U.S. Fish & Wildlife Service

Barton Springs Salamander
(Eurycea sosorum)

Recovery Plan

September 2005

BARTON SPRINGS SALAMANDER
(*Eurycea sosorum*)

RECOVERY PLAN

Southwest Region
U.S. Fish and Wildlife Service
Albuquerque, New Mexico

Approved: ACTING ______________________________
Regional Director, Southwest Region
U.S. Fish and Wildlife Service

Date: August 18, 2005

Concurrence: ______________________________
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Date: August 29, 2005

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We would also like to acknowledge the work of Matthew Lechner, Lisa O'Donnell, and Krishna Gifford in preparing early drafts of this recovery plan during their previous roles as U.S. Fish and Wildlife Service liaisons to the recovery team.

EXECUTIVE SUMMARY

Species' Status: The Barton Springs salamander (*Eurycea sosorum*) was federally listed as an endangered species on May 30, 1997 (62 FR 23377-23392). The U.S. Fish and Wildlife Service (Service) has assigned the salamander a recovery priority number of 2C. Critical habitat has not been designated for this species. The Barton Springs salamander is also listed as endangered by the State of Texas.

Habitat Requirements and Limiting Factors: The Barton Springs salamander has only been documented at four spring outlets (collectively known as Barton Springs) within the City of Austin's Zilker Park in Travis County, Texas. Habitat for the Barton Springs salamander occurs in stenothermal (that is, having a narrow temperature range) springflows with substrates that are free of sediment and have various mixtures of gravel, cobble, aquatic plants, and leaf litter.

The primary threats or reasons for listing the Barton Springs salamander were "the degradation of the quality and quantity of water that feeds Barton Springs" as a result of urban expansion over the watershed. The species' restricted range makes it vulnerable to both acute and chronic groundwater contamination. The salamander is also vulnerable to catastrophic hazardous materials spills, increased water withdrawals from the Edwards Aquifer, and impacts to the surface habitat.

Recovery Strategy: Comprehensive regional plans are needed to address water quality and quantity threats. A number of interested parties are working on comprehensive regional approaches to aid in the conservation of this species; however, these approaches have not been fully implemented. Because of the extremely limited range of this species, captive breeding is important as insurance against extinction while other conservation measures are being put in place. Local surface habitat management and education and outreach programs are also important components of the recovery strategy for this species. While additional actions may be necessary to ensure the recovery of the Barton Springs salamander, further study is needed to guide and refine management and assess effectiveness of the various protection efforts. See Section 2.1, Recovery Strategy for a more detailed discussion.

Recovery Goal: The goal of this recovery plan is to ensure the long-term viability of the Barton Springs salamander in the wild to the point that it can be delisted.

Recovery Criteria:

Reclassify status from endangered to threatened: The Barton Springs salamander should be considered for reclassification when (1) the Barton Springs watershed is sufficiently protected to maintain adequate water quality (including sediment quality) and ensure the long-term survival of the Barton Springs salamander in its natural environment; (2) a plan is implemented to avoid, respond to, and remediate hazardous material spills within the Barton Springs watershed such that the risk of harm to the Barton Springs salamander is insignificant; (3) an Aquifer Management Plan is implemented to ensure adequate water quantity in the Barton

Springs watershed and natural springflow at the four spring outlets that comprise Barton Springs; (4) healthy, self-sustaining natural populations of Barton Springs salamanders are maintained at the four spring sites; (5) surface management measures to remove local threats to the Barton Springs ecosystem have been implemented; and (6) captive breeding populations have been established and a contingency plan is in place to ensure the survival of the species should a catastrophic event destroy the wild population.

Delisting: The Barton Springs salamander should be considered for removal from the List of Endangered and Threatened Wildlife (List) when (1) the measures listed above have been implemented and shown to be effective; (2) the Barton Springs salamander populations continue to be self-sustaining and stable; and (3) commitments are in place to maintain conservation measures and recovered status.

Actions Needed:

(1) Protect and, as necessary, improve water quality (including the quality of sediment) within the Barton Springs watershed.
(2) Minimize catastrophic water quality threats.
(3) Sustain adequate water quantity at Barton Springs.
(4) Manage surface habitat at Barton Springs.
(5) Maintain captive populations of Barton Spring salamanders for research and restoration purposes.
(6) Develop and implement an outreach plan.
(7) Monitor the current salamander populations and the results of recovery efforts.

Estimated Cost (Dollars x 1000): Cost estimates reflect costs for specific actions needed to achieve Barton Springs salamander recovery. Estimates do not include costs that agencies or other entities normally incur as part of their mission or normal operating expenses. The following table provides cost estimates for recovery actions listed in the Implementation Schedule (Section 4.0) of this document. Some costs for recovery actions were not determinable; therefore, the total cost for recovery is likely higher than this estimate. Costs for land acquisition were not included in this figure because the amount of land needed to protect water quality and ensure the recovery of the Barton Springs salamander has not been determined and furthermore land costs may change significantly over time.

Total Estimated Cost of Recovery by Recovery Action Priority (Dollars H 1000):

Year	Priority 1(a) Actions	Priority 1(b) Actions	Priority 2 Actions	Priority 3 Actions	Total
1 and 2	800	1,180	415	230	**2,625**
3 and 4	355	545	200	170	**1,270**
5 and 6	340	310	85	85	**820**
7 and 8	340	260	85	85	**770**
9 and 10	340	260	85	85	**770**
Total	**2,175**	**2,555**	**870**	**655**	**6,255**

Date of Recovery: If all actions are fully funded and implemented as outlined, including full cooperation of all partners needed to achieve recovery, recovery criteria for downlisting from endangered to threatened could be met within ten years; recovery criteria for delisting could be accomplished within ten years following reclassification. Monitoring to ensure recovery criteria have been met should begin prior to reclassification and continue at least five years after delisting.

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ACRONYMS AND ABBREVIATIONS

AMEC – AMEC Earth and Environmental Center for Watershed Protection
ASCE – American Society of Civil Engineers
BCCP – Balcones Canyonlands Conservation Plan
BMP – Best Management Practice
BOD – Biological Oxygen Demand
BS/EACD – Barton Springs/Edwards Aquifer Conservation District
CAMPO – Captial Area Metropolitan Planning Organization
cfs – cubic feet per second
CoA – City of Austin
CPCP – Captive Propagation and Contingency Plan
CWP – Center for Watershed Protection
EHA – Espey, Huston and Associates, Inc.
EPA – U.S. Environmental Protection Service
ESA – Endangered Species Act of 1973, as amended
HCo – Hays County
HCP – Habitat Conservation Plan
km – kilometers
LCRA – Lower Colorado River Authority
List – List of Endangered and Threatened Wildlife
mm – millimeters
mg/l – milligrams per liter
MTBE – Methyl Tertiary-Butyl Ether
NFHTC – National Fish Hatchery and Technology Center
NPDES – National Pollutant Discharge Elimination System
NRCS – Natural Resources Conservation Service
PAH – Polycyclic Aromatic Hydrocarbon
PCB – Polychlorinated Biphenyl
PCE - Polychloroethylene
PIT – Passive Integrative Transponder
Secretary – Secretary of the Interior
Service – U.S. Fish and Wildlife Service
TCEQ – Texas Commission on Environmental Quality (formerly TNRCC)
TNRCC – Texas Natural Resource Conservation Commission
TCo – Travis County
TVMDL – Texas Veterinary Medical Diagnostic Laboratory
TPWD – Texas Parks and Wildlife Department
TxDOT – Texas Department of Transportation
TXSt – Texas State University – San Marcos
μg/l – micrograms per liter
μS/cm – microsiemen per centimeter
USDA – U.S. Department of Agriculture
USGS – U.S. Geological Survey
UT – University of Texas at Austin
VOC – Volatile Organic Compound

1.0 BACKGROUND INFORMATION

1.1 Introduction

The Endangered Species Act of 1973, as amended (16 U.S.C. 1531 *et seq.*) (ESA), establishes policies and procedures for identifying, listing, and protecting species of wildlife and plants that are endangered or threatened with extinction. The ESA defines an "endangered species" as "any species which is in danger of extinction throughout all or a significant portion of its range." A "threatened species" is defined as "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range." According to the 1990 U.S. Fish and Wildlife Service's (Service) Recovery Planning Guidelines, recovery is defined as "the process by which the decline of an endangered or threatened species is arrested or reversed, and the threats to its survival are neutralized, so that its long-term survival in nature can be ensured." The goal of the recovery process is to restore listed species to a point where they are secure, self-sustaining components of their ecosystem, so that the protections of the ESA are no longer necessary (delisting).

The Secretary of the Interior (Secretary) is responsible for administering the ESA's provisions as they apply to this species. Day-to-day management authority for endangered and threatened species under the Department of Interior's jurisdiction has been delegated to the Service. To help identify and guide species recovery needs, section 4(f) of the ESA directs the Service to develop and implement recovery plans for listed species or populations. Recovery plans are strictly advisory documents developed to provide recovery recommendations based on resolving the threats to the species and ensuring self-sustaining populations in the wild. As such, actions listed in recovery plans are entirely voluntary and should not be interpreted as regulations, mandates, or legal obligations.

Recovery plans are to include (1) a description of site-specific management actions necessary to conserve the species or population; (2) objective, measurable criteria that, when met, will allow the species or populations to be removed from the Federal List of Threatened and Endangered Species (List); and (3) estimates of the time and funding required to achieve the plan's goals and intermediate steps. Section 4 of the ESA and regulations (50 CFR Part 424) promulgated to implement listing provisions also set forth the procedures for reclassifying and delisting species on the List. A species may be delisted if the Secretary determines that the species is no longer endangered or threatened due to one or more of the following five factors listed in section 4(a)(1) of the ESA that are considered when a species is added to the List. These factors are:

Listing Factor A - the present or threatened destruction, modification, or curtailment of its habitat or range;
Listing Factor B - overutilization for commercial, recreational, scientific, or educational purposes;
Listing Factor C - disease or predation;
Listing Factor D - the inadequacy of existing regulatory mechanisms; and

Listing Factor E - other natural or manmade factors affecting its continued existence.

Under 50 CFR Part 424.11(d), a species may be delisted when the scientific and commercial data available substantiate that the species or population is neither endangered nor threatened for one of the following reasons: (1) extinction, (2) recovery, or (3) original data for classification of the species were in error.

Reasons for listing – The Service listed the Barton Springs salamander as an endangered species based on the following threats: (1) degradation of the quality and (2) degradation of the quantity of water that feeds Barton Springs resulting from urban expansion (listing factor A), (3) modification of the salamander's surface habitat (listing factor A), (4) inadequacy of existing regulatory mechanisms to protect the salamander and lack of a comprehensive plan to protect the Barton Springs watershed from increasing threats to water quality and water quantity (listing factor D), and (5) the salamander's extreme vulnerability to environmental degradation because of its restricted range in an entirely aquatic environment (listing factor E).

This recovery plan describes in detail the listing factors that formed the basis for the Barton Springs salamander's addition to the List and the current threats associated with each listing factor. The recovery plan then delineates recovery criteria that will demonstrate the threats have been alleviated, based on implementation of the recovery actions (Table 1).

Table 1 - Summary of the Barton Springs Salamander Listing Factors and Threats, Recovery Criteria to Measure Recovery Success, and Recovery Actions.

Listing Factor	**Threat** (Section 1.6)	**Recovery Criteria** (Section 2.2)	**Recovery Actions** (Sections 2.3, 2.4, and 4.0)
A	water quality degradation	1, 2, 5, 6	1.1.1, 1.1.2, 1.1.3, 1.1.4, 1.1.5, 1.2.1, 1.2.2, 1.2.3.1,1.2.3.2, 1.2.3.3, 1.2.4.1, 1.2.4.2, 1.2.4.3, 1.2.4.4, 1.2.4.5, 1.2.5, 1.2.6, 1.2.7, 4.1.1, 4.1.7, 4.2, 4.3, 4.4, 5.1, 5.2, 5.3, 6.2, 7.1
	water quantity degradation	3, 5, 6	2.1.1, 2.1.2, 2.1.3, 2.1.4, 2.1.5, 2.1.6, 2.1.7, 2.2.1, 2.2.2, 4.1.1, 4.1.4, 4.1.7, 5.1, 5.2, 5.3, 6.1, 7.1
	surface habitat modification	5, 6	3.1, 3.2, 3.3, 3.4, 4.1.1, 4.1.7, 6.1, 7.1
D	lack of regulations and comprehensive mechanisms to protect Barton Springs watershed from increasing threats to water quality	1	1.2.1, 1.2.4.1, 4.1.1, 7.1

Listing Factor	**Threat** (Section 1.6)	**Recovery Criteria** (Section 2.2)	**Recovery Actions** (Sections 2.3, 2.4, and 4.0)
	lack of regulations and comprehensive mechanisms to protect Barton Springs watershed from increasing threats to water quantity	3	2.2.1, 4.1.1, 4.1.4, 7.1
E	restricted range in an entirely aquatic environment makes the salamander extremely vulnerable to decreasing water quality	1, 2, 4, 5, 6	4.1.1, 4.1.2, 4.1.3, 4.1.5, 4.1.6, 4.1.7, 5.1, 5.2, 5.3
	restricted range in an entirely aquatic environment makes the salamander extremely vulnerable to decreasing water quantity and catastrophic events	3, 4, 6	4.1.1, 4.1.2, 4.1.3, 4.1.4, 4.1.5, 4.1.6, 4.1.7, 5.1, 5.2, 5.3

1.2 Description and Taxonomy

The Barton Springs salamander (Figure 1) is a member of the Family Plethodontidae (lungless salamanders). Texas species within the genus *Eurycea* inhabit springs, spring-runs, and water-bearing karst formations of the Edwards Aquifer (Chippindale 1993). They are aquatic and neotenic, meaning they retain larval, gill-breathing morphology throughout their lives. These neotenic salamanders, including the Barton Springs salamander, do not metamorphose and leave water. Instead, they live in water throughout their life cycle where they become sexually mature and eventually reproduce.

Figure 1. Barton Springs Salamander (Photo courtesy of C. Riley Nelson)

The Barton Springs salamander was first collected from Barton Springs in 1946 (Brown 1950, Texas Natural History Collection specimens 6317-6321) and formally described in 1993 (Chippindale et al.). Adults reach about 2.5 to 3 inches (63-76 mm) in total length. Adult body morphology includes reduced eyes and elongate, spindly limbs that are indicative of a semi-subterranean lifestyle. The head is relatively broad and deep in lateral view, and the snout appears somewhat truncate when viewed from above. On either side of the base of the head is a set of three feathery gills that are bright red. The coloration on the salamander's upper body varies from light to dark brown, purple, reddish brown, yellowish cream, or orange. The characteristic mottled salt-and-pepper color pattern on the upper body surface is due to brown or black melanophores (cells containing pigments called melanin) and silvery-white iridiophores (cells containing pigments called guanine) in the skin. The arrangement of these pigment cells is highly variable and can be widely dispersed in some Barton Springs salamanders, which can cause them to have an overall pale appearance. In other salamanders the melanophores may be so dense that individuals have a dark brown appearance. The ventral side (underside) of the body is cream-colored and is often translucent so that some internal organs and developing eggs in females are readily visible. The tail is relatively short with a well-developed dorsal (upper) fin and poorly developed ventral (lower) fin. The upper and lower mid-lines of the tail usually exhibit some degree of orange-yellow pigmentation. Juveniles closely resemble adults (Chippindale et al. 1993). Newly hatched larvae are about 0.5 inch (12 mm) in total length and may lack fully developed limbs or pigment (Chamberlain and O'Donnell 2003).

<u>Sympatric species</u> – The Barton Springs salamander is sympatric with (occurs in the same range as) the Austin blind salamander (*Eurycea waterlooensis*), which was described by Hillis et al. (2001). The Austin blind salamander species is closely related to the Texas blind salamander (*Eurycea* [formerly *Typhlomolge*] *rathbuni*), found in the southern portion of the Edwards Aquifer in San Marcos, Texas (Hillis et al. 2001). Like Barton Springs, San Marcos Springs also has two sympatric species of salamanders, the subterranean Texas blind salamander and the San Marcos salamander (*Eurycea nana*), which is found near the spring outlets in Spring Lake. The Barton Springs salamander is more closely related to the San Marcos salamander than either the Austin blind or Texas blind salamanders (Hillis et al. 2001).

Morphological characteristics that distinguish the Austin blind salamander (from the Barton Springs salamander) include eyespots covered by skin instead of image-forming lenses, an extended snout, fewer costal grooves, and pale to dark lavender coloration (Hillis et al. 2001). In June 2001, the Austin blind salamander was designated a candidate for listing as endangered or threatened (67 FR 40657).

1.3 Population Status and Distribution

The Barton Springs salamander has been found only at the four spring outlets that make up Barton Springs (Figure 2). This species has one of the smallest geographical ranges of any vertebrate species in North America (Chippindale et al. 1993, Conant and Collins 1998). Barton Springs, located in Zilker Park near downtown Austin, Texas (Figures 2 and 3), is an aquifer-fed system consisting of four hydrologically connected springs: (1) Main Springs (also known as Parthenia Springs or Barton Springs Pool); (2) Eliza Springs (also known as the Elks Pit); (3) Sunken Garden Springs (also known as Old Mill or Walsh Springs); and (4) Upper Barton Springs (Pipkin and Frech 1993). Collective flow from this group of springs represents the fourth largest spring system in Texas (Brune 1981). The salamander was first observed in Barton Springs Pool and Eliza Springs in the 1940s, Sunken Garden Springs in 1993 (Chippindale et al. 1993), and the intermittent Upper Barton Springs in 1997 (City of Austin 1998b).

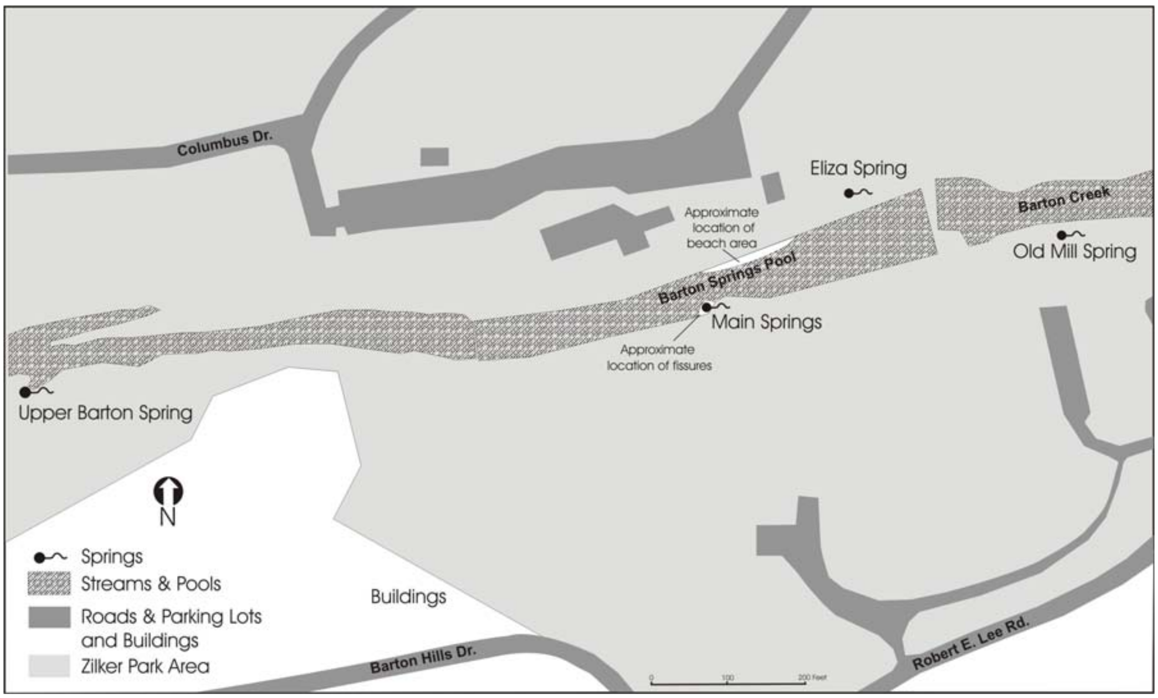


Figure 2. Barton Springs at Zilker Park

The extent of the Barton Springs salamander's range within the Barton Springs Segment of the Edwards Aquifer (Figures 4 and 5), and thus the degree of subsurface connection among these spring populations, is unknown. Sweet (1978) suggested the species was troglobitic (cave-adapted) and that the salamanders observed from the surface were discharged from the springs. However, City of Austin biologists have observed Barton Springs salamanders swimming directly into various spring outlets including Main Springs in Barton Springs Pool (Dee Ann Chamberlain and Lisa O'Donnell, City of Austin, pers. comm. 2004). Chippindale et al. (1993) characterized the species as a predominately surface-dwelling salamander capable of living underground. Reproduction of the Barton Springs salamander is believed to occur inside the Edwards

Aquifer since salamander larvae are found in surface water year-round, but very few eggs (which are white and very visible) have been observed in the wild (Chamberlain and O'Donnell 2003).

