap fill segments 4.5-6.5 (B2)	1500	0.0003	0.45 w/Uretek	0.05 w/Bentogrout	0.4	0.45
Subtotal Phase II				**0.25**	**2.19**	**2.4**

Table 21. (continued)

Activity	**Area** (ft.^{2})	***E. waterlooensis* Density + 1 SD** (no./ft.^{2})	**Lethal Take** (no.)		**Harassment Take w/ Conservation Measures** (no.)	**Total Take** (no.)
			No Conservation Measures	**With Conservation Measures**		
Bypass Phase III:						
Cofferdam and dewatering segments 1-4.5 (B3)	7100	0.0003	2.13	0.21	1.92	2.13
Cofferdam and Dewatering Segments 4.5-5.5 (1/3 B2)	858	0.0003	0.26	0.03	0.23	0.26
Subgrade Gap Fill Segments 1-4.5 (B3)	2625	0.0003	0.79 w/Uretek	0.08 w/Bentogrout	0.71	0.79
Subgrade gap fill 4.5-5.5 (B2)	750	0.0003	0.23 w/Uretek	0.02 w/Bentogrout	0.21	0.23
Rock Anchors Segments 4-5(B2)	*		0.0033 no grout containment	0.0003 w/grout containment	0.003	0.004
Rock Anchors Segments 1-3(B3)	*		0.011 no grout containment	0.001 w/grout containment	0.01	0.011
Eliza Outflow Diversion	350	0.009	3.15	.315	2.84	3.15
Subtotal Phase III				**0.66**	**5.9**	**6.6**
Dam Repairs	1050	0.0003	0.32	0.03	0.29	0.32
Total Take				**1**	**9**	**10**

7.1.3.2 Potential Long-term, Cumulative Effects

The estimated expected lethal Take due to these projects is 39 *E. sosorum* and 1 *E. waterlooensis*. Although 39 may appear to be a large number of *E. sosorum*, 30 of these would be salamanders from the Eliza Spring population and is 8.6% of the average abundance of 348 salamanders observed since habitat reconstruction in 2003 through 2010. The remaining 9 salamanders from Parthenia Springs are 10.5% of the average abundance of 86 salamanders seen since habitat reconstruction in 2005 through 2010. Loss of these small percentages of salamanders from either spring site should not have a significant long-term effect on salamander abundance and population size. Loss of 1 *E. waterlooensis* should not significantly affect the long-term health of the populations or species; if it did, population size would already be so small that the species would already be functionally extinct based on simple evolutionary models of small populations (Maynard Smith 1998; Lynch 1996). Thus, the projects proposed here would be irrelevant. Take due to harassment could result in temporary reduction in *E. sosorum* and *E. waterlooensis* abundance simply because salamanders have retreated to epigean or subterranean areas where they aren't detectable during monthly surveys.

The most significant potential long-term cumulative effect would be an unnatural delay or decrease in reproduction. Anthropogenic noise and disturbance from the construction projects might trigger such responses, yet, captive *E. sosorum* and *E. waterlooensis* continue to reproduce with 60-70 dB of ambient air noise. Similar disturbance from construction does not appear likely to deter reproduction. However, it is clear that *E. sosorum* adults reduce or delay reproduction in the wild under extended adverse environmental conditions such as droughts (See Section 4.3). Based on resource allocation theory of long-lived vertebrates (Pianka 1983), they are also likely to reduce reproduction when food is scarce. If construction activities were to mimic environmental changes typical of droughts, such as reduced flow velocity or decreased dissolved oxygen concentration, then we might expect recruitment in Parthenia and Eliza Spring to decrease. If natural environmental conditions are favorable, we might expect an increase in recruitment after projects are completed, as adults resume reproduction and juveniles grow into adults. If construction occurs during drought, it isn't clear whether it would magnify effects on *Eurycea* populations. Drought has significant effects on *Eurycea sosorum* populations, yet one response of salamanders is an apparent retreat to subterranean habitat. This behavior would buffer the animals from noise and disturbance at the surface imposed by construction.