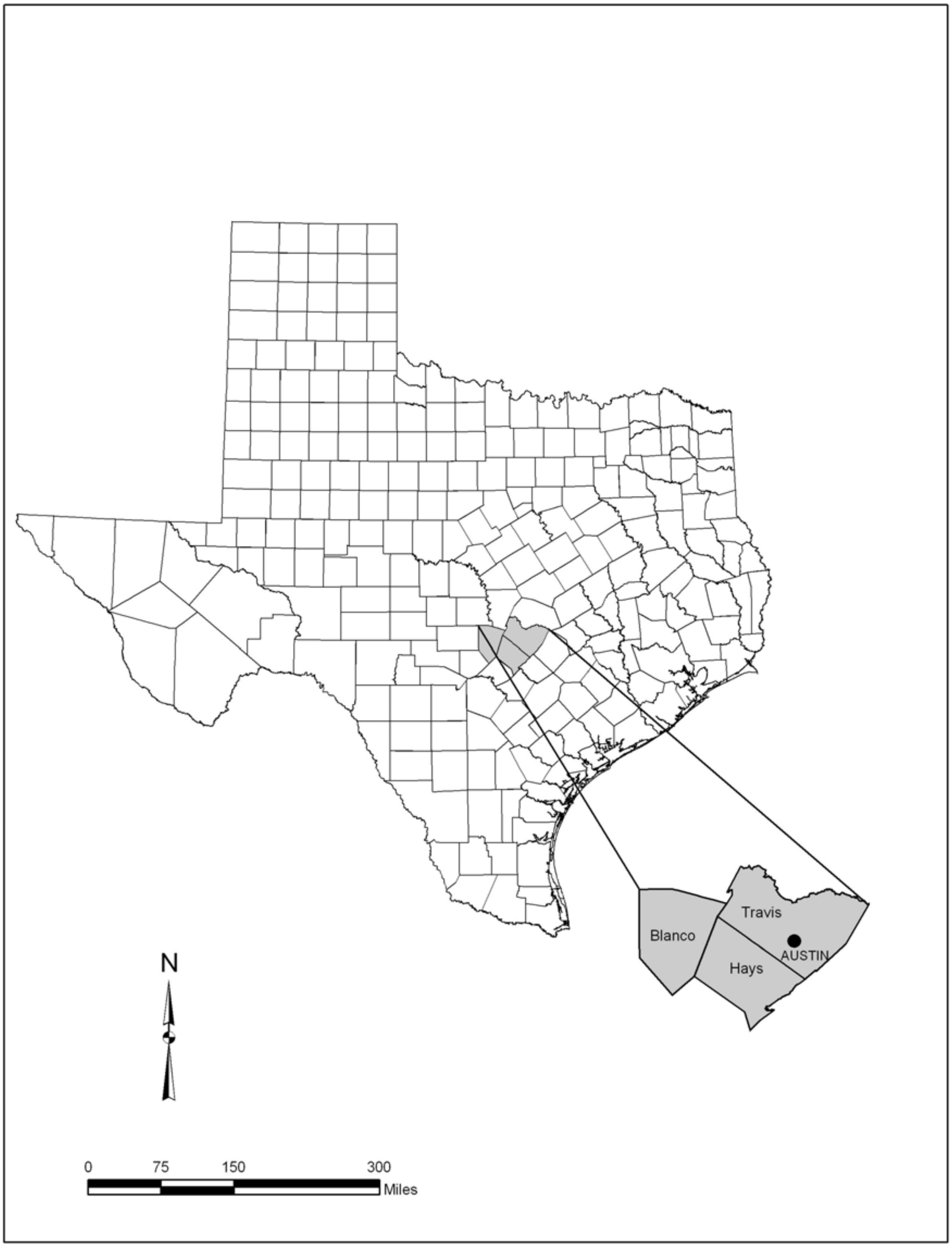


Figure 3. Location of Barton Springs, Travis County, Texas

The City of Austin initiated salamander surveys in (1) Barton Springs Pool in 1993, (2) Sunken Garden Springs and Eliza Springs in 1995, and (3) Upper Barton Springs in 1997. Salamanders in Barton Springs Pool are found primarily in the immediate area of the spring outlets. They have also been found in the "beach" area which is a concrete bench lying underwater immediately adjacent to the walkway on the north side of Barton Springs Pool. Salamanders are rarely seen in the deep end of the pool, which is often covered by sediment, or in the shallow end (Figure 2). The survey area has gradually shifted from transects that included the beach and the deep end, to the immediate area around the spring outlets where salamanders appear to be most abundant. Monthly surveys conducted since 1993 have resulted in a number of salamander observations ranging from 1 to 100 (City of Austin 1998b, City of Austin 1993-2003, unpublished data).

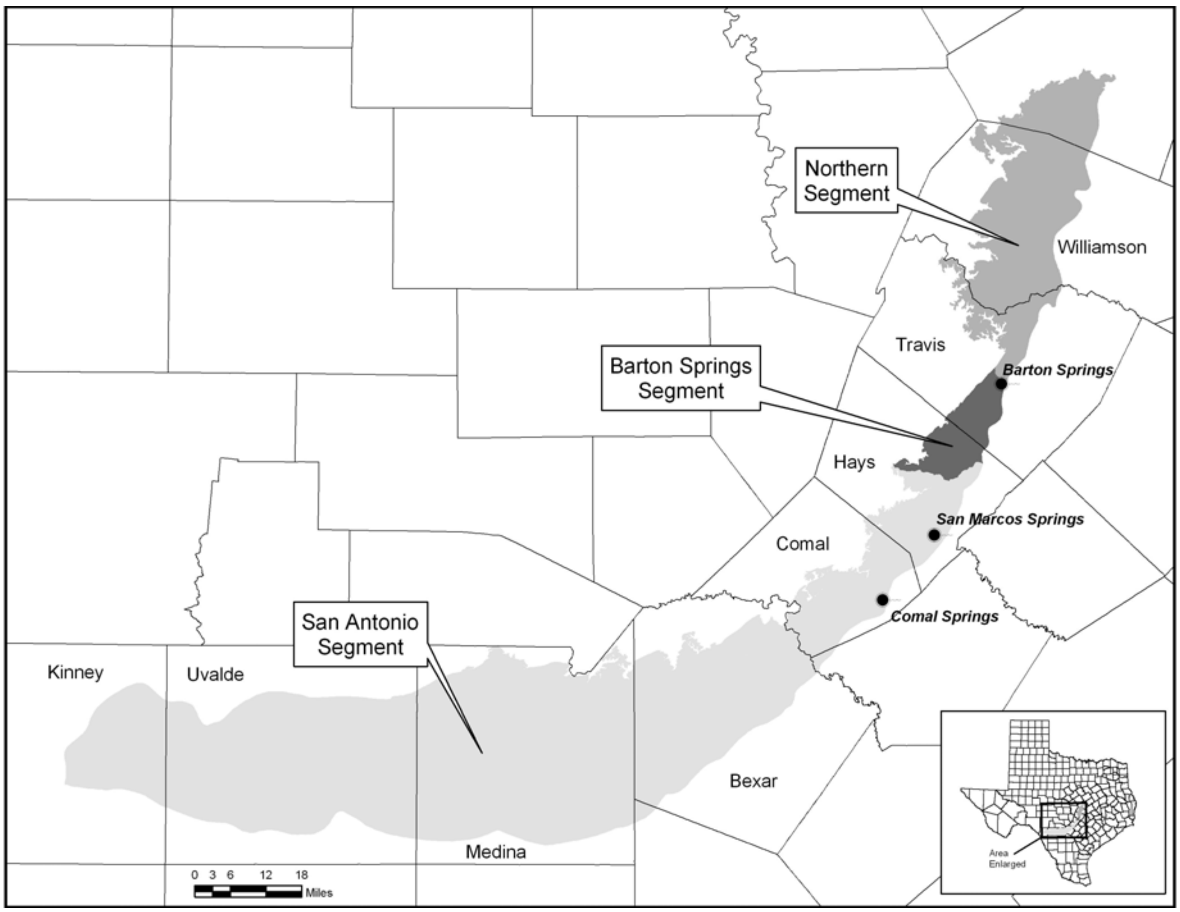


Figure 4. Major Segments of the Edwards Aquifer

"Dozens or hundreds" of individuals were reported at Eliza Springs during the 1970s (J.R. Reddell, referenced in Chippindale et al. 1993). Biologists from the University of Texas at Austin found very few individuals (0 to 2) during surveys conducted from 1987 through 1992 (Chippindale et al. 1993). Surveys conducted from 1995 to March 2003 by biologists from the City of Austin using scuba and snorkel equipment have documented an average of 12 salamanders per month with a peak in 1997 (59 salamanders) which was followed by a steady decline. Following efforts to improve habitat conditions in late

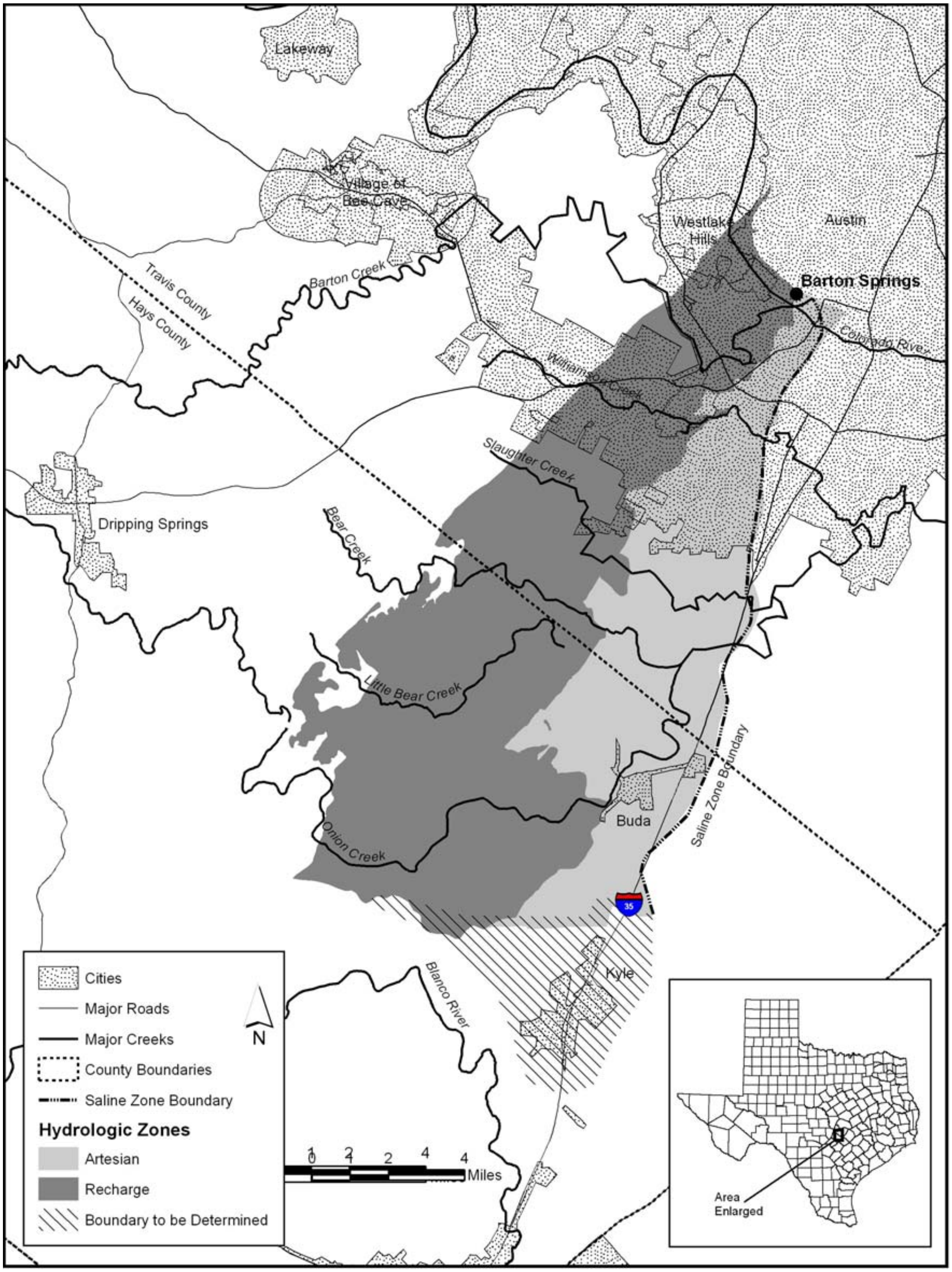


Figure 5. Extent of the Barton Springs Segment of the Edwards Aquifer

2002 and 2003 (see Section 1.7, Conservation Measures), observed numbers increased to 233 in January 2004.

Salamanders have been found in the bottom of Sunken Garden Springs, its spring run, and the confluence of the spring run and Barton Creek. Total numbers of salamanders observed at Sunken Garden Springs have ranged from 0 to 85 over the years (City of Austin and Service 1996-2003, unpublished data). While salamander numbers at Sunken Garden Springs appear to be related to flow patterns, the fluctuations cannot be explained solely by flow. Other factors also likely play a role in the changes in the number of salamanders observed. For example, a decrease in salamander numbers observed during the winter of 2002-2003 may have been due to the presence of Mexican tetras (*Asyanax mexicanus*) which are non-native predatory fish (Chamberlain and O'Donnell 2003).

In April 1997, biologists from the City of Austin and Service discovered 14 adult salamanders at Upper Barton Springs, which flows intermittently. Salamander numbers observed since that time have ranged from 0 to 14 at this site (City of Austin 1998b, City of Austin 1997-2004, unpublished data). Since salamanders are absent when this spring is dry, survey numbers are dependent on surface flow. However, some surveys at this spring have not found salamanders even during periods when the spring was flowing (Chamberlain and O'Donnell 2003). Other factors such as salamander behavior, the occurrence of gas bubble trauma, and water quality degradation may also be important.

Various searches have failed to document Barton Springs salamanders at other springs in the Barton Springs Segment of the Edwards Aquifer including Cold Springs, Campbell's Hole, and Backdoor Springs, which are all located along Barton Creek. Biologists searching springs in the nearby Bear Creek watershed in the early 1990s did not find salamanders (Chippindale 1993).

<u>Austin Blind Salamander</u> – Because the Austin blind salamander was only recently described (Hillis et al. 2001), City of Austin survey counts did not distinguish between the two species until July 1998. The numbers of salamander observations fluctuate at each of the sites at Barton Springs. These fluctuations may be correlated with factors such as springflow; frequency of floods; dissolved gas levels; abundance of cover, food, and predators; sedimentation; and water quality (Chamberlain and O'Donnell 2003). The Austin blind salamander is rarely seen on the surface, and typically only small juveniles are found (Hillis et al. 2001, Chamberlain and O'Donnell 2003). They are most abundant in Sunken Garden Springs and are rarely found in Eliza Springs and Barton Springs Pool. Austin blind salamanders have not been found at Upper Barton Springs to date (Hillis et al. 2001, City of Austin 1997-2003, unpublished data).

1.4 Habitat

Hydrology – The four springs (Main, Eliza, Sunken Garden, and Upper Barton) and associated subterranean areas of the Barton Springs system (Figure 2) provide the only known habitat for the Barton Springs salamander. Water passing into, and through, Barton Springs comes from the Barton Springs Segment of the Edwards Aquifer and, occasionally, from Barton Creek[1]. The Edwards Aquifer is a karst aquifer, characterized by features such as caves, faults, fractures, sinkholes, sinking streams (streams that lose water to an aquifer), springs, and other conduits. The Edwards Aquifer collectively supplies water to at least eleven counties in central and southern Texas. The aquifer has three segments commonly referred to as the Southern (San Antonio) Segment, the Barton Springs Segment, and the Northern Segment (Figure 4) which are separated by hydrologic and geologic divides within the Edwards Aquifer.

The Barton Springs Segment of the Edwards Aquifer is the part of the Edwards Aquifer that provides water for the springs of the Barton Springs complex. The Barton Springs Segment is located in southern Travis and northern Hays counties (Figure 5) and has approximate boundaries of (1) the interface of the "bad-water" zone between freshwater in the Barton Springs segment and saline water in the east, (2) the Colorado River which divides the Barton Springs Segment from the Northern Segment, (3) a groundwater divide between the watersheds of Onion Creek and the Blanco River that separates the Barton Springs Segment from the Southern Segment which lies further to the south, and (4) a geologic divide to the west that occurs between the contiguous Edwards Limestone overlying the Barton Springs Segment and the Glen Rose Limestone (Slade et al. 1985, 1986). This aquifer segment covers about 155 square miles (401 square km) (Slade et al. 1986) and provides groundwater for municipal, industrial, agricultural, and domestic uses for over 50,000 people (BS/EACD 2004).

Similar to the other segments of the Edwards Aquifer, the Barton Springs Segment consists of two zones: a recharge zone and an artesian zone (Figure 6). The recharge zone covers about 90 square miles (233 square km). Recharge is the process by which water enters an aquifer. Recharge occurs primarily as direct infiltration of runoff crossing the outcrop of the Edwards Aquifer, where porous Edwards Limestone is exposed at the ground surface. Water recharges the aquifer in one of three ways: (1) infiltration through the soils and rock strata overlying the aquifer, (2) percolation through upland recharge features (caves, sinkholes, faults, fractures, and other open cavities); or, (3) percolation through recharge features in creeks that cross the recharge zone.

Most of the water recharging the Barton Springs Segment of the Edwards Aquifer (approximately 85 percent) is derived from percolation through the six creeks that cross the recharge zone (Slade et al. 1985, Barrett and Charbeneau 1996). These creeks include (from north to south) Barton, Williamson, Slaughter, Bear, Little Bear, and Onion

[1] When Barton Creek floods, some of the surface flow enters the pool; however, during normal flow, the water from Barton Creek enters the bypass channel upstream from the main pool and does not enter the pool itself.

creeks (Figures 6 and 7). Recharge features in creek bottoms overlying the recharge zone allow only a limited flow of water during a storm event; therefore, water that is in excess of the flow capacities of recharge features leaves the recharge zone as creek flow. Because the six major creeks that flow through the recharge zone contribute a substantial amount of recharge to the Barton Springs Segment of the Edwards Aquifer, protection and conservation of surface water in these creeks is important to maintaining water quality at Barton Springs. The remaining 15 percent of recharge occurs for the Barton Springs Segment of the Edwards Aquifer in the upland areas and in smaller tributaries of the six main creeks in the recharge zone (Slade et al. 1985).

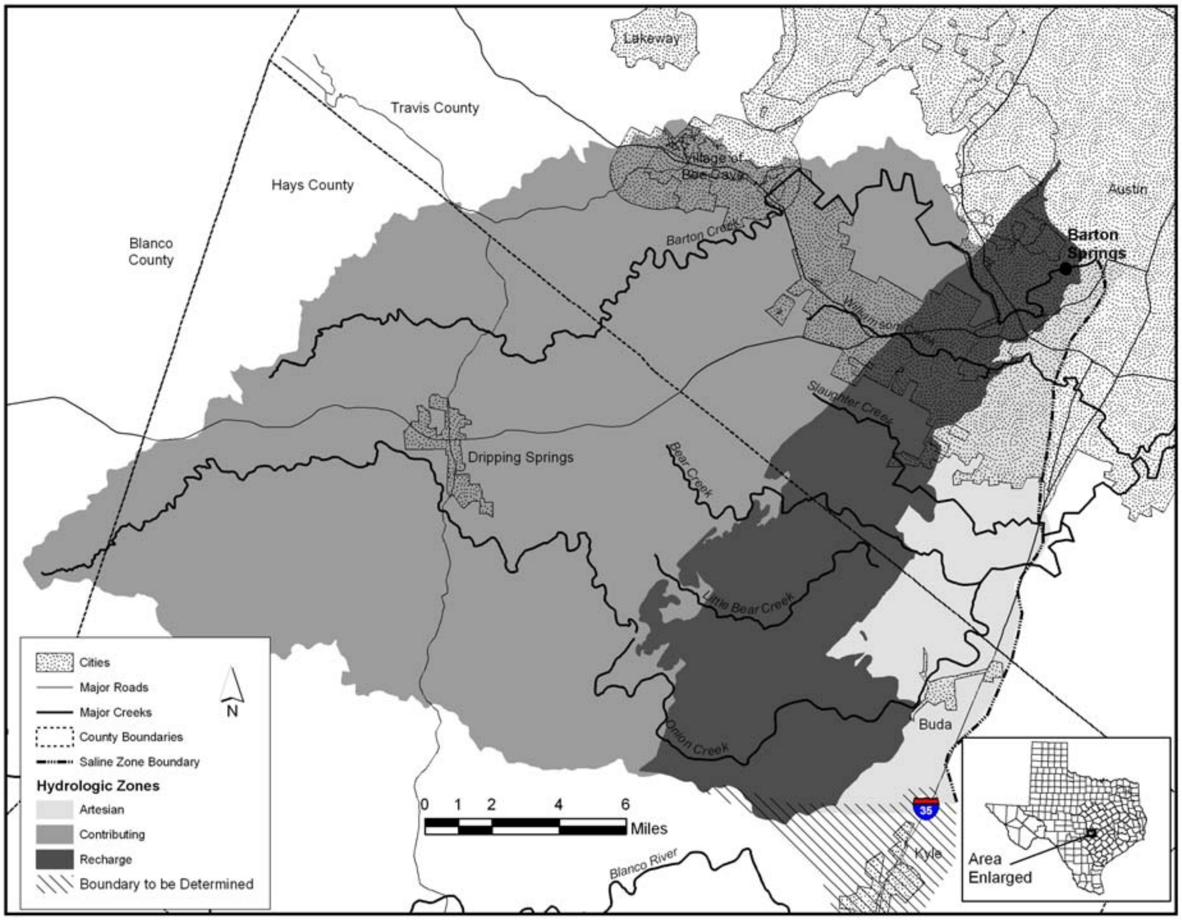


Figure 6. Hydrologic Zones of the Barton Springs Watershed

Direct infiltration of rainfall through the soils into the aquifer makes up a small portion of the total water recharged within the aquifer itself. Much of the rainfall in upland areas overlying the aquifer is either evaporated, used by plants, or is retained in shallow, subsurface water tables before it reaches the aquifer.

The artesian zone is down gradient from the recharge zone in the eastern portion of the Barton Springs Segment of the Edwards Aquifer. Impermeable layers of clay cover this portion of the aquifer, which causes groundwater to be confined under pressure. The confined groundwater can be forced to the land surface as artesian springs or wells.

Because much of the water moving through the aquifer is pressurized in dissolution cavities that transport water, portions of the recharge zone can exhibit characteristics of an artesian system.

A third area, known as the contributing zone, contributes water to the Barton Springs Segment of the Edwards Aquifer, but is not a part of the aquifer itself (Figure 6). The contributing zone encompasses the watersheds of the upstream portions of the six major creeks that cross the recharge zone (Figure 7), and therefore provides the source for most of the water that will enter the aquifer as recharge. The contributing zone spans about 264 square miles (683 square km) and includes portions of Travis, Hays, and Blanco counties. The recharge and contributing zones (hereafter referred to collectively as the "Barton Springs watershed") together make up the total area that provides water to the Barton Springs Segment of the Edwards Aquifer, which equals about 354 square miles (916 square km) (Slade et al. 1986).

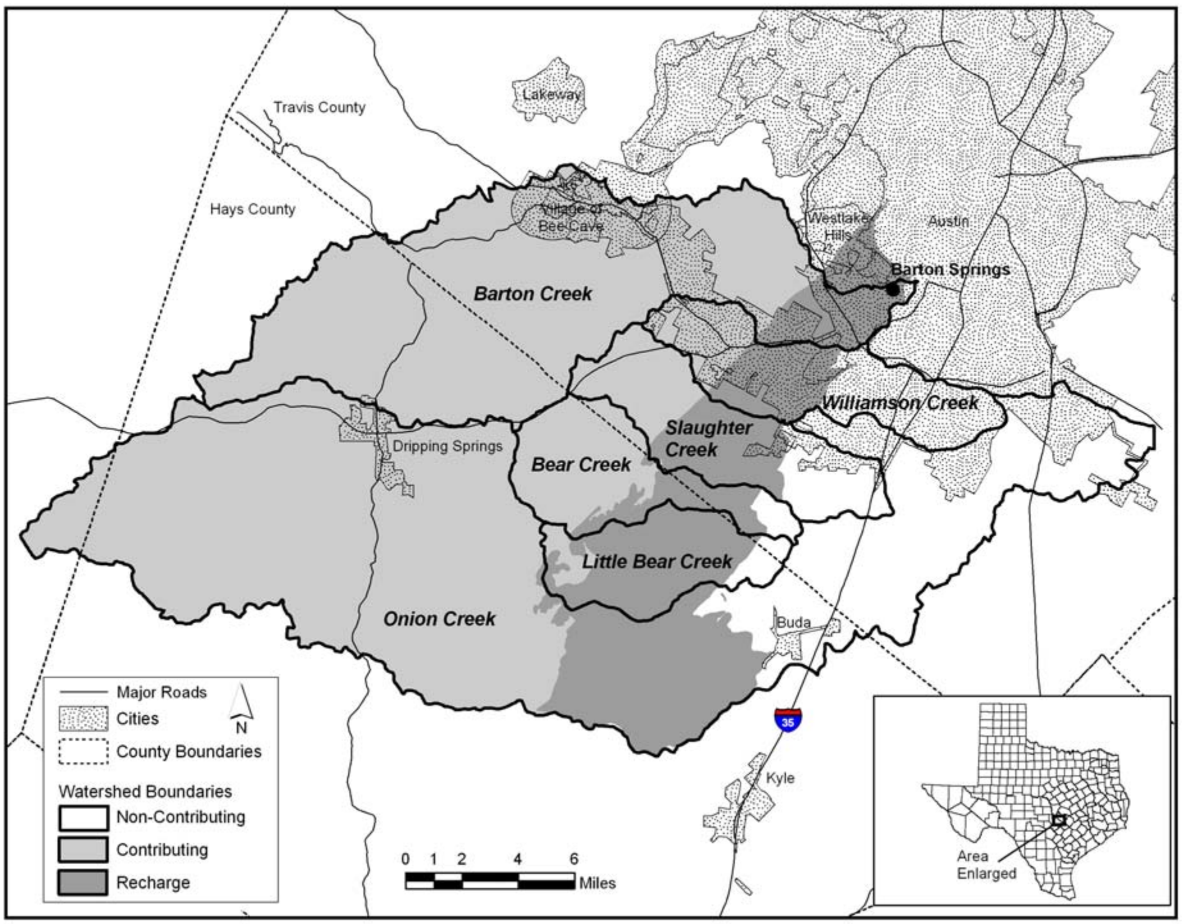
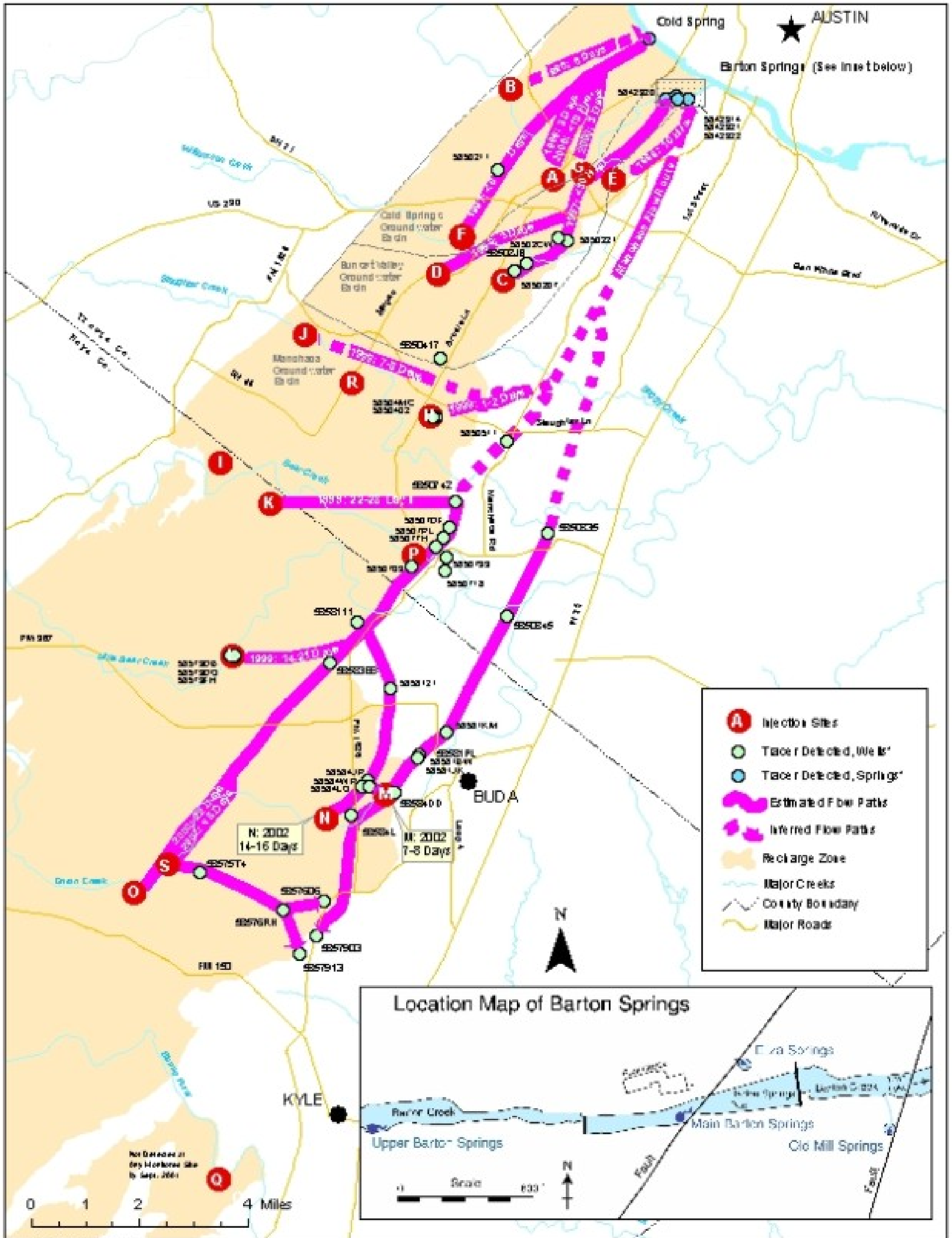


Figure 7. Creek Watersheds of the Barton Springs Segment of the Edwards Aquifer

After entering the recharge zone through faults and fractures on the land surface, surface water moves through the aquifer via groundwater flow paths inside caverns, conduits, and other dissolution features that vary in size. Groundwater movement in the western part of the Barton Springs Segment of the Edwards Aquifer flows generally to the east and north (Figure 8).

Water levels throughout the Barton Springs Segment of the Edwards Aquifer are highly interrelated and correlate with spring water discharges at Barton Springs. Runoff flowing across the recharge zone and entering the aquifer reaches the water table quickly, as demonstrated by the comparison of surface water levels at streamflow stations to groundwater levels. Water levels in wells typically begin rising within one hour after water levels begin to rise in the creeks.



* Monitored wells and springs with no detections are not shown.
** All travel times are to the Springs (Cold Spring and Barton Springs).

Figure 8. Summary of Groundwater Tracing Results (1996-2000)

Groundwater-tracing studies conducted from 1996 to 2002 have delineated several groundwater flow paths and measured groundwater velocities for the Barton Springs Segment of the Edwards Aquifer. Three separate groundwater basins (Manchaca, Sunset Valley, and Cold Springs) were mapped within the Barton Springs Segment (BS/EACD 2003b, Figure 8). Each basin has at least one dominant groundwater flow path where groundwater flow converges. The flow of groundwater along these dominant flow paths ranges from about 1 mile (1.6 km) per day under low groundwater flow conditions to about 5 miles (8 km) per day under moderate to high groundwater flow conditions. A dye-tracer injected in a cave on Onion Creek in 2002 was found to have reached Barton Springs within 3 days after traveling a distance of 18 miles (29 km) (BS/EACD 2003b). This research emphasizes the importance to the Barton Springs ecosystem and aquifer resources of protecting the quality and quantity of water in each of the six major creeks.

The volume of water discharged at Barton Springs is dependent on the water level in the Barton Springs Segment of the Edwards Aquifer. Under low flow conditions in the aquifer, surface flow ceases in Barton Creek immediately upstream of the Main Springs and many of the spring outlets become dry for extended periods. During the record drought of the 1950s, flow at Barton Springs was reduced to a record daily low of 10 cubic feet per second (cfs) (Brune 1981, BS/EACD 2004). This represented an 80 percent reduction from the long-term mean flow of 53 cfs (BS/EACD 2004). During the drought of 1995 and 1996, both Eliza and Sunken Garden Springs ceased to flow when the water level in Barton Springs Pool was lowered for routine maintenance; therefore, it is likely that the spring sites within Barton Springs are hydrologically related. This does not necessarily indicate that salamanders move between spring sites; however, it may indicate that any factor that causes a change in water quantity at one spring site could also have the ability to affect water quantity at the other spring sites at Barton Springs.

<u>Surface Habitat</u> – "Surface" habitat for the Barton Springs salamander refers to the spring pools and spring runs where the Barton Springs salamander is observed as opposed to its subsurface aquifer habitat. The Barton Springs salamander inhabits relatively stable aquatic environmental conditions. These conditions consist of perennially flowing spring water that is generally clear, clean, mostly neutral (pH about 7), and stenothermal (narrow temperature range) with an annual average temperature of 21° to 22°C (about 70° to 72°F) (City of Austin 1997). Flows of clean spring water with a relatively constant, cool temperature are essential to maintaining the well-oxygenated water necessary for salamander respiration and survival. Dissolved oxygen concentrations average about 6 mg/l (City of Austin 2001) and are directly related to springflow. Higher concentrations occur during periods of high spring discharge (City of Austin 1997).

In addition to stenothermic water flows, Barton Springs salamanders appear to prefer clean, loose substrate for cover. Salamanders are found primarily under boulder, cobble, and gravel substrates, but may also be found in aquatic plants, leaf litter, and woody debris (Sweet 1978, 1984; Chippindale et al. 1993). City of Austin biologists frequently find Barton Springs salamanders in aquatic moss (*Amblystegium riparium*) that grows on bare rocks and the walls in Barton Springs Pool, Eliza Springs, and Sunken Garden

Springs (Chamberlain and O'Donnell 2003). In addition to providing cover, moss and other aquatic plants harbor a variety and abundance of the aquatic invertebrates that salamanders eat. Historical records indicate a diversity of plants once resided in Barton Springs Pool, including arrowhead (*Sagittaria platyphylla*), water primrose (*Ludwigia* spp.), wild celery (*Vallisneria americana*), cabomba (*Cabomba caroliniana*), water stargrass (*Heteranthera sp*.), southern naiad (*Najas guadalupensis*), and pondweed (*Potamogeton sp.*) (Alan Plummer Associates, Inc. 2000). City of Austin biologists are working to restore the diversity and abundance of plant communities to promote the health of the Barton Springs ecosystem (see Section 1.7, Conservation Measures).

1.5 Life History and Ecology

Diet – Barton Springs salamanders appear to be opportunistic predators of small, live invertebrates. Chippindale et al. (1993) found amphipod remains in the stomachs of wild-caught salamanders. The gastro-intestinal tracts of 18 adult and juvenile Barton Springs salamanders and fecal pellets from 11 adult salamanders collected from Eliza Springs, Barton Springs Pool, and Sunken Garden Springs contained ostracods, copepods, chironomids, snails, amphipods, mayfly larvae, leeches, and adult riffle beetles. The most common organisms found in these samples were ostracods, amphipods, and chironomids (City of Austin, unpublished data).

Respiration – Barton Springs salamanders do not have lungs, but breathe through their gills and skin. Primary respiration in neotenic salamanders is through the gills; however, a substantial amount of gas exchange occurs through the skin (Boutilier et al. 1992, Hillman and Withers 1979). They also require water moving across their gills and bodies for respiration. In a study involving three *Eurycea* species closely related to the Barton Springs salamander, Norris et al. (1963) found that metabolic rates and oxygen consumption are highest in juveniles and decrease with increasing body size. Oxygenation of salamander eggs is critical to embryonic development since gas exchange and waste elimination occur through semipermeable membranes that surround the salamander embryo (Duellman and Trueb 1986).

Reproduction – Gravid females, eggs, and larvae are typically found throughout the year in the Barton Springs, which suggests that the salamander can reproduce year-round. Information obtained from captive-raised Barton Springs salamanders indicates that females can develop eggs within 11 to 17 months after hatching. One male also displayed courtship behavior (tail undulation) at one year from hatching (Chamberlain and O’Donnell 2003). In the wild, females with eggs are typically at least 1.6 inches (40 mm) total length (Chamberlain and O’Donnell 2003).

Observations of courtship among captive pairs of Barton Springs salamanders (Chamberlain and O’Donnell 2003) are consistent with Arnold’s (1977) description of the tail-straddling walk which is a behavior unique to plethodontid salamanders. During courtship, the male deposits a spermatophore (sperm packet attached to a glycoprotein base), which then becomes attached to a plant, rock, or other substrate. The spermatophore is picked up by the female (Arnold 1977). Females store the spermatophore in a specialized portion of the cloaca, known as the spermatheca. Females of some salamander species may store spermatophores for up to 2.5 years before ovulation and fertilization occur (Duellman and Treub 1986). Females of some species may also store more than one spermatophore from one or different males (Houck et al. 1985a, 1985b). In 2001, a captive Barton Springs salamander female laid viable eggs one month after being isolated, which indicates that females of this species can store sperm for at least this length of time (Chamberlain and O’Donnell 2003). In most salamanders, fertilization is internal and occurs during egg-laying whereby sperm are released onto eggs as they pass through the female’s cloaca (Sever 2000).

Similar to most amphibian eggs (Duellman and Treub 1986), a salamander egg consists of an ovum (egg cell) surrounded by a series of concentric capsules. The ova of Barton Springs salamanders are white and generally surrounded by three capsules (Chamberlain and O'Donnell 2003). Occasionally, an egg capsule will contain two viable embryos that can independently develop and hatch into larvae (Lynn Ables, Dallas Aquarium, pers. comm.; Chamberlain and O'Donnell 2002).

Egg-laying events have been reported by each of the institutions that have attempted captive breeding efforts. These include the City of Austin, San Antonio Zoo, U.S. Geological Survey (USGS) Environmental and Contaminants Research Center in Columbia, Missouri, and Dallas Aquarium. Eggs are laid by female salamanders one at a time and receive no parental care. Although a female can lay a single egg in minutes, the entire egg-laying event may take several hours, depending on clutch size (Chamberlain and O'Donnell 2003). Biologists associated with the City of Austin's captive breeding program have observed clutch sizes ranging from 5 to 39 eggs with an average of 22 eggs as based on 32 clutches (Chamberlain and O'Donnell 2003, City of Austin, unpublished data). Of the 34 egg-laying events at the Dallas Aquarium, clutch size ranged from 10 to 55 (Lynn Ables, Dallas Aquarium, pers. comm., 2000). Females may lay all or only a few of their eggs. In some cases, females may reabsorb their unlaid eggs within a few weeks after egg-laying (Chamberlain and O'Donnell 2003).

Since the City of Austin began surveying salamanders in 1993, only four eggs have been found in the wild. The first egg was found detached near a spring orifice in Sunken Gardens Springs in May 2002. The diameter of the outer egg capsule was about 0.3 inches (7 mm), and the embryo was about 0.1 inches (3 mm) in diameter. The egg later hatched in captivity. The other three eggs were found near spring orifices in Barton Springs Pool (December 2002, May and August 2003) (Dee Ann Chamberlain, City of Austin, pers. comm., 2003). Embryos begin to develop some pigmentation during the later stages of development (Chamberlain and O'Donnell 2003).

Hatching of eggs in captivity has occurred within 16 to 39 days after eggs have been laid (Chamberlain and O'Donnell 2003). Hatching success in captive Barton Springs salamanders may be highly variable as indicated by hatching rates of 0 to 100 percent that have been reported by the City of Austin (Chamberlain and O'Donnell 2002, 2003). Egg mortality has been attributed to (1) fungus (Chamberlain and O'Donnell 2002, 2003), (2) hydra (small invertebrates with stinging tentacles) (Lynn Ables, Dallas Aquarium, pers. comm., 2000), and (3) other possible factors such as infertility (Chamberlain and O'Donnell 2003).

City of Austin biologists have generally found the first three months following hatching to be a critical period for juvenile survival (Chamberlain and O'Donnell 2003). Newly hatched larvae have a yolk sac to sustain their nutritional needs in the early days after hatching. Larvae feeding on prey items have been observed 11 and 15 days after hatching (Lynn Ables, Dallas Aquarium, pers. comm., 1999).

Although reproduction has occurred in captivity, it has been sporadic. No consistent methods or techniques have been found to enhance egg production. Eggs have been laid in tanks that simulate spring upwellings as well as in 20-gallon aquariums that use a non-circulating, closed system. At times, females have held eggs for over a year before the eggs are either laid or reabsorbed. City of Austin biologists believe that stable environmental conditions, water quality, adequate space, habitat heterogeneity, and food availability may influence egg laying (Chamberlain and O'Donnell 2003). Providing substrates that have a rough surface (not smooth like glass) may facilitate successful spermatophore deposition and transfer (Whitaker 2001). To successfully propagate the species over the long term, critical factors that induce reproduction in captivity need to be identified.

<u>Longevity</u> – The longevity of the Barton Springs salamander in the wild is unknown. As of January 2004, the City of Austin had two Barton Springs salamanders (one male, one female) in captivity that were collected as adults in June 1996. The Dallas Aquarium also had a few salamanders that were collected as adults in the spring of 1995 (Chamberlain and O'Donnell 2003). Assuming these salamanders were at least one year old when collected, known longevity for Barton Springs salamanders in captivity is at least 10 years.

<u>Diseases</u> – Other than gas bubble trauma (See Section 1.6, Threats), only a few physiological anomalies have been reported in the wild for the Barton Springs salamander. An adult Barton Springs salamander collected from Barton Springs Pool in February 2001 was found to be infected with immature trematodes (*Clinostomum* sp.) that invaded tissue near the salamander's vent (Chamberlain and O'Donnell 2002). In January 2001, a gravid salamander was collected with an extra toe on one foot that possible could have been the result of a trematode infection. As these trematodes have life cycles that require at least two intermediate hosts, there is apparently no transmission of trematodes between individual amphibians (Chamberlain and O'Donnell 2002).

Biologists from the City of Austin have identified an unknown myxosporidian parasite, and several pathogens (fungi and bacteria in the genera of *Aeromonas* and *Pseudomonas*) that have affected salamanders in captivity (Chamberlain and O'Donnell 2003). It is not known whether these pathogens are present in the spring habitats of the salamanders or what threat they may pose to salamanders in the wild. However, it is important to understand how parasites and pathogens might affect captive breeding and potential reintroduction efforts.

<u>Predators</u> – Predation on Barton Springs salamanders in the wild is probably minimal when adequate cover is available for salamanders to hide from predators. Most of the potential predators that are native to the Barton Springs ecosystem are opportunistic feeders. Predation is unlikely unless the salamanders become exposed. Crayfish (*Procambarus clarkii*) and other large predatory invertebrates may prey on salamanders or salamander larvae and eggs (Gamradt and Kats 1996). Predatory fish found at Barton Springs include mosquitofish (*Gambusia affiinis*), longear sunfish (*Lepomis megalotis*), and largemouth bass (*Micropterus salmoides*). Mosquitofish have been known to prey on

frog and salamander larvae in areas where the fish have been introduced (Gamradt and Kats 1996, Goodsell and Kats 1999, Lawler et al. 1999). Longear sunfish are known to prey on aquatic vertebrates, and largemouth bass are opportunistic predators that feed primarily on smaller fishes and crayfish. Mexican tetras are non-native fish and aggressive generalist predators that are occasionally found in Barton Creek, Barton Springs Pool, Upper Barton Springs, and Sunken Garden Springs.

1.6 Threats - See Section 1.1, Introduction for an explanation of how each of the threats faced by the Barton Springs salamander relate to one or more of the five listing factors.

Water Quality
(Listing Factors A,D,E)

Water quality at Barton Springs is influenced by both groundwater and surface water. The Barton Springs system depends on groundwater flow from the Barton Springs Segment of the Edwards Aquifer. This segment of the aquifer is fed by six stream systems (Barton Creek, Williamson Creek, Slaughter Creek, Little Bear Creek, Bear Creek, and Onion Creek) that enter the aquifer through recharge areas. In addition to providing groundwater to the aquifer through a recharge area, Barton Creek periodically provides water to the surface habitat of Main Springs and Upper Barton Springs. Both of these springs lie directly in the Barton Creek floodplain and are subject to high flow of surface water in Barton Creek itself. Main Springs, however, receives surface water from Barton Creek only when floodwater in the creek overtops the pool's upstream dam during floods.