The cumulative effects could only become apparent after the drought if populations do not rebound as expected. Unfortunately, we do not know the time frame of post-drought resumption of reproduction. Data presented here indicate that *E. sosorum* populations have not fully recovered yet; little reproduction and recruitment are occurring one year after the low spring flow period of 2008-2009. The construction projects proposed here are expected to last 6 – 9 months, which is less than the length of the two most recent droughts.

The logic for continuing the project despite drought is that the salamanders would have already retreated to subterranean habitat and experienced the decrease in reproduction associated with drought. Cessation and resumption of construction would subsequently impose harassment from the project during the post-drought period when salamander populations would begin to recover. The most critical period for species persistence is the post-drought return of reproduction and recruitment.

One possible strategy for reducing cumulative effects of the projects would be to limit construction to periods of average or higher discharge. These conditions coincide with higher rainfall and more floods of Barton Springs. Floods during a construction project not only delay work, they have the potential to carry cofferdams and other materials downstream into salamander habitat. These flow conditions also coincide with periods of greatest reproduction and recruitment in salamander populations, so the effects of construction would likely have a greater long-term cumulative effect if reproduction is delayed.

8.0 Conclusions

In the judgment of the U. S. Army Corps of Engineers, these projects will affect and are likely to adversely affect *E. sosorum* or *E. waterlooensis.* The Corps requests Formal Consultation with the U.S. Fish and Wildlife Service under Section 7 of the Endangered Species Act. Further, the Corps requests for these two projects Take of 385 *E. sosorum* (39 lethal and 346 non-lethal in the form of harassment) and Take of 10*E. waterlooensis* (1 lethal and 9 non-lethal in the form of harassment). Construction methods, designs, and activities are such that there will not be permanent alteration to designated salamander habitat.

The potential lethal effects of these projects can be effectively reduced by the proposed Conservation Measures, which include selective construction methods combined with the on-site monitoring activities of permitted City of Austin staff. Much of the construction disturbance is similar to disturbance caused by regular recreation and cleaning, but the duration of disturbance will be greater. In Barton Springs Pool, aquatic recreation will be limited during the bypass repair.

The project will only affect two of the four springs that harbor salamander populations. The analyses presented here indicate that the ecological health of the salamander populations in both Eliza and Parthenia Spring has improved since the listing of *E. sosorum*. Both populations show evidence of reproduction and recruitment under favorable environmental conditions, even though both of these populations also regularly experience more human disturbance than Old Mill and Upper Barton Spring. These two populations have shown they can rebound in response to habitat improvement and after the recent severe drought. These salamanders also have shown natural avoidance behaviors that will help buffer then from detrimental effects and have demonstrated resilience to temporary disturbances such as those that would be introduced by the projects considered here.

Finally, while choosing not to repair the bypass culvert would avoid the associated one-time take, it would not necessarily prevent future detrimental effects on protected salamander species. Continued deterioration of the bypass culvert will result in more holes erupting in the floor, allowing more water from Barton Springs Pool to flow into the bypass without effective methods of control. If this occurs during a severe drought, as the first incident did, temporary stabilization methods may be ineffective in maintaining water in surface habitat of Eliza Spring. Placing limestone blocks in the mouth of the bypass may control loss of water somewhat, but at the price of deteriorated habitat in Eliza Spring to an unknown degree. Impeding the outflow velocity from Eliza Spring for an extended period of time will exacerbate detrimental effects of the drought on the salamander populations. Slower flow will reduce the entrainment of oxygen in the water during a period when dissolved oxygen is already dipping into concentrations low enough to be a concern. This affects not only salamander health, but also compromises the ecological integrity of the aquatic community that supports *E. sosorum* and *E waterlooensis*. The likely effects of not repairing the bypass could be much worse than the anticipated and mediated effects of the repair project. The project has been designed to incorporate methods and Conservation Measures that are more protective of endangered and protected salamanders than unknown effects of future bypass failure.

9.0 References

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