The hydrologic connections between groundwater and surface water in the Barton Springs watershed are the ecological basis for maintaining adequate water quality for organisms that depend on the aquifer for survival, such as the Barton Springs salamander. Surface runoff in the contributing and recharge zones of the Barton Springs watershed directly influences the quality of water that discharges at Barton Springs. Under normal (that is, non-flood) conditions, several water purifying processes help to maintain the quality of water entering the aquifer and ultimately discharging at Barton Springs. Water purification processes can be physical (for example, filtration of rainwater through percolation), chemical (for example, oxidation of metals), and biological (for example, microbial decomposition of organic materials). These processes naturally occur in the soils and relatively shallow water tables overlying the aquifer over a time span of up to several years. In some cases, natural processes may only temporarily store contaminants for later release over time. During periods of high precipitation, stormwater runoff in urban areas can enter the recharge zones of the six stream systems and rapidly transport sediment, fertilizer nutrients, and toxic contaminants (pesticides, heavy metals, petroleum hydrocarbons, etc.). These potential pollutants and contaminants can be washed off the land surface overlying the aquifer without allowing adequate time for the processes of natural purification to occur. Hauwert et al. (1998) reported that water from Williamson Creek can travel a distance of 4.5 miles (7 km) from the recharge area to the springs in less than 30 hours. Therefore, runoff water may be discharged at Barton Springs in as little as several hours to several days after it has entered the aquifer during an event of high precipitation.

Given the flow characteristics of recharge water from the six contributing streams, principal threats to water quality in the aquifer include (1) land uses that degrade the quality of stormwater runoff and (2) release of contaminants in the recharge areas in these watersheds that potentially can be transported to Barton Springs. Surface water quality can vary substantially for watersheds that have different land uses. The City of Austin

(1998a) and USGS (Veenhuis and Slade 1990) have both reported that mean concentrations for most water quality constituents such as total suspended solids and other pollutants are lower in undeveloped watersheds than those for urban watersheds. Impervious cover, the composition and health of the plant community, disturbed surface areas, point source contamination (that is, a stationary location or fixed facility from which pollutants are discharged), and operating stormwater treatment facilities can all alter the quality of runoff entering the aquifer. Where few natural buffers on the surface are present and the groundwater can move rapidly from the source area to Barton Springs, there may be limited opportunity for natural improvement of water quality to take place.

An analysis of spring discharge data by the City of Austin (2000) has indicated that degradation has occurred in a number of water quality parameters at Barton Springs over the years (Appendix A). Dissolved oxygen has decreased while conductivity, sulfates, turbidity, nitrate-nitrogen, and total organic carbon have increased. The percent changes in the constituents range from an increase of three percent for specific conductance to an increase of 127 percent for total organic carbon (see Appendix A). The magnitude of these changes in water quality at Barton Springs has been variable and is dependent on flow conditions (City of Austin 2000, 2005). These changes in water quality at Barton Springs may be related to cumulative impacts of urbanization including increased groundwater use. Variations in the quality of discharge at Barton Springs may also be related to seasonal changes in the amount of precipitation (City of Austin 1997). The extent to which these water quality changes have affected the Barton Springs salamander or its habitat is unknown. Investigation is needed to determine the levels of water quality degradation that will result in lethal and sublethal effects to the salamander.

Physical and Chemical Parameters of Water Quality Potentially Affecting the Barton Springs Salamander

Dissolved oxygen – Dissolved oxygen is critical for development of eggs, young, and adults; predator avoidance; feeding; reproduction; and basic survival processes in amphibians (Hillman and Withers 1979). Analysis of data by the City of Austin (2000) has indicated that dissolved oxygen at Barton Springs has been declining for a number of years. The median concentration of dissolved oxygen in Barton Springs (normalized to 50 cfs baseflow without recharge) decreased from 6.8 mg/l to 5.7 mg/l (16 percent) between 1975 and 2000 (City of Austin 2000, 2005). Dissolved oxygen levels at the springs have been below 4 mg/l approximately 11 percent of the time over a 4-year sampling period (City of Austin 2005); however, the levels of dissolved oxygen that could be harmful to the salamander are not known.

Conductivity – Conductivity is a measure of the electrical conductivity in water and is used to approximate salinity in terrestrial and aquatic environments. Water salinity reflects the concentration of dissolved inorganic solids (that is, salts such as chlorides or sulfates) in water that can affect the internal water balance in aquatic organisms. During periods of low flow, the Edwards Aquifer may be influenced by encroachment of saline water from the “bad-water” zone into groundwater flow paths of the spring complex

(Perez 1986, City of Austin 1997). Sunken Garden Springs tends to have the highest specific conductance levels of all the springs and may continuously discharge water influenced by the "bad-water" zone (City of Austin 1997).

High conductivity has been associated with detrimental effects on aquatic salamanders. In a study using saline well water taken from the "bad water" zone, San Marcos salamanders (*Eurycea nana*) were found to sustain 100 percent mortality within 24 hours in well water that had a conductivity of 1145 μS/cm and a dissolved oxygen level of 6.8 to 7.6 mg/l (Edwards Aquifer Research and Data Center as reported in City of Austin 2001). In comparison, maximum conductivity levels have been measured periodically above 1000 μS/cm at Barton Springs (City of Austin 1997).

Conductivity can be influenced by urban runoff and other anthropogenic (human-caused) factors as particles from the land surface are flushed into streams during storm events. At Barton Springs, average conductivity has increased since 1975 during all flow conditions (City of Austin 2000, 2005). The greatest reported change occurred during baseflow with recharge, from 590 to 646 μS/cm (a 9 percent increase). In contrast, the mean baseflow concentration in rural springs located in the Jollyville Plateau region is 566 μS/cm and in urban springs is 867 μS/cm. Thus, the increase in conductivity at Barton Springs could indicate a trend toward a more urban signature in the spring water (City of Austin 2000, 2005).

<u>Supersaturation and Gas Bubble Trauma</u> - A recently discovered condition affecting Barton Springs salamanders may be related to water quality. Between January 28, 2002 and June 26, 2002, 17 Barton Springs salamanders were found at Upper Barton Springs and 2 at Sunken Garden Springs with bubbles of gas occurring throughout their bodies. Three similarly affected salamanders also were found at Upper Barton Springs in February and March 2003 (Dee Ann Chamberlain, City of Austin, pers. comm. 2003). Of the 19 salamanders affected in 2002, 12 were found dead or died shortly after they were found. Both adult and juvenile salamanders have been affected.

The incidence of gas bubbles in salamanders at Barton Springs is consistent with a disorder known as gas bubble disease or gas bubble trauma (Bouck 1980; Crunkilton et al. 1980; Fickeisen et al. 1980; Montgomery and Becker 1980; Colt et al. 1984a, 1984b; Krise 1993; Krise and Smith 1993; Fidler and Miller 1994; Mayeaux 1994). In gas bubble trauma, bubbles below the surface of the body and inside the cardiovascular system produce lesions and necrotic tissue that can lead to secondary infections (Fidler and Miller 1994). Death from gas bubble trauma is apparently related to an accumulation of internal bubbles in the cardiovascular system (Fidler and Miller 1994).

Although no Austin blind salamanders have been found with this condition, symptoms often associated with gas bubble trauma have been found in several other species at Upper Barton Springs including Mexican tetras, mosquitofish, stonerollers (*Campostoma anomalum*), Rio Grande leopard frog (*Rana berlandieri*) tadpoles, crayfish, and beetle larvae (Hydrophilidae) (Chamberlain and O'Donnell 2003; TVMDL 2003). All of these species had problems with buoyancy, and individuals of two fish species had bulging eyes. Pathology reports on the affected animals, excluding the Mexican tetras, indicated that their symptoms were consistent with gas bubble trauma. In most species, including the Barton Springs salamander, no other problems such as pathogens were found (Chamberlain and O'Donnell 2003; TVDML 2003).

Gas bubble trauma is caused by supersaturated water that has dissolved atmospheric gases (nitrogen, oxygen, carbon dioxide, and trace gases) in concentrations greater than 100 percent (Bouck 1980; Crunkilton et al. 1980; Fickeisen et al. 1980; Montgomery and Becker 1980; Nebeker et al. 1980; Colt et al. 1984a, 1984b; Krise 1993; Krise and Smith 1993; Fidler and Miller 1994; Mayeaux 1994). Anthropogenic factors that can lead to supersaturation include waterfall discharge from hydroelectric dams, warm water discharges from cooling facilities, algal blooms, and air or gas injection by pressurized pumps. Supersaturated groundwater in aquifers, wells, and springs may be the result of high pressures and/or increases in temperature as the water surfaces (Fidler and Miller 1994).

During the time of the salamander events in 2002 and 2003, supersaturation percentages were high (above 110 percent) at all four of the springs during the period in which affected salamanders were found. Upper Barton Springs had the highest supersaturation with up to 125 percent in 2002 and up to 131 percent in 2003. A well that is used to monitor water quality along the aquifer flowpath to Upper Barton Springs had over 160 percent supersaturation when tested on April 16, 2002. Although baseline data of total dissolved gases is not available for the Barton Springs watershed in general, Upper Barton Springs has always been known for its constant bubbling (that is, degassing) which would indicate that this spring is normally supersaturated whenever it is flowing.

Potentially, contaminants could play a role in gas bubble trauma by affecting an organism's tolerance to supersaturation. Studies of atrazine (Allran and Karasov 2000) and fuel oil (McGrath and Alexander 1979) indicate that these compounds can affect respiration and gas exchange in tadpoles. A study of elevated nitrate and nitrite levels under supersaturation showed sublethal effects that included disequilibrium and bent tails in tadpoles and a larval salamander (Marco et al. 1999). Of the four springs of Barton Springs, Upper Barton Springs may have the greatest potential for contaminant interaction with supersaturation. Triazine herbicides (for example, atrazine and simazine), polycyclic aromatic hydrocarbons (PAHs), solvents, and elevated levels of nitrate have been found in water and sediment samples from Upper Barton Springs (City of Austin, USGS, unpublished data). As indicated by groundwater tracing, Upper Barton Springs has a greater proportion of aquifer water from urban area sources than the other three spring sites (Hauwert et al. 2002, BS/EACD 2003b). In addition, nitrate-nitrogen in Upper Barton Springs is generally 1 mg/l higher than the other three spring outlets (Chamberlain and O'Donnell 2003, unpublished data). The potential for synergistic effects occurring between contaminants and supersaturated water on salamanders should be evaluated.

Pollutants and Contaminants Potentially Affecting the Barton Springs Salamander

Pollutants and contaminants occurring within the Barton Springs watershed can potentially affect the salamander and its habitat. Toxic effects to aquatic organisms from contaminants may be either lethal or sublethal and may include morphological and developmental aberrations, lowered reproductive and survival rates, and changes in behavior and certain biochemical processes (Rand et al. 1995). Each type of contaminant (for example, petroleum hydrocarbons, heavy metals, and pesticides) can have different effects on aquatic ecosystems (Hoffman et al. 1995). The Barton Springs salamander may be especially vulnerable to contaminants due to the salamander's semipermeable skin and reproductive processes. Although only limited data are available on the vulnerability of the Barton Springs salamander to toxic effects from contaminants, much is known about the effects of various compounds on many other aquatic species. Research has shown that amphibians (particularly eggs and larvae) are sensitive to many contaminants including heavy metals, pesticides, nitrites, salts, and petroleum hydrocarbons (Harfenist et al. 1989). Some crustaceans (particularly amphipods) on which these salamanders feed are especially sensitive to contaminants in water (Mayer and Ellersieck 1986, Burton and Ingersoll 1994, Phipps et al. 1995).

Sediments – Sediments are mixtures of silt, sand, clay, and organic debris that occur within water bodies either as (1) deposited sediment layers or (2) suspended sediments. Sediments in karst systems originate both at the land surface and from within the aquifer. Sediments originating from the surface wash into the aquifer through recharge features, whereas sediments originating from within the aquifer are the products of internal weathering of subsurface rock layers (White and White 1968, Ford and Williams 1989, Mahler and Lynch 1999). Sediment derived from soil erosion has been cited by Menzer and Nelson (1980) as the greatest single source of pollution of surface waters by volume. Sediments can often act as sinks for contaminants and accumulate these constituents to levels not normally found in the water column (Menzer and Nelson 1980). Due to high organic carbon content, sediments eroded from contaminated soil surfaces can concentrate and transport contaminants (Mahler and Lynch 1999). Contaminant compounds such as PAHs, petroleum hydrocarbons, and pesticides may be adsorbed onto sediment particles in concentrations that are orders of magnitude greater than their concentrations in the water column (Mahler and Lynch 1999).

Sediment may affect aquatic organisms in a number of ways. Excessive deposition of sediment can physically reduce the amount of available habitat and protective cover for aquatic organisms. Once deposited in large volumes, sediment can become anoxic (devoid of oxygen) and cease to provide suitable habitat. Silt and sediment can clog the interstitial spaces of the substrates surrounding the spring outlets that offer protective cover and an abundant supply of well-oxygenated water for respiration. A study conducted in Prairie Creek State Park, California, found that densities of two salamander species were significantly lower in the streams that experienced a large infusion of sediment from road construction after a storm event. The vulnerability of the salamander species in this study was attributed to their reliance on interstitial spaces in the streambed habitats (Welsh and Ollivier 1998).

Sediments suspended in water can smother or clog gill structures in aquatic organisms thereby affecting respiratory processes (Garton 1977, Schueler 1987). Other effects of suspended sediments in highly turbid waters can include: (1) limiting the development of eggs and larvae of aquatic organisms, (2) reducing the abundance of food resources, (EPA 1986), and (3) obstructing vision (Schueler 1987). Some levels of contaminants carried by sediments can also be toxic to aquatic organisms (Menzer and Nelson 1980, Landrum and Robbins 1990, Medine and McCutcheon 1989).

Sediments taken into karst aquifers by surface runoff play a fundamental role in determining aquifer water quality (Mahler et al. 1999). Sediment flowing through karst aquifers can be a vector for contaminant transport (Ford and Williams 1989, Mahler et al. 1999). In comparison to nonkarstic aquifer systems, karst aquifers are more vulnerable to the effects of pollution due to (1) a large number of conduits that offer no filtering capacity, (2) high groundwater flow velocities, and (3) relatively short residence times that water is inside the aquifer system (Field 1998, Ford and Williams 1989).
Highly fractured limestone bedrock such as those found in the recharge areas of the Barton Springs watershed may allow rapid transportation of sediments to springs along with water movement. Of the four spring outlets associated with Barton Springs, Main Springs is the most studied spring for sediment discharge. Sediments are generally discharged from Main Springs after a rainfall of approximately 1.5 inches or greater within its watershed. The total amount of sediment discharged from Main Springs in a 24-hour period following a 2-inch rainfall event is approximately one metric ton (Mahler and Lynch 1999).

The Barton Springs salamander and its prey species are directly exposed to sediment-borne contaminants discharging through the four spring outlets. Trace metals such as arsenic, cadmium, copper, lead, nickel, and zinc were found in sediments of Barton Springs in the early 1990s (City of Austin 1997). Adverse effects to the salamander and its prey from such contaminants may occur when water quality criteria for sediment contaminants are exceeded. Criteria for evaluating the quality of sediment contaminants as suggested by the Texas Commission on Environmental Quality (TCEQ) (formerly the Texas Natural Resource Conservation Commission (TNRCC)) (TNRCC 2000), MacDonald et al. (2000), and EPA (1997) have been exceeded in approximately one-half of samples taken from salamander habitat (City of Austin 1995-2001, unpublished data). Sediment samples taken in creeks supplying water to habitat of the Barton Springs salamander have also exceeded these criteria at various times.

In addition to the threat to the salamander and its prey species from sediment-borne contaminants, sediments may also contribute to possible habitat degradation. Prior to the early 1990s, Barton Springs (including Main, Eliza, and Sunken Garden Springs) had abundant coarse gravel, cobble, and plants with little sediment accumulation (David Hillis, University of Texas, pers. comm. 2002). Areas of high quality salamander habitat with clean cobble and healthy aquatic macrophytes have since been impacted by the deposition of sediment (City of Austin 1998b). A 2 to 6 inch accumulation of sediment was known to cover available habitat at Sunken Garden Springs prior to habitat restoration efforts (see Section 1.7, Conservation Measures), and Upper Barton Springs had similar sediment levels (City of Austin 1998b, City of Austin 2001, unpublished data). The build-up of sediment at Eliza Springs had also reached depths in excess of one foot before habitat restoration activities took place (see Section 1.7, Conservation Measures). Although its exact origin is unknown, excessive levels of sediments discharging from the spring outlets may be an effect of urbanization. Horner et al. (1997) found that interstitial spaces in streambed sediments begin to fill as impervious cover increases within the watershed. Also, Mahler and Lynch (1999) determined that a significant proportion of sediment discharging from Main Springs after a storm event originated from surface runoff.

An excess of sediments and sediment-borne contaminants may have contributed to declines in salamander populations in the past. The lowest recorded observed counts of the salamander (ranging from one to six individuals) by City of Austin biologists at Main Springs, occurred over a five-month period following an October 1994 flood. During the flood, Barton Creek overtopped the dam that ordinarily diverts stream flow away from the Barton Springs Pool and Main Springs. The flood deposited a large amount of silt and debris over salamander habitat in the pool, and the area occupied by the salamander during the following months was reduced to relatively small, silt-free areas immediately adjacent to the spring outlets (City of Austin 1998b). In addition, sediments collected from Barton Creek and Barton Springs Pool after the flood were found to be contaminated with PAHs at concentrations known to be toxic to *Hyalella azteca*, an amphipod prey species of the Barton Springs salamander (Ingersoll et al. 1996, City of Austin 1998b).

<u>Nutrients</u> – Sources of nutrients in water include human and animal wastes, industrial pollutants, and fertilizers used on croplands, lawns, and golf courses. Excessive nutrient levels typically cause algal blooms that ultimately die back and cause progressive decreases in dissolved oxygen concentration in the water (Lampert and Sommer 1997, Wetzl 2001). Low levels of dissolved oxygen can affect salamanders and other amphibians by reducing respiratory efficiency, metabolic energy, reproductive rate, and ultimately survival (Norris et al. 1963, Hillman and Withers 1979, Pianka 1987, Boutilier et al. 1992).

Analyses of historical water quality data (pre-1978) suggest that nutrient levels have increased in Barton Springs, possibly reflecting degradation of water quality (City of Austin 2000). These data, however, may also reflect differences in the way nutrient data were collected in the past. Therefore, comparison of trends in nutrient levels should be qualified according to the standards used to determine nutrient levels. Nutrient-induced algal blooms periodically occur upstream from salamander habitat in Barton Creek and may be an indicator of water quality problems such as wastewater discharge or fertilizer runoff. Elevated nutrient levels within the Barton Springs watershed have been attributed to the presence of golf courses (City of Austin 1997, City of Austin, unpublished data, 2000-2002). Golf courses are often irrigated with effluents (treated municipal sewage) which can pose a particular water quality risk when existing containment (for example, retention ponds) is insufficient to contain effluents during storm events. In addition to effluent irrigation, overfertilization of golf courses may contribute to pollution of surface water and groundwater at Barton Springs.

Heavy Metals – Heavy metals are metallic elements that have an atomic weight greater than sodium (atomic wt. = 22).[2] The heavy metals group includes potentially toxic metals such as arsenic, copper, lead, and mercury. Concentrations of heavy metals in water reflect both background levels in soils and bedrock of a particular watershed as well as inputs from anthropogenic sources. Sources of heavy metals in stormwater runoff include operational wearing of vehicles, paint flaking, metal corrosion, and the leaching of wood preservatives, paving materials, and deicing salts. Increases in heavy metals associated with construction on land may occur in stormwater runoff unless adequate controls are implemented.

Heavy metals can affect an organism's survival, growth, reproduction, development, behavior, and metabolism (Eisler 1988, Pattee and Pain 2003). Adverse effects from heavy metals are more commonly found in early life stages or individuals that have relatively long exposures (Eisler 1988, Pattee and Pain 2003). Synergistic and additive effects may also occur when heavy metals are mixed with other toxic chemicals (Eisler 1988).

Heavy metals have been detected in sediments and in the water column at Barton Springs. Relatively high levels of lead have been detected at Sunken Garden Springs (Hauwert and Vickers 1994). At current concentrations, heavy metals in sediment at Barton Springs may be toxic to salamander prey species. Several heavy metals (arsenic, cadmium, copper, mercury, nickel, and silver) detected in the four spring systems of Barton Springs exceed threshold effect levels (TELs) in sediment for a salamander prey species, the amphipod *Hyalella azteca* (City of Austin, USGS, unpublished data; Ingersoll et al. 1996). A TEL represents "the concentration below which adverse effects are expected to occur only rarely" (Smith et al. 1996 as cited in MacDonald et al. 2000).

Pesticides – Sources of pesticides in urban areas include lawns, road rights-of-way, managed turf areas such as golf courses, parks, and ball fields. A considerable number of pesticides occur in urban streams and lakes as a result of runoff (CWP 2003). Pesticide residue concentrations found in surface water in urban watersheds reflect pesticide use associated with residential, commercial, and industrial land uses. Some pesticides commonly applied in urban areas such as lawns and golf courses tend to degrade rapidly in the environment, but certain pesticides can remain biologically active for extended periods (Eisler 1986, Hill 2003). Pesticides could impact salamander populations through contact with or ingestion of contaminated water, sediments, or food items (Hill 2003). Pathways for exposure of salamanders to pesticides include a semipermeable skin, development of eggs and larvae in water, and bioaccumulation of pesticide in the food chain. Pesticides also may affect the quality and quantity of amphibian prey and habitat (Bishop and Pettit 1992).

[2] The atomic weight of an element is the average proportionate weight of all isotopes of that particular element in comparison to the carbon 12 isotope.

Several studies have found morphological and developmental aberrations and changes in biochemical processes in a variety of amphibians continuously exposed to a variety of concentrations of atrazine (0.1 µg/l to 400 µg/l) (Allran and Karasov 2000, Christin et al. 2003, Gendron et al. 2003, Goulet and Hontela 2003, Hayes et al. 2003, Papaefthimiou et al. 2003, Rohr et al. 2003, Sullivan and Spence 2003). Atrazine (up to 0.56 µg/l) as well as trace amounts of diazinon, carbaryl, and simazine have been detected in spring discharge water in salamander habitat after a stormwater runoff event (Mahler and Van Metre 2000).

Petroleum Hydrocarbons and PAHs – PAHs are chemically related to petroleum hydrocarbons and are the byproducts of combustion (for example, vehicular combustion). Petroleum hydrocarbons are believed to enter water supplies through sewage effluents, urban and highway runoff, and chronic leakage or acute spills of petroleum and petroleum products (Eisler 1987, Hauwert and Vickers 1994, Albers 2003). A study by Van Metre et al. (2000) demonstrated that increases in PAH concentrations are correlated with increases in automobile use. This study also revealed a shift in PAH source in the U.S. over the last 40 years from uncombusted to combusted fossil fuels, an indicator that increased PAH concentrations are a result of increasing urbanization rather than other sources such as oil seeps and petroleum spills. Petroleum and petroleum byproducts can affect living organisms adversely by causing direct toxic action, altering water chemistry, reducing light, decreasing food availability, and smothering habitat (Albers 2003). PAH exposure can cause impaired reproduction, reduced growth and development, and tumors or cancer in species of amphibians, reptiles, and other organisms (Eisler 1987, Albers 2003). PAHs are also known to cause lethality, reduced survival, altered physiological function, inhibited reproduction, and changes in species populations and community composition of freshwater invertebrates (Albers 2003).

Petroleum hydrocarbons have been detected periodically in the aquifer and at Barton Springs at various concentrations in several sampling events (City of Austin 1998a, Hauwert and Vickers 1994). Although PAHs have been detected at mostly low concentrations from 25 sites sampled on Barton Creek (City of Austin 1998a), sediment data from Barton Creek has shown high concentrations of PAHs at two sites above Barton Springs Municipal pool (City of Austin 1997). In particular, concentrations of PAHs measured in sediment lying within drainage ways that flow into Barton Creek above Barton Springs Pool (as presented in LCRA 2002) have been measured at concentrations greater than those expected to impact aquatic life (MacDonald et al. 2000). Staff biologists from the City of Austin have identified a possible source of this PAH contamination in the Barton Springs watershed (and possibly throughout the City of Austin). This research indicates that coal tar sealants used on paved surfaces can be eroded during runoff events and thereby contribute PAH-bearing particles to nearby drainages and waterbodies (Mahler et al. 2003). The sealants are commonly used to maintain parking lots in the Austin area and are typically reapplied every three years or so. Although normally confined to the bottom of Barton Creek just above the upper dam of the municipal pool, the coal tar PAHs have the potential to be intermingled with PAHs from other sources within the Barton Creek watershed during high flood stages. As a result, salamander exposure to PAHs could increase following flood events.

Factors Influencing Concentrations of Pollutants and Contaminants at Barton Springs

Impervious Cover and Stormwater Runoff – Arnold and Gibbons (1996) defined impervious cover as "any material that prevents the infiltration of water into the soil." Types of impervious cover include roads, rooftops, sidewalks, patios, paved parking lots, and compacted soil. As areas are cleared of natural vegetation and the topsoil is replaced with impervious cover, rainfall no longer percolates through the ground in areas with impervious cover but is instead rapidly converted to surface runoff. The effects of impervious cover involve both the construction phase of development and the operation and maintenance of developed acreage. Increases in impervious cover have been shown to cause measurable water quality degradation (Klein 1979, Bannerman et al. 1993, CWP 2003), loss of habitat for sensitive aquatic organisms (Booth 1991, May et al. 1997, CWP 2003), reduction in stream biodiversity (Klein 1979, Benke et al. 1981, Garie and McIntosh 1986, Jones and Clark 1987, Weaver and Garman 1994), stream warming (Galli 1990), and channel instability within a watershed (Booth 1991, Booth and Reinelt 1993, Schueler 1994). Klein (1979) suggested that impairment of stream quality can be prevented if watershed imperviousness does not exceed 15 percent in general, and watershed imperviousness does not exceed 10 percent for more sensitive stream ecosystems.

Research has shown a relationship between the ecological health of stream systems and the percentage of impervious cover (Klein 1979, Schueler 1987, Todd 1989, Veenhuis and Slade 1990, Booth and Reinelt 1993, Schueler 1994). Several studies have shown relationships between the amount of impervious cover and adverse biological effects including (1) lower diversity, (2) shifts in relative abundance, (3) impaired growth, and (4) reduced reproduction of aquatic organisms. This has been documented in macroinvertebrates (animals with no backbone that are visible without magnification) and fish (Klein 1979, Garie and McIntosh 1986, Pedersen and Perkins 1986, Jones and Clark 1987, Hogg and Norris 1991, Weaver and Garman 1994, Horner et al. 1997, May et al. 1997).

Impervious cover generally increases runoff volumes and peak discharges in streams (Leopold 1968, Hollis 1975, Klein 1979, Schueler 1987, Konrad and Booth 2002). The increased amount and velocity of runoff caused by impervious cover can produce greater stream channel erosion and destabilization of streambanks (Klein 1979, Booth and Reinelt 1993, Schueler 1994). A cycle of bank destabilization and active erosion is initiated when stream channels adjust to high flow volumes by expanding their cross-sectional area either by (1) increasing the width of the stream or (2) cutting into the stream bed (Hammer 1972, Booth 1990, Booth and Reinelt 1993, Schueler 1994, Pizzuto et al. 2000). The erosion that accompanies bank destabilization can lead to increased sediment transport in streams (Dartiguenave et al. 1997). Relatively low levels of impervious cover (that is, 10 to 20 percent) have been shown to enlarge channels and increase flooding events in streams (Leopold 1968, Klein 1979, Schueler 1994). In many studies, measures of impervious cover of about 10 percent have been identified as the level at which stream ecosystem impairment begins (Klein 1979, Booth 1991, Schueler 1994, Booth and Reinelt 1993). Salamander habitat could be affected by the greater sediment transport caused by higher surface runoff as a result of increased impervious cover overlying the aquifer.

Impervious cover is a major contributor of pollutant loads in stormwater runoff in urban areas (City of Austin 1990, Bannerman et al. 1993, Dartiguenave et al. 1997, CWP 2003). These pollutants include:

(1) sediment from construction activities and streambank erosion;
(2) suspended solids;
(3) nutrients;
(4) hydrocarbons and metal compounds from vehicles and machinery;
(5) household paints and solvents;
(6) trash and debris;
(7) fertilizers; and
(8) pesticides.

A nationwide analysis of 173 urban watersheds found that impervious cover was one of the most significant variables in predicting nutrient loading by storm events (Driver and Lystrom 1986). Impervious cover increases nutrient loading in urban runoff by rapidly transporting nutrients to streams and other waterbodies (Horne and Goldman 1994, Dartiguenave et al. 1997). Griffin et al. (1980) studied 16 urban watersheds and found that amounts of nutrients and heavy metals in these watersheds were relative to the percentage of impervious cover in individual watersheds. Best management practices (BMPs) are often used in urban areas to offset water quality impacts caused by stormwater runoff. However, several factors affect the effectiveness of these control mechanisms with respect to removing pollutants from runoff (see "Best Management Practices" in this section).

Higher percentages of impervious cover in a watershed may also change aquifer water quality by increasing the amount of surface runoff water with respect to baseflow in streams (Klein 1979, Finkenbine et al. 2000). Baseflow can be defined as that portion of streamflow that originates from shallow, subsurface groundwater sources in the absence of other inputs such as surface runoff. Baseflow effectively drains the shallow, underground water reservoirs, eventually leading to their depletion in the absence of substantial recharge (ASCE 1996). In general, baseflow is relatively uncontaminated due to the filtration that occurs as rainwater percolates through the soil overlying an aquifer. During rainfall events, streamflow shifts from high quality baseflow water to stormwater runoff which normally carries pollutants and contaminants into stream systems (Klein 1979, Bannerman et al. 1993, Schueler 1994, Barrett and Charbeneau 1996, Dartiguenave et al. 1997, CWP 2003). Impervious cover may cause a reduction in the water quality of recharge water as the shift from baseflow to stormwater runoff occurs. This water quality degradation could be reflected in aquifer springflows into salamander habitat.

Studies conducted in watersheds located in Austin, Texas, and on the Barton Springs Segment of the Edwards Aquifer have documented relationships between impervious cover and non-point pollution source loading. Non-point pollution sources originate from flow distributed over the land surface, as opposed to being discharged from a single, known location. In a study of pollutant loads from various land use areas in Austin, stormwater runoff pollutant loads were found to increase with increasing impervious cover and population density. This study also found that pollutant loading rates of the more urbanized watersheds were higher than those of the small suburban watersheds (City of Austin 1990). Soeur et al. (1995) determined that stormwater pollution loadings were correlated with development intensity in Austin.

Development-related changes in median concentrations for water quality constituents were determined from data derived from water quality databases of the City of Austin by Veenhuis and Slade (1990) (Appendix B). The data represent several thousand water quality analyses for dozens of water quality constituents in 18 stream sampling sites in Austin. The watersheds surrounding the sites range in impervious cover from less than 1 percent to 42 percent. The data for each water quality constituent in Appendix B are provided by flow category for each sampling site (rising stages of storms and falling stages of storms). The appendix shows that substantial degradation occurred in each constituent sampled except for dissolved solids from stormwater runoff from all impervious cover ranges. For most water quality constituents, the median concentrations for storm samples are increased by about 200 to 300 percent or more from watersheds containing less than one percent impervious cover to watersheds containing two to seven percent impervious cover. Therefore, considerable water quality degradation could occur by the time a watershed reaches 10 percent impervious cover.

Construction Activities – Soil disturbed during construction activities is easily eroded and carried away by runoff from a storm event unless best management practices are followed and structural water quality control mechanisms are properly maintained. The City of Austin (1995) estimated that construction-related sediment and in-channel erosion accounted for approximately 80 percent of the average annual sediment load in the Barton Springs watershed. In addition, the City of Austin (1995, 1997) estimated that total suspended sediment loads have increased 270 percent over pre-development loadings within the Barton Springs Segment of the Edwards Aquifer. Williamson Creek has the highest density of development of any stream in the Barton Springs watershed and also has the highest loadings per unit area for total suspended sediment and total nitrogen (City of Austin 1995).

Wastewater Discharge – Threats from domestic wastewater include fecal bacterial pathogens, nutrient-induced algal blooms, oxygen reducing organic materials, and toxic contaminants such as heavy metals and pharmaceuticals. The primary sources of wastewater discharge to the environment that may affect the recovery of the salamander are septic tank fields, sewage collection systems, and disposal of treated wastewater by irrigation. Limitations for wastewater treatment systems in the recharge and contributing zones of the Barton Springs Segment of the Edwards Aquifer include:

(1) inadequate depth of soil;
(2) effluent loading limitations in clay soils with little infiltrative capacity;
(3) excessive anaerobic soil conditions due to low porosity and

high soil saturation;
(4) limited biological treatment due to low organic matter content soils;
(5) channelization of effluent through either lateral bedding planes or through fractures and conduits;
(6) thin or no topsoil for treatment processes on land and pollutant attenuation; and,
(7) a potential for rapid runoff from sites with steep slopes (EHA 1985).

About 5,900 septic tanks exist within the Barton Springs watershed (Barrett and Charbeneau 1996). Septic tanks can be a potential source of nitrogen and bacterial pathogens to the aquifer. In the Lake Travis watershed, a study of on-site systems documented a considerable discharge of nitrates to shallow subsurface wells (EHA 1985). For the majority of the recharge and contributing zones, soil and geologic conditions are marginally suitable for conventional septic systems with drain field disposal. Although alternative treatment and disposal systems are being developed to overcome many of these limitations, there are no enforcement systems in place in the contributing and recharge zones to ensure facilities are operating properly (City of Austin 1996).

Threats from disposal of treated domestic wastewater by irrigation are primarily related to overloading soil treatment processes. Excess of treated wastewater by irrigation can cause poor assimilation and discharge of pollutants through subsurface pathways and surface runoff. Many irrigation tracts are managed for golf courses or other recreational uses. This can result in heavier applications of fertilizers and pesticides that can be infiltrated through the soil into the groundwater or carried off by surface water discharge.

<u>Transportation Infrastructure</u> – Highways and other roadways can have major effects on local groundwater quality (TNRCC 1994, Barrett et al. 1995). The Capital Area Metropolitan Planning Organization's (CAMPO) Transportation Plan (2000) states that "...roadways may affect adjacent water resources with trash, oil and grease, and accidental spills of transported materials." Problems associated with transportation systems have previously been discussed by McKenzie and Irwin (1983), Dupuis and Kobriger (1985), Dorman et al. (1988), and Buckler and Granato (1999). Effects on water resources from transportation systems can be hydrological (that is, related to changes in the amount of runoff) and related to water quality including:

(1) decreasing flow capacity in drainages;
(2) reducing storage volume in ponds, lakes and aquifers;
(3) decreasing water quality and clarity;
(4) smothering benthic (bottom-dwelling) organisms; and
(5) exposure of aquatic organisms to contaminants in surface runoff.

Major contaminants and pollutants can be generated by all phases of highway construction, maintenance, and use. Highway construction itself has the potential to cause substantial sediment loading to nearby receiving waters. In addition to hazardous materials spilled during traffic accidents, vehicle use on highway systems also generates petroleum-related compounds such as PAHs, particulates, metals, and deicers (Buckler and Granato 1999). Maintenance activities on highway corridors can also contribute toxic materials to nearby waters. Bridge cleaning has the potential to allow drift of cleaning solutions and associated contaminants into water drainages. Water systems close to highway corridors may also be impacted by the use of agricultural chemicals (specifically, herbicides and fertilizers) used to control vegetation growth along roadways.

TCEQ lists highways and roads as the fifth most common potential source of groundwater contamination in the Edwards Aquifer (TNRCC 1994). Elevated concentrations of metals, Kjeldahl nitrogen, and organic compounds have been detected in groundwater near highways and their control structures. Highway construction can also cause large increases of suspended solids into receiving waters (Barrett et al. 1995). Several major highways (a segment of State Highway 45, the southern extension of Loop 1 (MO-PAC), and the Southwest Parkway) have been built in the area overlying the Barton Springs watershed over the last decade to accommodate projected population growth and traffic demands. In addition to these existing roadways, several miles of the remainder of State Highway 45 is proposed to be built in the Barton Springs watershed within the next few years (CAMPO 2004).

Hazardous Materials Spills – The Barton Springs watershed is at considerable risk from accidental releases of hazardous materials and is particularly at risk from spillage of hazardous materials in transport (City of Austin 1995). Any hazardous materials spill within the Barton Springs watershed could have the potential to threaten the long-term survival and sustainability of the Barton Springs salamander. Numerous highways and pipelines that are major transport arteries for various petroleum products and chemicals cross the watershed. A catastrophic spill could occur if a pipeline ruptured or a transport truck overturned and its contents entered the recharge areas of the watershed. Transportation accidents involving hazardous materials at bridge crossings are of particular concern because recharge zones in creek beds can transport spilled materials directly into the aquifer. Because the four springs of the Barton Springs complex are hydrologically related, a contaminant spill that spreads into all four springs has the potential to eliminate the entire salamander species and/or its prey base within its habitat. Contaminant spill information was compiled by the TCEQ for Hays and Travis counties for the years 1983 through 2000 (Table 2). The table provides an indication of the kinds of contaminants spilled and their spill frequency within each county and its watersheds.

In addition to the spill events reported in Table 2, three major petroleum pipeline spills have occurred over the Barton Springs Segment of the Edwards Aquifer. Two of these spills have occurred over the recharge zone within the last 20 years (Rose 1986). Each of the petroleum pipeline ruptures was caused by construction activities such as digging of utility line trenches. Approximately 10,000 barrels of crude oil were recovered in each of these spills. Although petroleum fumes were detected in caves almost 2 miles (3.2 km) from one of the spill sites, the impacts of the two spills on water quality in the aquifer and Barton Springs are unknown.

Table 2 - Contaminant Spills in Travis and Hays Counties for the Years of 1983 – 2000 as Compiled by the Texas Natural Resource Conservation Commission

County	Contaminant	Number of Events
Hays	Gasoline	13
	Diesel	3
	Freon; Chlorinated solvents; Tetrachloroethene Trichlorethene (1,2) Dichloroethane; Dichlorethane; Trihalomethanes and chlorinated hydrocarbons	1 each (5 total)
	Unknown	5
Total Reported Contaminant Events in Hays County		**26**
Travis	Gasoline	55
	Petroleum hydrocarbons	7
	Diesel	5
	Gasoline and diesel	4
	Solvents	4
	Volatile organic compounds (VOCs)	4
	Lead	3
	Polycyclic aromatic hydrocarbons (PAHs) and petroleum hydrocarbons	3
	Waste oil	2
	Chlorinated solvents	2
	Petroleum hydrocarbons and metals	2
	Gasoline and waste oil; Gasoline and diesel and alcohol fuel; Chromium, organics, and hydrocarbons; Petroleum hydrocarbons, perchloroethylene (PCE), arsenic and BA; Hydrocarbons; Paint solvents and benzene; VOCs and metals; Perchloroethylene; Methylene chloride and petroleum hydrocarbons; Petroleum hydrocarbons and chlorinated solvents; Petroleum hydrocarbons; Metals; Polychlorinated biphenyls (PCBs), petroleum hydrocarbons, VOCs and metals; Petroleum hydrocarbons, VOCs, chlorinated solvents, and petroleum hydrocarbons; Organic carbon and VOCs (chlorobenzene; 1,4 dichlorobenzene)	1 each
	Unknown	9
Total Reported Contaminant Events in Travis County		**115**

Measures for Minimizing Degradation of Water Quality in the Barton Springs Watershed

Impervious Cover Limitations – Klein (1979) recommends that watershed imperviousness should generally not exceed 15 percent and that watershed imperviousness should not exceed 10 percent for sensitive stream ecosystems. Overall impervious cover in the Barton Springs watershed is approximately five percent (LCRA 2002). The level of impervious cover varies among the six major drainages within the watershed. As of 2000, the six watersheds that provide water to Barton Springs had the following impervious cover levels (LCRA 2002): (1) six percent in Barton Creek, (2) sixteen percent in Williamson Creek, (3) seven percent in Slaughter Creek, (4) five percent in Bear Creek, (5) three percent in Little Bear Creek, and (6) three percent in Onion Creek. The percentage of impervious cover within the Barton Creek watershed is likely to increase as the human population increases.[3]

Currently, no single regulatory mechanism exists to restrict increases in impervious cover throughout the Barton Springs watershed; however, there are several state regulations (such as TCEQ's Edwards Rules) and municipal ordinances (such as the City of Austin's Ordinance #920903-D "Save Our Springs" and similar ordinances for the City of Dripping Springs and Village of Bee Cave) that are designed to minimize water quality degradation from new development. The Edwards Rules regulate activities that may potentially pollute the Edwards Aquifer. These rules apply to all zones (recharge, transition, and contributing) of the Edwards Aquifer and were designed to ensure that:

> "the existing quality of groundwater not be degraded, consistent with the protection of public health and welfare, the propagation and protection of terrestrial and aquatic life, the protection of the environment, the operation of existing industries, and the maintenance and enhancement of the long-term economic health of the state" (30 Texas Administrative Code Chapter 213).

Significant changes to the Edwards Rules were implemented in 1999 after the Barton Springs salamander was listed as endangered. These changes included a requirement for permanent BMPs that remove 80 percent of the increase in post-construction total suspended solid load to be installed in new developments over the Barton Springs watershed. Although there are no restrictions on impervious cover in the Edwards Rules, the regulations do provide incentives to developers in the form of exemptions and exceptions from permanent BMPs for developments with less than 20 percent impervious cover.

Based on trend data that shows degradation of water quality at Barton Springs over the years (see Appendix A), existing regulations for maintaining water quality may not adequately protect the Barton Springs salamander. To date, no comprehensive study has been conducted to evaluate the effectiveness of existing state and local regulations in

[3] In the year 2000, census figures showed that Hays County had 98,000 in population and Travis County had 812,000 (U.S. Census Bureau 2002). According to the Texas State Data Center (2002), projected increases in population for Hays and Travis counties by the year 2040 will be 175 percent and 69 percent, respectively.

protecting water quality in the Barton Springs watershed. In addition, Chapter 245 of the Texas Local Government Code permits "grandfathering" of state regulations. Grandfathering allows developments to be exempted from new requirements for water quality controls and impervious cover limits providing that the developments were planned prior to the implementation of such regulations. However, these developments are still obligated to comply with regulations that were applicable at the time when project applications for development were first filed. The potential impact of the grandfathering statute as enacted by the State of Texas has not been examined with respect to existing regulations that protect water quality in the Barton Springs watershed.

Buffer Zones – Buffer zones are natural areas that have not been disturbed by construction, development, or any other type of disturbance that can significantly alter existing vegetation. A buffer zone can protect an aquatic ecosystem from land use impacts by providing shade, baseflow storage, streambank stability, and filtration of upland runoff (May et al. 1997). Filtration in buffer zones is accomplished through soil buffering capacity, vegetation, and microorganisms to remove or break down pollutants (Mulamoottil et al. 1996).

The buffer size required to fully protect aquatic resources varies considerably depending on the (1) functional value of the resource such as wildlife habitat, water storage, and recreational opportunities, (2) intensity of adjacent land use, (3) buffer characteristics such as vegetation and undisturbed or highly eroded soils, and (4) specific buffer functions required (Castelle et al. 1994). A review of the scientific literature on buffer size requirements indicates that minimum buffer widths of 50 to 100 feet (15 to 30 meters) on each side of the stream are necessary to protect streams from degradation under most conditions (Johnson and Ryba 1992, Castelle et al. 1994, Schueler 1995, Fisher and Fischenich 2000). In a study on the effects of buffer zones on habitat of two salamander species (*Eurycea cirrigera* and *Desmognathus fuscus*), Willson and Dorcas (2003) found that relatively small buffer zones (for example, buffer zones that are 35, 100, or 200 feet wide for watersheds greater than 100 acres) alone do not provide adequate protection of the stream ecosystems. Relatively large areas of undisturbed land may be needed throughout the entire watershed to protect habitat for aquatic species in streams (Willson and Dorcas 2003).

Buffer Zones for Riparian Areas – Riparian areas are lands that are adjacent to streams, rivers, and areas such as lakes and reservoirs. Plant communities in riparian areas are usually diverse with a high degree of structural and compositional diversity (Gregory et al. 1991). Riparian areas comprise a relatively small proportion of the landscape but are much more important to the proper hydrological and ecological functioning of ecosystems than their small size would indicate (Gregory et al. 1991, Fisher and Fischenich 2000). The riparian area is an interface zone between terrestrial and aquatic ecosystems that plays a central role in the movement of water, air, sunlight, and nutrients through watersheds (Gregory et al. 1991). Riparian plants, in particular, moderate the effects of upland land use and play an important role in ecosystem structure and function.

Well-maintained buffer zones in riparian areas can substantially reduce effects of urban development (May et al. 1997). Buffer effectiveness is dependant on (1) function of the riparian area in the watershed, (2) composition and density of vegetation in the riparian area, (3) buffer width and length, and (4) slope (Fisher and Fischenich 2000). The extent of the riparian zone and the degree to which it can buffer the aquatic ecosystem from upland impacts depends on the size of the stream and the density and composition of vegetation (Fisher and Fischenich 2000). The effectiveness of riparian areas for buffering streams from the impacts of forestry and agriculture has been well studied, but less work has been focused on the effects of urbanization. The impact of urban development on the functioning of riparian areas can vary widely with amount of disturbance to streamside vegetation, the land use type and intensity, and the remaining buffering capacity of the area (May et al. 1997).

The City of Austin Ordinance #920903-D (Save Our Springs) and ordinances for the City of Dripping Springs and the Village of Bee Cave all include measures to protect riparian areas. In addition, Federal Emergency Management Agency floodplain regulations and section 404 of the Clean Water Act operate to restrict development of riparian areas along major creeks or headwater tributaries. Although mechanisms to protect riparian areas exist, buffer sizes based on site-specific characteristics need to be identified and evaluated for effectiveness.

<u>Buffer Zones for Stream Headwaters</u> – In general, many watershed regulations (including the Land Development Code for the City of Austin) recommend a correspondingly wider buffer for downstream portions of a stream network. However, recent evaluations have concluded that riparian buffers in headwater streams (generally, first or second-order systems) have a greater influence on water quality overall within a watershed than buffers set up in downstream reaches (Fisher and Fischenich 2000). Headwater streams are the hydrological capillaries of the watershed and serve as natural areas for water retention. Although extreme flood events may overwhelm the mitigating effects of headwater streams, surface runoff from non-flooding rain events is slowed and allowed to infiltrate into shallow groundwater through the headwater stream system. Approximately 80 percent of total stream length resides in these small order streams. During periods of low rainfall, baseflow in streams is generated primarily from release of retained shallow groundwater that has filtered through headwater buffers and stream channels. Loss of headwater streams and wetland areas may result in a dramatic alteration of downstream hydrology (Poff et al. 1997).

Headwater stream buffers are also important in maintaining water quality by allowing longer flow retention within the soil where natural filtration processes and pollutant removal occurs. Even ephemeral headwater streams are efficient at trapping sediment and pollutants adsorbed onto the sediment (Dieterich and Anderson 1998). By increasing the probability that such pollutants will be naturally degraded in headwater buffer soils, organisms downstream should have less exposure (Dieterich and Anderson 1998). During flood events, headwater streams and buffers provide the only natural moderation of peak flows and storm water velocities that are influenced by development. Depending on their size and effectiveness, headwater buffers have the ability to trap sediment from upland development if the erosion control practices during construction are inadequate. Structurally, the roots of vegetative buffers form the natural glue for small stream banks and can help prevent sediment loading caused by bank failure and erosion. This was identified in an assessment of Onion Creek, which determined that root binding by mature woody species in steeper banks of small channels is critical to the overall stabilization of the entire channel system (City of Austin 2003b).

Headwater streams help to maintain the ecological diversity found downstream in a watershed. They provide temperature control through riparian vegetation shading (Horne and Goldman 1994). Vegetative cover in headwater areas also provides diversity of habitat and shelter for wildlife. Habitat connectivity created by contiguous buffer systems allows for wildlife accessibility to nursery and feeding areas that otherwise would be less available in an urbanized landscape. This is important for species that use different parts of the watershed during different portions of their life cycle.

Downstream buffers have proportionally less effect on polluted water already in the stream. Buffer strips along larger streams may not significantly improve water that has been degraded by improper buffer practices higher in the watershed. However, buffer strips along larger systems also have unique benefits since these stream systems are typically longer and wider than those of low-order streams and have a greater potential to provide significant wildlife habitat and movement corridors (Fisher and Fischenich 2000). Buffers for both headwater streams and downstream reaches are needed to preserve the functionality of a watershed. Studies have indicated that a minimum buffer width should be set at approximately 50 to 100 feet (15 to 100 meters) on both sides of a stream (Johnson and Ryba 1992, Castelle et al. 1994, Schueler 1995), including headwater and lateral feeder streams, to provide adequate stream protection.

Buffer Zones for Environmentally Sensitive Areas – Buffers around sensitive environmental features such as recharge features of the Barton Springs Segment of the Edwards Aquifer can also contribute to water quality protection. Recharge features such as caves, sinkholes, faults, and fractures can have direct connections to the aquifer (City of Austin 1997). Within the Barton Springs watershed, approximately 15 percent of the recharge to the aquifer is derived through recharge features in upland areas between and in smaller tributaries of major creeks with the remaining recharge (85 percent) occurring within the major streams (Slade et al. 1986). Because pollutants in surface runoff may enter the aquifer through sinkholes or other recharge features with little or no attenuation (Field 1998), buffers around these features may maximize the potential for attenuation before water enters the aquifer.

Compact, clustered developments – Compact development (also known as open space development or low impact development) is a type of development that is characterized by (1) the preservation of large, undisturbed areas or open space across the development site and (2) limitations on the amount and distribution of impervious cover. The goal of this type of development is to reduce development effects on the surrounding environment. Compact development provides an opportunity to design subdivisions in a manner that reduces impervious cover and conserves undisturbed native land as much as possible. The protection of open spaces can produce benefits similar to those from limiting impervious cover such as decreases in stormwater runoff and pollutant transport (Arendt 1999). Increasing the amount of land preserved in its natural state may result in a reduction in the number of acres of managed landscape and turf (areas that are intensely managed through the use of irrigation, fertilization, or pest control practices) that can serve as a source of pollutants during stormwater runoff or irrigation events. A compact development that is clustered at a single site of a large area may also reduce the need for longer roads. In addition, a clustered design can be beneficial in protecting the surrounding watershed by reducing the amount of construction activities that lead to increased erosion and sediment transport.

Best Management Practices – BMPs are "methods that have been determined to be the most effective, practical means of preventing or reducing pollution from non-point sources" (EPA 2002). Types of BMPs can include public information programs, street sweeping, and structural controls such as wetlands, wet ponds, dry ponds, filters, and grassy swales. TCEQ defines permanent BMPs as "…measures that are used to control pollution…after construction is complete" (TNRCC 1999). Under TCEQ's Edwards Aquifer Rules (30 Texas Administrative Code 213), permanent BMPs must prevent pollution of surface water or stormwater that originates on-site or upgradient from the site and flows across the site. These rules also specify that permanent BMPs must prevent pollution of surface water downgradient of the site, including pollution caused by contaminated stormwater runoff from the site (TNRCC 1999).

There have been many studies of the effects of best management practices on the water quality of urban runoff including Welborn and Veenhuis (1987), Barrett et al. (1998), and Glick et al. (1998). Different types of BMPs – public information programs, wetlands, wet ponds, dry ponds, filters, grassy swales, and street sweeping – have removal efficiencies ranging from 0 to 90 percent (Table 3).

Table 3 - Removal Efficiencies of Best Management Practices (BMPs) for Control of Contaminants and Pollutants in Surface Runoff

BMP Type	Removal Efficiency
Public information program	5-10 percent for most water quality constituents
Wetlands	up to 90 percent (best for nutrients, some metals may actually increase)
Wet ponds	60-80 percent (best for sediment-related constituents)
Dry ponds	30-70 percent (best for sediment-related constituents)
Filters	30-70 percent (most filters are horizontal and are best for sediment-related constituents, efficiency depends on maintenance)
Grassy swales	10-20 percent (more efficient for sites with appropriate swale characteristics)
Street sweeping	0-10 percent (some evidence that street sweeping can increase pollutant loading)

The wide range (30 to 70 percent) in filter efficiencies indicates that the efficiency of a particular filter can depend on the maintenance of the filter material. As indicated by field inspections and other evidence, the efficiency of filters may decrease when the filters are not being properly maintained (Glick et al. 1998). Also, the efficiency of filters and ponds can be substantially reduced if they contain stormwater bypasses or overflows.

In an effort to mitigate urbanization effects, the City of Austin and other agencies have required BMPs to be designed and implemented throughout the Austin area. Over 1,000 BMPs currently exist in the Austin area and more are being developed. Although some grassy swales and wet ponds are being used as BMPs in the Austin area, filters are more prevalent (TNRCC 1999). Each type of BMP has a different level of effectiveness depending on on-site characteristics such as drainage area size, slope, soil type, vegetative structure, and percentage of impervious cover. BMPs also vary in their pollutant removal capabilities (TNRCC 1999, AMEC et al. 2001, Pennington et al. 2003). In 1987, the USGS published a report presenting data regarding the effects of two different runoff controls (a sand filter and a grass-lined swale) on the quality of runoff in Austin for 22 storm runoff events (Welborn and Veenhuis 1987). The sand filter produced a 21 percent decrease in dissolved volatile solids and an 81 percent decrease in fecal bacteria between the inflows and outflows of a pond with a sand filter. In comparison, the study found that the grass swale had no effect on water quality. However, Barrett et al. (1998) has reported significant removal efficiencies for two other grass-lined swales associated with highways in Austin. The differences in performance of the grass-lined swales were probably a result of the differences between the on-site characteristics of the study areas.

TCEQ's Edwards Aquifer Rules require the use of structural BMPs if the impervious cover of a site will exceed 20 percent impervious cover. BMPs have been implemented in the Austin area under various ordinances (for example, Ordinance #920903-D "Save Our Springs") and other rules to provide for better treatment of runoff. Although BMPs such as filters can remove substantial amounts of pollutants as water quality constituents, they generally do not completely eliminate water quality degradation caused by urbanization because some BMPs perform better than others in removing certain types of stormwater pollutants. Also, the performance capabilities of BMPs can be reduced or lost over time (CWP 2003). The effectiveness of BMPs for the Barton Springs watershed should be evaluated.

Water Quantity

(Listing Factors A,D,E)

Another potential threat to the Barton Springs salamander and its ecosystem involves low flow conditions in the aquifer and at Barton Springs. The long-term mean flow at the Barton Springs outlets (Barton Springs Pool, Eliza Springs, Sunken Garden Springs, and Upper Barton Springs) from 1917 to 1986 was 54 cfs. The lowest flow recorded at Barton Springs was about 10 cfs during a record drought in the 1950s (City of Austin 1998b, BS/EACD 2004), and the highest-recorded flow was 166 cfs. Discharge at Barton Springs decreases as water storage in the Barton Springs Segment of the Edwards Aquifer drops. Large declines in aquifer levels have historically been due to a lack of adequate rainfall recharging the aquifer rather than the result of groundwater withdrawal for public use. However, increased groundwater pumping can also reduce the quantity of water in the aquifer. Water supply wells in the Barton Springs Segment of the Edwards Aquifer include about 970 active wells that pump water for public, domestic, industrial, commercial, and agricultural uses. The Barton Springs/Edwards Aquifer Conservation District (BS/EACD), which is charged with regulating groundwater withdrawal in this segment of the aquifer, has issued annual pumping permits for approximately 10 percent of these wells (BS/EACD 2004). Pumping volumes (both permitted and non-permitted) reached approximately 10.8 cfs (2.5 billion gallons per year) in 2004 (BS/EACD 2004). These pumping rates are estimated to increase over time and reach 19.6 cfs by the year 2050 (Scanlon et al. 2000).

Groundwater flow modeling by Scanlon et al. (2000) indicated springflow at Barton Springs would likely decrease or cease as pumping levels in the Barton Springs Segment of the Edwards Aquifer reaches about 10 cfs. In 2004, the BS/EACD performed additional modeling to determine the "sustainable yield" of water in this segment of the aquifer. The BS/EACD defines sustainable yield as:

> "the amount of water that can be pumped for beneficial use from the aquifer under drought-of-record conditions after considering adequate water levels in water-supply wells and degradation of water quality that could result from low water levels and low spring discharge" (BS/EACD 2003a, BS/EACD 2004).

In the 2004 study, the BS/EACD recalibrated the model used by Scanlon et al. (2000) to more accurately predict springflow and aquifer declines under drought-of-record conditions and projected pumping rates for future years. The model indicates that under drought-of-record conditions, current pumping levels of 10 cfs would result in a mean monthly springflow of about 1 cfs for about one month. It also indicated that under drought-of-record conditions, projected pumping rates of 15 cfs would cause Barton Springs to cease flowing for at least four months (BS/EACD 2004).

The results of the BS/EACD sustainable yield simulations have considerable implications for the Barton Springs salamander and its habitat. If central Texas again experiences drought conditions similar to that of the 1950s, the continued survival of the species could be imperiled by critically low or no discharge at spring outlets. Low flows at Barton Springs could cause habitat degradation and a substantial loss of plant and animal life. Some effects of low flows have been observed at Barton Springs. Upper Barton Springs ceases to flow when the collective discharge from Barton Springs is about 40 cfs (David Johns, City of Austin, pers. comm., 2002). Also, Eliza Springs has ceased to flow when the dam gates in Barton Springs Pool are opened and water is drawn down during periods of low spring discharge. This has stranded and killed some salamanders. To prevent Eliza Springs from going dry, the water in Barton Springs Pool is no longer drawn down when flows are less than 54 cfs (City of Austin 1998b). It is possible that Eliza Springs and Sunken Garden Springs could cease to flow during a major drought under current pumping conditions even if the gates of Barton Springs Pool remained closed. This could result in the substantial loss of salamanders within its known range.

Decreased dissolved oxygen levels are another concern during low flow conditions. Concentrations of dissolved oxygen are directly related to spring discharge at Barton Springs (City of Austin 2000). Dissolved oxygen levels tend to be highest during periods of high recharge when a large volume of well-oxygenated surface water enters the aquifer. Dissolved oxygen levels are at their lowest when recharge is minimal and spring discharge is low (City of Austin 1997, 2000, 2005). Extended or frequent periods of low flow could result in low dissolved oxygen levels that may be detrimental to the development, reproduction, and survival of the Barton Springs salamander. Although the Barton Springs salamander survived the drought of the 1950s, it could have been adversely affected by low flows at Barton Springs. Also, a continual decline in dissolved oxygen in its habitat may have a greater influence on the salamander’s survival during future drought-of-record conditions or result in greater effects to the salamander occurring in combination with other threats, such as increased pollutant loading.

The sustainable yield simulations also indicated that under 1950s drought conditions and high rates of pumping, saline water from the “bad-water” zone has a greater potential to move into the freshwater portion of the aquifer (BS/EACD 2004). Consequently, the intrusion of saline water can cause specific conductance to increase in salamander habitat under low flow conditions. This may reduce salamander survival by reducing the solubility of oxygen which is needed for salamander respiration. Chloride, sodium, sulfate, and magnesium also increase during low spring discharge and show a marked increase when flows drop below 40 cfs (City of Austin 1997). Specific conductance at all of the spring sites has increased since 1975 during all flow conditions (City of Austin 2000, 2005). Sunken Garden Springs tend to have the highest specific conductance levels, which is most likely attributable to their proximity to the “bad-water” zone (City of Austin 1997).

Low flows at Barton Springs would also hinder salamander “rescue” efforts in the event of an emergency such as a catastrophic spill of a hazardous material. Even if adequate time to respond to a spill over the Barton Springs Segment of the Edwards Aquifer was possible before the spill reached the springs, collection of a large number of salamanders would be hampered during periods of low flow due to the reduction in salamander numbers. Collection of salamanders at a spring site that is completely dry at the time of the spill would not be possible.

Surface Habitat Modification
(Listing Factors A,D)

In addition to factors such as pollution, contamination, flooding, and low spring discharges (see Water Quality and Water Quantity in Section 1.6 of this document), other types of surface habitat modifications have been known to occur at Barton Springs. Many of these have resulted from the recreational use of Barton Springs Pool. For example, an improper application of chlorine (formerly used to clean the pool) resulted in a fish kill inside the pool in 1992. Following this event, salamanders were found only inside a 50-square foot area immediately surrounding the outflow of Main Springs rather than their usual distribution of approximately 4,300 square feet (400 square meters) (Chippindale et al. 1993).

Effects to Barton Springs salamanders also have been noted from the following activities:

(1) lowering of the water level in Barton Springs Pool for cleaning;
(2) use of high pressure fire hoses for cleaning in areas where salamanders occur;
(3) hosing sediment into salamander habitat;
(4) physical ateration of primary habitat by recreational pool users;
(5) runoff from the train station at Zilker Park;
(6) construction activities upgradient of Eliza Springs.

The City of Austin completed a Habitat Conservation Plan (HCP) in 1998, which was designed to avoid, minimize, and mitigate effects from the operation and maintenance of the pool (see discussion under Section 1.7, Conservation Measures). Since the HCP was first implemented, many of the methods once used to operate the pool have been modified to minimize effects on the salamander or discontinued entirely.

The reduction in available suitable habitat for the aquatic species occupying the Barton Springs ecosystem is also affected by flooding events at Barton Springs. As discussed in Section 1.6, *Pollutants and Contaminants Potentially Affecting the Barton Springs Salamander*, floods can increase sediment deposition, which can clog the interstitial spaces needed by the salamander for foraging and cover. Floods can also alter the salamander’s surface habitat by causing an infusion of debris into Barton Springs. Additionally, past flooding events have been known to dislodge large concrete sections from the shallow end of Barton Springs Pool, remove gravel from the beach area of the pool, and uproot plants from the pool's main channel.

Finally, the surface habitat of the Barton Springs salamander has been altered through the construction of man-made impoundments to enhance the recreational use of Barton Springs. Three of the known spring sites occupied by the salamander (Main Springs, Eliza Springs, and Sunken Garden Springs) were modified by impoundments built in the early to mid 1900s. A dam was constructed on Barton Creek upstream from Main Springs to form Barton Springs Pool in 1920. A second dam, located downstream from the first dam, was constructed at this site later that decade. A concrete culvert was constructed between the two dams to prevent surface water in Barton Creek from entering the swimming pool under normal flow conditions. A circular, stone, amphitheater was built around Eliza Springs in the early 1900s to serve as a meeting area for the local Elks Club. A concrete bottom was installed there in the 1960s. Springs now discharge from this site through seven openings (each one-foot in diameter) in the concrete floor and 13 rectangular vents along the edges of the concrete. In 1935, circular stone walls were constructed around Sunken Garden Springs to provide Austin citizens with an outdoor location for quite meditation and family picnics (Pipkin and Frech 1993). Although they were once popular swimming areas, Eliza Springs and Sunken Garden Springs are now closed to the public.

While the man-made structures help retain water in the spring pools during low flows, they have altered the salamander's natural environment. The impoundments have changed the Barton Springs ecosystem from a stream-like system to a more lentic (still water) environment, thereby reducing the water system's ability to flush sediments downstream and out of Barton Springs salamander habitat. They also limit the potential surface interactions between the salamander populations and other plant and animal species of Barton Creek.

1.7 Conservation Measures

The conservation measures discussed in this section are actions that are already completed or currently underway that may contribute to the recovery of the Barton Springs salamander. The listing factors addressed in part by each conservation measure are provided. See Section 1.1, Introduction for a discussion of listing factors.

Efforts to Protect the Barton Springs Watershed (Listing Factors A,D,E – *see Section 1.1 for an explanation of the listing factors)*

Several large-scale projects have implemented proactive actions that help protect the Barton Springs watershed. For example:

> <u>Land Acquisition and Conservation Easements</u> – In May 1998, City of Austin voters approved $65 million in utility revenue bonds for the purchase of land and conservation easements in the contributing and recharge zones of the Barton Springs Segment of the Edwards Aquifer for the protection of the city's drinking water quality. Approximately 15,000 acres were acquired (including fee title purchases and conservation easements). Most of the Shield Ranch is included in this total, which comprises a 6,593-acre conservation easement area with about 6.3 miles (10 km) along both sides of Barton Creek in the contributing zone. In November 2000, City of Austin voters approved over $13 million for the protection of open space within the Barton Springs watershed. As a result of these two approved propositions, the City of Austin has spent over $78 million and has protected approximately 16,662 acres (Junie Plummer, City of Austin, pers. comm., 2004).
>
> The Hill Country Conservancy is a nonprofit land trust committed to preserving open space overlying the Barton Springs Segment of the Edwards Aquifer. This organization works with private landowners, conservation buyers and sellers, the real estate and business communities, and numerous agencies of local, state, and Federal government to preserve land and protect water quality and quantity within the Barton Springs watershed. The Hill Country Conservancy has succeeded in conserving approximately 2,200 acres of its goal to preserve 50,000 acres in the Barton Springs watershed and is working to develop a conservation easement on the 5,685-acre Storm Ranch located in the contributing zone of the Barton Springs watershed.
>
> <u>Balcones Canyonlands Conservation Plan (BCCP)</u> – The BCCP is a regional habitat conservation plan developed by the City of Austin and Travis County. The goal of the BCCP is to acquire and manage at least 30,428 acres for the protection of 8 endangered species (2 birds and 6 karst invertebrates) and 27 species of concern (City of Austin and Travis County, Texas 1996). Although the Barton Springs salamander is not targeted for protection within the BCCP, land acquisition in the Barton Springs watershed under the BCCP benefits the

salamander through preservation of open space over the recharge zone, which has a direct influence on water quality.

Water Quality Protection Recommendations – In September 2000, a set of water quality protection recommendations was developed and distributed to local jurisdictions within the Barton Springs watershed. A working group, which represented broad expertise in water quality protection technology and consisted of staff from the City of Austin, Lower Colorado River Authority (LCRA), University of Texas at Austin, and local engineering firms, developed this document in an effort to outline site-specific management actions designed to minimize water quality degradation from new development in the Barton Springs watershed.

In 2001, the LCRA began construction on a new waterline that extended availability of treated surface water to portions of northern Hays and southwestern Travis counties. Although the project was intended to alleviate growing demands on groundwater pumping from the aquifer, the new waterline threatened to negatively affect the Barton Springs salamander by stimulating development over the Barton Springs watershed. Before construction on the pipeline began, the Service issued a biological opinion on the first phase of the waterline project. A biological opinion is a document issued by the Service that explains the Service's opinion as to whether or not a Federal action is likely to jeopardize the continued existence of listed species. Because LCRA's installation of the pipeline required a permit from the U.S. Army Corps of Engineers, this project was considered a Federal action. As part of the biological opinion, the Service and LCRA entered into a Memorandum of Understanding that contained the water quality protection recommendations to be used by developers intending to build in areas serviced by the new waterline. In addition to developments receiving water from the LCRA pipeline, these recommendations have also been used in other large developments to help minimize water quality impacts within the Barton Springs watershed.

Following the implementation of the September 2000 water quality protection recommendations, the same working group, in close coordination with Service staff, prepared and updated two, more detailed draft water quality recommendations documents in November 2002. A draft technical guidance document provided the scientific justification for the water quality recommendations and guidance on how the measures could be implemented. It also addressed the shortcomings of the September 2000 document, specifically addressing impacts from golf courses and wastewater disposal systems, and the need for monitoring. These recommendations provide scientific information and expert opinion on how water quality impacts from new developments can be minimized.

Edwards Aquifer Rules Optional Measures – In August 2004, the Service and TCEQ began a collaborative effort to develop voluntary guidelines that, if followed by project planners within the Edwards Aquifer region, would result in "no take" of several federally-listed, aquifer-dependant species including the Barton Springs salamander. As a result of this collaboration, the "Optional Enhanced Measures for the Protection of Water Quality in the Edwards Aquifer" were finalized in February 2005 as an addendum to TCEQ's technical guidance document for implementing the Edwards Aquifer Rules. In addition, the Service and TCEQ are committed to a monitoring and adaptive management program. These two agencies have met with many of the groups that are monitoring Edwards Aquifer water quality, and in some cases, biological resources. These groups have committed to sharing the results of their monitoring information, which will be stored in a centralized database and used for trend analyses. A scoping study to determine the types of monitoring data that are available for storage and analysis began in June 2005. If the analysis of the monitoring information indicates water quality degradation that could affect aquifer-dependant species such as the Barton Springs salamander, then the TCEQ and the Service would convene an expert group to evaluate the causes. If necessary, the agencies plan to modify the optional water quality measures to ensure the continued protection of these species.

<u>Regional Water Planning</u> – In December 2002, officials from Hays County and City of Austin launched an effort to develop a regional water quality protection plan. This effort was designed to produce ordinances or rules to be implemented by local, regulatory jurisdictions for the protection of water quality within the recharge and contributing zones of the Barton Springs Segment of the Edwards Aquifer, and gain the Service's endorsement that these ordinances will provide habitat protection for the Barton Springs salamander. Development of the plan directly involved those entities that ultimately would be responsible for enacting such ordinances as well as a number of environmental organizations, government agencies, stakeholders, and other community members. The regional water planning group outlined specific measures to enhance or maintain the existing surface and ground water quality within the Barton Springs watershed through a cooperative regional approach. In June 2005, this group finalized the "Regional Water Quality Protection Plan for the Barton Springs Segment of the Edwards Aquifer and its Contributing Zone." The chronic water quality threats faced by the salamander may be addressed if the water quality protection measures set forth in this plan are adopted by the local jurisdictions throughout the Barton Springs watershed.

<u>City of Austin and Texas Department of Transportation National Pollutant Discharge Elimination System (NPDES) Permits</u> – The City of Austin and Texas Department of Transportation are monitoring development and traffic to provide data necessary to implement a long-term program to reduce pollutant loading.

<u>City of Austin's Action Plan to Address Top Ten Pollutant Sources</u> – The City of Austin's Watershed Protection and Development Review Department has summarized the top pollutant sources in the Barton Springs watershed and have developed action plans that outline the steps needed to reduce pollutant loading

from each source. The action plans need to be refined and the roles of potential partners need to be clarified, which could occur through the regional water planning process mentioned above.

Efforts to Protect Surface Habitat (Listing Factors A,D)

City of Austin's HCP – As previously mentioned under "Modification of Surface Habitat," the City of Austin (1998b) is implementing an HCP to avoid, minimize, and mitigate incidental take of the Barton Springs salamander resulting from the continued operation and maintenance of Barton Springs Pool and adjacent springs. An HCP is a plan designed to offset any harmful effects that a proposed project may have on federally-listed species. Through the habitat conservation planning process, non-federal entities may receive an incidental take permit to conduct activities that might incidentally harm or "take" a listed species by mitigating their impacts with activities that promote species conservation. The City of Austin's HCP provides a comprehensive source for management decisions regarding salamander habitat in the pool area. The City of Austin has assumed management responsibility for the habitat and has an incidental take permit (effective until October 2013) that requires several measures to ensure that adverse management effects on the Barton Springs salamander are minimized and offset by beneficial actions.

Major provisions of the plan include:

(1) avoiding or minimizing the stranding of salamanders and other aquatic organisms by lowering the "beach" in Barton Springs Pool to keep it from going dry during drawdown for cleaning; modifying the gate system on the lower dam of Barton Springs Pool to slow the rate of drawdown and gradually lower the water level; and preventing drawdown of the pool when flows are less than 54 cfs;
(2) training lifeguard and maintenance staff to protect salamander habitat and the ecology of Barton Springs Pool;
(3) controlling erosion and preventing surface runoff from entering the springs;
(4) ecological enhancement and restoration;
(5) monthly monitoring of salamander numbers;
(6) public outreach and education;
(7) dedicating of a portion of the pool revenues to fund conservation and research efforts for the Barton Springs salamander;
(8) establishing and maintaining a captive breeding population of Barton Springs salamanders;
(9) developing a spill response plan to address spill prevention, containment, remediation, and salamander rescue.

Habitat Restoration – In the fall of 2002, City of Austin biologists initiated a concerted effort to improve the habitat conditions in Eliza Springs (City of Austin 2003a). The drainage infrastructure was cleaned of debris to increase flow from the aquifer and to allow for more natural flushing and draining of the spring ecosystem. Sediment flushing exposed a layer of gravel and cobble that had been embedded and thus unavailable as habitat for the salamanders. Several species of native aquatic plants, including water primrose, rush (*Eleocharis* sp.), and water hyssop (*Bacopa* sp.) have been successfully transplanted from upper Barton Creek into Eliza Springs. Although mosquitofish and crayfish have dominated Eliza Springs in the past, the combination of relocating these species and improved springflows is reducing their numbers. Following these habitat improvements, salamander numbers at Eliza Springs began to increase in May 2003. City of Austin biologists found 233 salamanders during a survey of Eliza Springs in January 2004 (City of Austin 2002-2004, unpublished data).

In March 2005, efforts to restore and enhance habitat at Sunken Garden Springs were conducted as part of a local Eagle Scout project. Boy Scout volunteers and City of Austin biologists worked to fortify the highly-eroded soil along the stone walls that encircle the spring pool. Blocks of concrete and rusted wires were removed to increase flow, and several species of native aquatic plants were transplanted from Eliza Springs into Sunken Garden Springs. City of Austin biologists will continue to monitor the salamander population at this spring site to help determine if these habitat improvements will increase the number of salamanders observed at this location.

<u>Catastrophic Spill Response and Salamander Rescue</u> – The City of Austin is developing a catastrophic spill response plan to address spills of hazardous materials or other pollutants that occur in the Barton Springs watershed and threaten to eliminate the Barton Springs salamander from the wild. The plan is intended to address immediate threats to the survival of the species rather than spills that may have a long-term effect on the salamander populations. It will include: (1) a description of the potential sources of significant spills such as pipelines, hazardous material storage facilities, and roadways; (2) a delineation of the responsibilities of various response agencies and their roles; (3) a discussion of available aquifer flow and contaminant modeling; (4) a list of procedures (such as salamander rescue protocol) that will be followed in the event of a potentially catastrophic spill.

Captive Breeding (Listing Factors A,E)

Even with the best management practices and guidelines in place, an emergency situation could arise that threatens the continued existence of the Barton Springs salamander. Spills of hazardous materials in the Barton Springs watershed can pose an acute threat to this isolated population. It will be necessary, therefore, to maintain captive populations of Barton Springs salamanders for possible reintroduction. A scenario could develop where it becomes necessary to collect additional animals from the wild and hold them in captivity until an emergency situation has passed. The situation could be short or long-term.

Captive propagation and maintenance of the Barton Springs salamander has met with limited success, and knowledge of the requirements for captive propagation remains rudimentary. Captive breeding efforts will run a high risk of failure until these requirements are understood. Further, salamander collection depends on continuous springflow at the spring sites. Ideally, salamander collection would occur slowly over a long period of time at all of the spring sites to maximize genetic diversity and minimize depletion of wild populations. Large numbers of salamanders would be collected only during an imminent threat of springflow loss or in the event of a potentially catastrophic spill, assuming adequate notification time to respond before the spill reaches the springs.

The City of Austin has committed to fund and develop a permanent captive breeding program for the Barton Springs salamander (City of Austin 1998b; Chamberlain and O'Donnell 2002, 2003). As part of this commitment, Austin is building a captive breeding facility at the Austin Nature and Science Center. City of Austin biologists are working with the American Zoo and Aquarium Association to develop a captive breeding plan. Their goal is to maintain a viable and genetically diverse captive population as specified in their HCP (City of Austin 1998b). As of December 2003, the City of Austin had over 100 Barton Springs and Austin blind salamanders in captivity at a temporary facility; however, these numbers are expected to increase in future years (Chamberlain and O'Donnell 2003; Dee Ann Chamberlain and Lisa O'Donnell, City of Austin, pers. comm., 2004). Several salamanders are also on display at the "Splash!" exhibit at Barton Springs.

In September 2004, Longhorn Partners Pipeline, L.P. (Longhorn) provided funds to establish a captive breeding site and refugium for the Barton Springs salamander at the National Fish Hatchery and Technology Center (NFHTC) in San Marcos, Texas. In addition to funds provided for equipment and facility costs, Longhorn provided funds to hire and retain a biologist to establish and operate the systems needed to maintain the refugium. Longhorn will annually fund the salary of a biologist to operate the refugium as long as refined product flows through the pipeline or until such time that the Service ceases to operate the facility as a refugium for the Barton Springs salamander.

Salamander Monitoring (Listing Factors A,E)

The City of Austin conducts monthly surveys for Barton Springs salamanders in Barton Springs Pool, Eliza Springs, Sunken Garden Springs, and Upper Barton Springs (see Section 1.3, Population Status and Distribution). In addition, City of Austin biologists have developed a technique based on photographing the unique patterns of pigments on the head and body to identify individuals in the captive breeding program. This technique could also be used in the wild to provide better population estimates and allow individuals to be tracked over time (Lisa O'Donnell, City of Austin, pers. comm. 2003).

Water Quality Monitoring (Listing Factors A,D)

The City of Austin and USGS regularly conduct water quality monitoring at Barton Springs. The City of Austin's water quality monitoring schedule includes:

(1) continuous monitoring of pH, specific conductance, temperature, turbidity, total dissolved gas, dissolved oxygen, and depth using multiprobe data loggers in Barton Springs Pool, Eliza Springs, and Upper Barton Springs (when

flowing). Monitoring for Sunken Garden Springs will be contingent on funding;

(2) testing twice a week for bacteria in Barton Springs Pool;

(3) biweekly analyses of nutrients, total suspended solids, and chlorophyll A in Barton Springs Pool. A companion sample collected at the downstream dam is analyzed for total suspended solids and chlorophyll A. Field parameters measured include pH, temperature, turbidity, dissolved oxygen, and specific conductance;

(4) quarterly tests for nutrients, total suspended solids, major ions, and heavy metals (arsenic, copper, iron, lead, nickel, and zinc) in all four springs (when flowing). Field parameters measured include pH, temperature, turbidity, dissolved oxygen, and specific conductance;

(5) semi-annual analyses that include the above quarterly list of parameters in addition to a more comprehensive list of metals and organic compounds. Field parameters include pH, temperature, turbidity, dissolved oxygen, and specific conductance;

(6) annual analyses at all four springs that include the above quarterly list of parameters, in addition to a more comprehensive list of metals and organic compounds. Field parameters are collected including pH, temperature, turbidity, dissolved oxygen, and specific conductance.

Education and Outreach (Listing Factors A,D,E)

The Austin Nature and Science Center directs the “Splash!” exhibit to raise public awareness about the Edwards Aquifer. Resources at the “Splash!” exhibit include: (1) models of the Edwards Aquifer; (2) exhibits illustrating the importance of healthy buffer and riparian zones; (3) water quality monitoring; (4) an Edwards Aquifer database and library; (5) aquaria displaying the aquatic life of upper and lower Barton Creek, Barton Springs, and the Colorado River.

The Austin Nature and Science Center coordinates educational activities with local school teachers and classrooms, public outreach programs, and adult educational programs such as the Master Naturalist Program. Through the efforts of the Austin Nature and Science Center and the support and assistance of local, state, and Federal agencies, thousands of central Texas citizens and visitors will have the opportunity to understand the importance of Barton Springs and the Edwards Aquifer and the need for protection of these unique resources.

To provide the opportunity for the public to experience karst ecosystems on the Edwards Aquifer, karst preserves are being maintained by the City of Austin, Texas Cave Management Association, neighborhood associations, and private owners. Existing preserves include the Goat Cave Karst Preserve, the Lady Bird Johnson Wildflower Center, the Village of Western Oaks Karst Preserve, Whirlpool Cave Preserve, Dick Nichols Park, and the Slaughter Creek Metro Park.

Other outreach programs coordinated by the City of Austin include: (1) Earth Camp, a field trip program for schools in the Austin Independent School District that educates children on Barton Springs, salamanders, watersheds, karst aquifers, and preservation of water quality; (2) Earth School, an in-school lesson for fifth-graders that educates students on the effects of pollution on watersheds and aquifers; (3) Hydrofiles, a program that provides creek monitoring information and data analyses to participating high school students and teachers; (4) printed educational outreach materials intended to publicize the sensitivity of both the Edwards Aquifer and the Barton Springs and Austin blind salamanders.

2.0 RECOVERY

The following section presents a strategy for recovery of the species, including objective and measurable recovery criteria and site-specific management actions to monitor and reduce or remove threats to the Barton Springs salamander, as required under section 4 of the ESA. The Recovery Plan addresses the five statutory listing/recovery factors (section 4(a)(1) of the ESA; see Section 1.1, Introduction) to the current extent practicable to demonstrate how the recovery strategy and specific actions will ameliorate threats to the Barton Springs salamander. The recovery criteria provide benchmarks for recovery allowing the Barton Springs salamander to be downlisted to threatened status and ultimately removed from the list of threatened and endangered species.

2.1 Recovery Strategy

To meet the goal and objectives of this recovery plan in recovering the Barton Springs salamander, the ecosystem upon which the Barton Springs salamander depends must be conserved. The five broad areas outlined below form the basis of the Recovery Strategy for the Barton Springs salamander. Additional information is still needed to fully implement some of the actions outlined below. All actions should be modified and/or adaptively managed as new information becomes available. Many of these actions should occur simultaneously to ensure recovery of the species.

Protection of Water Quality (Listing Factors A,D,E)

All available information indicates that the Barton Springs salamander is restricted to the four spring outlets of Barton Springs, the pools surrounding these springs, and an unknown area within the Barton Springs Segment of the Edwards Aquifer. Since most of the water that leaves the aquifer flows through Barton Springs, the salamander may be affected by changes in water quality occurring in the Barton Springs watershed.

Avoidance and Remediation of Catastrophic Spills

A plan for responding to major spills of hazardous materials and pollutants within the Barton Springs watershed should be developed, and measures to avoid or completely contain catastrophic spills need to be implemented. To minimize the potential of a contaminant spill reaching salamander habitat, contingency planning for spills should include rerouting of trucks with hazardous materials, and installing or retrofitting hazardous materials traps, as necessary. Where possible, planning for emergency response to spills in the Barton Springs Segment of the Edwards Aquifer should be part of existing emergency response plans pertinent to this area. An evaluation of the effectiveness of the catastrophic spill plan in minimizing risks to the Barton Springs salamander is needed to meet recovery criteria.

Avoidance and Minimization of Chronic Water Quality Degradation

Minimizing Effects from Expanding Urbanization – There are few point discharges of water pollution within the Barton Springs watershed. Therefore, most of the potential sources of water quality degradation come from stormwater runoff and direct infiltration of contaminants in the uplands (Barrett and Charbeneau 1996). The highest potential for stormwater degradation comes from areas that have been developed.

The Austin area is experiencing rapid residential and commercial development and an increase in transportation infrastructure. Existing development has been shown to cause degradation of water quality within the Barton Springs watershed (see Section 1.6, Threats). However, most of the land within the Barton Springs watershed has not yet been developed. Water flowing through Barton Springs has been kept clean principally due to the filtration capacity of the remaining undeveloped land within the watershed. New development within the Barton Springs watershed should be built with the protection of water quality as a primary concern.

A comprehensive plan providing guidance for water quality protection in urban development should be implemented uniformly throughout the Barton Springs watershed. Development within certain local jurisdictions may comply with building ordinances designed to protect water quality; however, other development located outside those jurisdictions may not be held to similar standards. A regional approach that provides the same guidance to all developments throughout the Barton Springs watershed would be the most efficient method for developing and implementing mechanisms to protect water quality and the Barton Springs salamander. Such mechanisms should be created with a goal of preventing further degradation of surface water and the underlying aquifer as demonstrated by the following objectives: (1) development does not result in an increase in annual average stormwater pollutant loads over pre-development conditions for discharges from a site; (2) development is designed, constructed, and maintained in a manner that does not alter the form, function, and hydrology of the drainage network/stream system; (3) water quality constituents are maintained at levels that allow for the long-term survival of the Barton Springs salamander in its natural environment (see Section 2.2 for further discussion).

A regional approach to address all components of water quality protection within the Barton Springs watershed would be the most efficient way to protect the salamander and its habitat. A single authority could effectively adopt, implement, and enforce regulations over the entire Barton Springs watershed or relatively large portions of it. Alternatively, local jurisdictions within the watershed could jointly agree to regulate new development under similar regulations. Examples of large-scale, regional approaches to address water quality include the development of water quality recommendations used in the construction of developments receiving water from the LCRA pipeline, and the regional water quality planning process discussed in Section 1.7, Conservation Measures. Based on available scientific information and expert opinion (see Section 1.6, *Measures for Minimizing Degradation of Water Quality in the Barton Springs Watershed* for further discussion) regarding the effects of urbanization, protecting water quality within the Barton Springs watershed from new development should involve the following components:

- Impervious cover limits – Research from the Austin area and other parts of the country consistently show a negative relationship between water quality and the percentage of impervious cover. Detectable degradation of stream ecosystems is known to occur by the time a watershed reaches 10 percent impervious cover. The CWP (2003) suggests that BMPs can offset some of the effects of up to 5 percent of impervious cover in a watershed given effective stormwater treatment, but more research is needed to determine the effectiveness of BMPs in removing effects of impervious cover. Impervious cover limits are particularly pertinent for the recharge zone, since water enters directly through the porous limestone formation and receives little or no filtration before reaching Barton Springs. In combination with BMPs designed and maintained to keep water quality at pre-development levels, impervious cover limits should be an integral part of a regional plan for the protection of water quality in the Barton Springs watershed.

- Buffer zones for streams and other sensitive environmental features (caves, sinkholes, fissures, springs) – Buffers are natural areas where existing vegetation has not been altered by disturbance. Riparian buffers in particular can play an important role in water quality protection (including baseflow quality), hydrological retention, and maintenance of flow regime by: (1) preserving physical aquatic habitat; (2) providing effective pollutant removal; (3) protecting against streambank erosion; (4) providing flood control (Johnson and Ryba 1992, Schueler 1995, Fisher and Fischenich 2000). Based on existing literature, buffers less than 50 to 100 feet (15 to 30 meters) on either side of the stream are known to provide little protection of water quality and riparian habitat (Johnson and Ryba 1992, Castelle et al. 1994, Fisher and Fischenich 2000); however, larger buffers (for example, buffers greater than 100 feet in width) may be necessary to adequately protect water quality and wildlife habitat functions (Johnson and Ryba 1992).

  Several factors must be considered in determining an adequate buffer width and configuration including:

  (1) intensity of adjacent land use;
  (2) steepness of slope;
  (3) stream order;
  (4) soil characteristics (such as depth, texture, erodibility, moisture, and pH);
  (5) floodplain size and frequency of inundation;
  (6) hydrology;
  (7) buffer characteristics (such as type, density, structure of vegetation, and buffer length).

As an example, larger buffers may be necessary when the buffer zone is in poor condition (such as sparse vegetation, disturbed and/or eroded soils); is surrounded by intense land use; or is located within a watershed that has a large percentage of impervious surfaces (such as urban and suburban areas) that can increase the volume of runoff as well as nutrients, contaminants, and sediment in the runoff itself (Castelle et al. 1994, Fisher and Fischenich 2000, Kennedy et al. 2003).

Providing riparian buffers for headwater streams has a greater influence on overall water quality within a watershed than those buffers occurring in downstream reaches (Fisher and Fischenich 2000). However, greater length and width of buffer strips along larger systems can be beneficial in providing significant wildlife habitat and movement corridors (Fisher and Fischenich 2000). Buffers for both low-order, headwater streams and relatively larger stream systems are necessary to preserve the functionality of a watershed and should be considered during the development of a regional plan to protect water quality.

In addition to riparian buffers, other sensitive environmental features (such as caves, sinkholes, faults, fracture zones, springs, seeps, wetlands) that influence water quality should be buffered from development activities. State and local regulations generally recommend a minimum buffer zone of 150 feet (45 meters) around the perimeter of the feature to be protected provided there is adequate vegetative cover and the soils inside the buffer zone have not been eroded. This distance generally provides adequate vegetative cover and surface area for the removal of pollutants in surface runoff before the runoff enters the feature.

- Compact, clustered developments – Compact development (also known as open space development) is a form of development that reduces the average lot size, limits the disturbance and expense from infrastructure sprawl, generally provides better protection for environmentally sensitive or historically significant features, and provides neighborhood preserves or parks while maintaining overall density. Benefits to water quality include the preservation of large, contiguous, undisturbed areas; protection of hydrologically sensitive areas; reductions in impervious cover; fewer intensively managed landscapes (such as lawns); and stormwater detention and filtration. These benefits are achieved by clustering development density on one portion of the site in exchange for reduced density elsewhere on the site (Arendt 1999). Low impact development designs that rely primarily on vegetative and other structural approaches increase the likelihood of long-term water quality protection and minimize future maintenance responsibilities. Such designs should be encouraged by local jurisdictions on a regional scale for new developments over the Barton Springs watershed.

- Structural water quality controls – The structural controls that are most effective in protecting water quality in the Barton Springs watershed should be determined. Retention irrigation systems have often been used for developments over the Barton Springs watershed as the BMP for the prevention of water quality degradation. However, other BMPs, such as vegetative filter strips, sedimentation-sand filtration, and sedimentation basins combined in series, may also accomplish this goal if appropriately engineered and maintained. Data demonstrating effectiveness in preventing water quality degradation for the Barton Springs watershed should be gathered to adequately assess the success of BMPs (including BMPs in series). The use of those BMPs found to be the most effective in preventing degradation of water quality should be encouraged on a regional scale.

- Other strategies to reduce pollutant loads – Other strategies to reduce pollutant loads from new and expanding developments over the Barton Springs Watershed should be developed and implemented. These strategies may include controlling or minimizing wastewater disposal systems, erosion and sediment control, ensuring sufficient funding for inspection and maintenance of BMPs, integrated pest management, and public education. Because effluent-irrigated golf courses may cause water quality degradation, strategies that address this source of pollutant loading should also be evaluated and implemented. Examples of strategies to minimize effects of golf courses and other managed turf areas include nutrient balances, minimized turf areas, water quality controls, buffers for waterways and recharge features, and ongoing monitoring. Such strategies should be outlined during a regional planning process and implemented throughout the Barton Springs watershed.

Development of a Land Preservation Strategy – Land preservation through acquisition, conservation easements, or deed restrictions can provide permanent protection for water quality and quantity generated on preserved tracts. Preservation of undeveloped land may also be used to offset higher levels of impervious cover for specific development projects while maintaining low levels of impervious cover throughout the Barton Springs watershed. Because some tracts may be more beneficial in protecting water quality and quantity in the aquifer, a strategy to preserve key tracts of land, such as those that are mostly undeveloped with creeks and other significant recharge features, should be developed as part of a regional approach to protect water quality within the Barton Springs watershed. Specific funding mechanisms should also be proposed to implement this strategy.

Reduction of Pollutant Loads from Existing Development – Because degradation of water quality at Barton Springs has been documented (City of Austin 2000, 2005), efforts should be made to reduce pollutant loads from existing development and other existing sources of pollution such as golf courses. Such reductions may be achieved through the construction of water quality ponds that are commonly known as “retrofit ponds.”

Limitations to this approach include the existing lack of open space in previously developed areas to site the ponds and a relatively high cost of pond construction. Retrofit projects may also result in undesirable impacts such as destruction of sensitive riparian or canyon areas where the ponds must be sited due to drainage patterns and topography. Structural retrofits should be considered and implemented when: (1) space is available, (2) it is reasonably cost-effective and (3) specific water quality problems have been identified. Public outreach and educational efforts to reduce pollutant sources from existing developments (in particular from landscape practices, automotive fluids, and household wastes) are important strategies to complement structural controls.

Reduction of Pollutant Loads from Transportation Infrastructure – To avoid or minimize catastrophic and/or chronic water quality degradation in the recharge and contributing zones of the Barton Springs watershed and underlying aquifer, water quality control structures and hazardous material traps on existing transportation infrastructure such as roads and bridges should be examined. If it is found that certain structures are potential contributors to pollutant loads or pose a significant risk of catastrophic spills, these sites should be retrofitted. A plan should be developed and implemented to route hazardous cargoes away from the recharge zone and critical environmental features. All water quality control structures and hazardous material traps should be regularly monitored and maintained.

Sustain Water Quantity at Barton Springs (Listing Factors A,D,E)

An overall Aquifer Management Plan should be developed and implemented to conserve the Barton Springs salamander and maintain sufficient high quality springflows. The plan should address short-term and long-term approaches that can be used for managing water quantity and groundwater use from the Barton Springs Segment of the Edwards Aquifer. Because there is a substantial number of users dependent on the aquifer, creation of this plan should involve representation from multiple user groups to assure equitable consideration of various human needs (social and economic) while allowing salamander recovery actions to be implemented. The protection of baseflow is needed to ensure adequate flow at Barton Springs. Several of the water quality protection methods mentioned above (such as limiting impervious cover and providing riparian buffers and buffers for headwater streams) are also beneficial in protecting water quantity and should be addressed in a regional Aquifer Management Plan. Pumping limits should also be an integral part of this plan. Groundwater pumping from the Barton Springs Segment of the Edwards Aquifer should be limited such that spring flow at Barton Springs does not drop below a point that would threaten the long-term survival of the Barton Springs salamander in its natural environment. Reduction of groundwater pumping during periods of drought is particularly critical. More studies may be necessary to determine how much pumping can be sustained while still maintaining the salamander and its ecosystem during drought conditions.

BS/EACD Proposed HCP – The BS/EACD is a groundwater conservation district mandated to conserve, protect, and enhance the groundwater resources of the Barton Springs Segment of the Edwards Aquifer (BS/EACD 2004). Their jurisdiction covers portions of both Travis and Hays counties. Since the district tracks and regulates the amount of groundwater pumping from the Barton Springs Segment of the Edwards Aquifer, its involvement in developing an Aquifer Management Plan is essential. This organization is developing a regional HCP that will identify the effects of groundwater pumping on the Barton Springs and Austin blind salamanders and will include measures to avoid, minimize, and mitigate for those effects that are the result of permitted groundwater pumping. BS/EACD staff are collaborating with experts and various agencies to develop a plan that addresses the needs of the salamanders, groundwater demands and sustainability, and appropriate planning and aquifer management strategies that will protect the Barton Springs and Austin blind salamanders from degradation of water quantity.

Manage Local Surface Habitat (Listing Factors A,D)

Surface habitat management at Barton Springs is another area of concern for species conservation. The City of Austin has obtained an incidental take permit for pool cleaning activities and accepted the responsibility for management of the salamander species and its habitat at Barton Springs. The HCP developed for the permit application incorporates an adaptive approach to enhance local surface habitat conditions for the Barton Springs salamander. Salamander populations at all four spring sites are monitored monthly as a condition of the City of Austin's incidental take permit.

The quality and quantity of water discharging from Barton Springs can be affected by a variety of activities and occurrences within the Barton Springs watershed, such as contaminant spills, land use practices, and groundwater pumping. Because of this, efforts to maintain surface habitat conditions at Barton Springs should be undertaken by a variety of organizations, municipalities, governmental agencies, and others within the watershed. Protecting water quality and quantity at Barton Springs under normal circumstances is necessary not only to ensure the long-term protection of the salamander in the wild, but also to maximize the possibility that enough salamanders can be collected during rescue efforts in the event of a catastrophic spill.

Maintain a Captive Population for Research and Restoration Purposes (Listing Factors A,E)

The purpose of recovery under the ESA is to remove or reduce threats to listed species so they are conserved in their natural ecosystem. For this reason, captive populations alone do not constitute recovery nor meet the purpose of the ESA. The establishment of captive populations should be considered a precautionary measure, while the primary focus should be placed on conservation of the ecosystem. Though the main strategy of this recovery plan is to reduce risks and conserve the species in its native ecosystem, we include captive propagation as a tool to provide additional assurance that the species will be conserved for the long-term. Because of its restricted range, the threat of a catastrophic event eliminating the entire population of the salamander in the wild can only be addressed by maintaining captive populations of Barton Springs salamander.

Captive populations should be established and carefully maintained so that suitable stock is available for reintroduction or supplementation purposes, as needed. A Captive Population and Contingency Plan (CPCP) should be developed that identifies protocols for establishing and maintaining captive populations as well as the conditions that trigger bringing large numbers of individuals in from the wild (for example, an emergency such as a large contamination spill at the springs). This plan should be developed in a manner that is consistent with the Service's *Policy Regarding Controlled Propagation of Species Listed Under the Endangered Species Act* (65 FR 56916-56922).

Due to the challenges of conducting field research on this species which spends part of its life in inaccessible locations, biological research on the Barton Springs salamander may be facilitated using individuals from a captive population. This would also avoid depleting the wild population for research activities.

Research needed to effectively manage a captive breeding program suitable for use in restoration efforts includes: (1) salamander population genetics should be more fully characterized to provide information needed to design a captive propagation plan; (2) captive breeding techniques should be developed to ensure dependable captive breeding and rearing techniques for Barton Springs salamanders; and (3) reintroduction techniques should be developed.

Develop and Implement Education and Outreach Programs (Listing Factors A,D,E)

As conservation of this species and its ecosystem will involve the support and participation of a wide variety of people and organizations, public information and education is an important component of this recovery strategy. The City of Austin plans to move their captive breeding facility to the Austin Nature and Science Center. This should be an effective location for disseminating information about the Barton Springs and Austin blind salamanders to the public. Local jurisdictions, government agencies, non-profit organizations, and other groups should also disseminate information to the public regarding the importance of protecting water quality and quantity within the Barton Springs watershed. Developers can incorporate environmental educational programs into their development plans for residential, industrial, and commercial developments. Helpful topics to include are information about endangered aquatic species, karst geology, best management practices, buffer zone maintenance, fertilizer application, pesticide use, organic gardening, water conservation, and disposal of hazardous household chemicals. Development of kiosks, displays, video, and other media to present material covering a variety of non-point source pollution control topics should be encouraged. Alternative educational efforts, such as recharge feature displays and educational nature trails are also encouraged.

2.2 Goal, Objectives, and Recovery Criteria

Goal - The goal of this recovery plan is to reduce the threats to the Barton Springs salamander and secure the conservation of the salamander at a level whereby the species can be removed from the list of threatened and endangered species (delisted). Progress toward recovery can be demonstrated by downlisting Barton Springs salamander to threatened status.

Objective 1 - Protect water quality (Listing Factors A,D,E - see Section 1.1, Introduction for an explanation of listing factors)**.**

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

Objective 2 - Prevent or contain catastrophic spills (Listing Factors A,E)**.**

> **Downlisting Criterion 2 -** A comprehensive hazardous material spills plan for the Barton Springs watershed is developed and implemented with measures to avoid or completely contain catastrophic spills.

The risk of harm to the Barton Springs salamander from hazardous spills should be reduced to an insignificant level. This criterion needs to be refined by developing a methodology for assessing risk to the Barton Springs salamander.

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

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

Objective 3 - Protect water quantity (Listing Factors A,D,E)**.**

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

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

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

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

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

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

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

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

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

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

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

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

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

Downlisting Criterion 6(a) - A CPCP is developed and implemented.

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

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

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

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

2.3 Recovery Program Outline

The actions needed to meet recovery criteria are organized below into seven categories: (1) water quality, (2) water quantity, (3) surface habitat management, (4) salamander monitoring and research, (5) captive breeding, (6) public outreach and education, and (7) post-delisting monitoring. Planning and scientific research activities will generate information that assists with management of the species and assessing the success of the recovery program for the Barton Springs salamander. Monitoring the implementation of those management actions should ensure that management tools are appropriately and effectively addressing impacts on the species. If the tools are not effective, then changes in management should be made and additional planning and scientific research may be necessary. This section provides an outline of the recovery program. The Narrative of Recovery Actions (Section 2.4) discusses the outline in more detail. The listing factor(s) (see Section 1.1, Introduction and Table 1) to be addressed by the recovery actions listed below are identified in parenthesis after each action. As discussed in Section 1.1, Introduction, implementation of this recovery plan is strictly voluntary and dependent on the cooperation and commitment of numerous partners in conservation.

1.0 Water Quality

1.1 Minimize catastrophic water quality threats

- 1.1.1 Identify, field verify, and map stream crossings and major recharge features and potential sources of catastrophic spills (A)
- 1.1.2 Develop a comprehensive database to track potential sources of spills that occur in the Barton Springs watershed (A)
- 1.1.3 Develop and implement a catastrophic spill avoidance plan (A)
- 1.1.4 Develop and implement a comprehensive regional spill containment and remediation plan (A)
- 1.1.5 Implement effective maintenance procedures for existing and future spill containment structures (A)

1.2 Avoid chronic water quality degradation

- 1.2.1 Develop and implement a regional approach to water quality protection that encompasses the entire Barton Springs watershed (A,D)
- 1.2.2 Maintain a comprehensive water quality database for the Barton Springs watershed to house water quality information. Evaluate the data to identify adaptive management actions to ensure long-term water quality protection (A)

1.2.3 Design hypothesis-driven monitoring of physical and chemical constituents (sediment, nutrients, and contaminants) present during baseflow and stormflow conditions. Evaluate the data to determine specific water quality constituents that affect the Barton Springs salamander and its prey base and habitat

1.2.3.1 Evaluate sediment quality at specific sites throughout the Barton Springs watershed (A)

1.2.3.2 Determine chronic and acute contaminant transport through the aquifer and potential interactions with salamander habitat (A)

1.2.3.3 Conduct baseflow, stormwater, and biological monitoring at the springs and at sites throughout the Barton Springs contributing and recharge zones (A)

1.2.4 Gather information needed to assess adequacy of pollution control measures and implement pollution control measures to protect water quality at Barton Springs

1.2.4.1 Monitor and evaluate the compliance of existing regulations requiring the use of BMPs and the effectiveness of new and existing BMPs on minimizing sediment and other contaminant input into the aquifer and contributing streams (A,D)

1.2.4.2 Monitor and evaluate the effectiveness of pollution mitigation programs (A)

1.2.4.3 Evaluate buffer zone size and location for sensitive environmental features (A)

1.2.4.4 Implement programs to protect critical environmental features (caves, sinkholes, fissures, springs, and riparian zones) (A)

1.2.4.5 Reduce pollutant loading from existing development and transportation infrastructure (A)

1.2.4.6 Monitor and evaluate the extent and effect of impervious cover (A)

1.2.5 Develop, implement, and modify programs to identify and correct problems from point and non-point source discharges (A)

1.2.6 Use existing information and conduct research to determine the potential effects of different levels of water quality constituents, pollutants, and contaminants on the Barton Springs salamander, its prey base, and its habitat (A)

1.2.7 Develop and implement a land preservation strategy for the Barton Springs watershed (A)

2.0 Water Quantity

2.1 Gather and evaluate information necessary to ensure adequate water quantity

2.1.1 Determine aquifer characteristics and recharge patterns (A)

2.1.2 Develop Barton Springs watershed models to predict effects of increasing impervious cover, flooding, and groundwater pumping (A)

2.1.3 Monitor aquifer and springflow levels under normal and drought conditions (A)

2.1.4 Monitor bad water line encroachment under low flow conditions (A)

2.1.5 Investigate aquifer recharge enhancement potential in the recharge and contributing zones (A)

2.1.6 Refine understanding of water quantity requirements for the Barton Springs salamander and determine withdrawal volumes and aquifer levels that will maintain adequate springflow (A)

2.1.7 Refine understanding of water balance within the Barton Springs Segment so major sources of recharge and discharge can be located and quantified (A)

2.2 Design, implement, and when needed, modify measures to provide adequate water quantity to Barton Springs

2.2.1 Develop and implement a regional Aquifer Management Plan using Barton Springs watershed model predictions to ensure protection of aquifer levels and springflows under normal and drought conditions (A,D)

2.2.2 Develop, implement, and modify measures to protect existing recharge features from plugging and filling (A)

3.0 Surface Habitat Management

3.1 Maintain a comprehensive database on the spring habitats of the Barton Springs salamander (A)

3.2 Monitor the health and stability of the salamander prey base (A)

3.3 Implement research programs to further study the habitat requirements of the Barton Springs salamander (A)

3.4 Continue to monitor, manage, and provide protection for existing spring habitats, and modify management actions when new information warrants changes (A)

4.0 Salamander Monitoring and Research

4.1 Implement research programs to determine the life history characteristics (for example, fecundity, mortality, longevity, age/size at maturity, and growth rate) that govern population dynamics (such as, intrinsic rate of increase/decrease and population viability) of the Barton Springs salamander

4.1.1 Monitor Barton Springs salamander populations in the wild to ensure long-term stability and viability (A,D,E)

4.1.2 Explore and develop marking techniques and conduct mark/recapture research (E)

4.1.3 Determine gene flow and migration between the four spring sites and genetic variation within, and among, the sites (E)

4.1.4 Investigate effects of various flow levels, especially low flows, on the salamander and the spring ecosystem (A,D,E)

4.1.5 Investigate the reproductive and other life history characteristics of the Barton Springs salamander (E)

4.1.6 Investigate the genetic characteristics and variation in the Barton Springs salamander at the individual and population level (E)

4.1.7 Conduct a population viability analysis of the Barton Springs salamander (A,E)

4.2 Investigate the prevalence, character, and cause of gas saturation in the water of spring habitats in the Barton Springs watershed (A)

4.3 Determine the short and long-term impacts of gas bubble trauma on the Barton Springs salamander (A)

4.4 Develop and implement actions that prevent, avoid, or minimize the effects of gas bubble trauma on the Barton Springs salamander and other aquatic life in the spring ecosystem (A)

5.0 Captive Breeding

5.1 Develop a comprehensive Barton Springs salamander captive propagation and contingency plan consistent with the Service's *Policy Regarding Controlled Propagation of Species Listed Under the Endangered Species Act* (A,E)

5.2 Develop dependable captive breeding and reintroduction techniques (A,E)

5.3 Establish, maintain, and monitor captive breeding populations to maintain adequate captive populations (A,E)

6.0 Public Outreach and Education

6.1 Develop, evaluate, and update education and outreach programs and materials to increase public awareness about the Barton Springs salamander and its habitat (A)

6.2 Develop, evaluate, and disseminate information about how to avoid spills and other sources of water quality degradation within the Barton Springs watershed (A)

7.0 Post-delisting monitoring

7.1 Develop a post-delisting monitoring plan for the Barton Springs salamander (A,D,E)

2.4 Narrative of Recovery Actions

Underlined recovery actions represent the most stepped-down levels of the Recovery Program Outline and Narrative. These items are discrete, specific actions and are listed in the Implementation Schedule with associated time and cost estimates and potential partners or responsible parties (Section 4.0).

1.0 Water Quality

1.1 Minimize catastrophic water quality threats

Information should be gathered and evaluated to design measures to avoid catastrophic water quality degradation. These measures should be implemented and modified, as necessary. Plans should be developed, implemented and, as necessary, modified to avoid, if possible, or contain and remediate catastrophic spills within the Barton Springs watershed.

1.1.1. <u>Identify, field verify, and map stream crossings and major recharge features and potential sources of catastrophic spills</u>

Mapping and field verification of all major recharge features is vital to protection of the aquifer and the salamander. Because hazardous cargo routes have not been designated for the City of Austin and surrounding jurisdictions within the Barton Springs watershed, hazardous materials may be transported on any major roadway in the area. Teams of surveyors and hydrologists from local and regional agencies should compile a comprehensive map that identifies (1) all roadways and drainage conveyance systems near Barton Springs watershed streams and (2) major recharge features that have the potential to rapidly transport pollutants from a spill site to Barton Springs and their hydrologic connection to the aquifer.

To date, no agency or group of agencies has completed a comprehensive and detailed map of the existing infrastructure components that are potential sources of catastrophic spills. The comprehensive mapping of potential spill sources should include pipelines, underground storage tanks, and both sanitary and stormwater sewer systems. The mapping project should also include stream crossings, major recharge features, and critical environmental features that may provide rapid conveyance of pollutants to the springs. More intensive dye-tracing studies should also be conducted to determine which potential spill areas will result in contaminant flows to specific springs. These studies should be done at different aquifer levels since the velocity of contaminant movement, the dilution and dispersion of contaminants, and the springs that will discharge the contaminants may change with aquifer conditions.

A method to assess risk of a catastrophic spill and its effects on the Barton Spring salamander should be developed. The information collected through the implementation of this task and action 1.1.2 should be used to analyze the risk of a catastrophic spill occurring within the Barton Springs watershed and help in the development of a catastrophic spill avoidance plan (action 1.1.3) and a regional spill containment and remediation plan (action 1.1.4).

1.1.2 Develop a comprehensive database to track potential sources of spills that occur in the Barton Springs watershed

The City of Austin and surrounding jurisdictions within the Barton Springs watershed, in conjunction with the BS/EACD and TCEQ, should use information gathered through action 1.1.1 to develop a comprehensive database to monitor the potential sources of spills as well as actual spills in both the recharge and contributing zones of the watershed. This information should be used to analyze the risk of a catastrophic spill occurring within the Barton Springs watershed and to develop a catastrophic spill avoidance plan (action 1.1.3) and a regional spill containment and remediation plan (action 1.1.4) and to collect the information necessary to evaluate and, as necessary, modify these plans.

1.1.3. Develop and implement a catastrophic spill avoidance plan

A plan to avoid catastrophic spills of pollutants and/or contaminants within the Barton Springs watershed should be developed and implemented. The routing of hazardous cargoes away from the recharge zone and critical environmental features would greatly diminish the potential for a catastrophic spill to threaten water quality of the springs and survival of the Barton Springs salamander. Travis County, the City of Austin, TCEQ, Texas Department of Transportation (TxDOT), and all jurisdictions within the Barton Springs watershed should identify appropriate hazardous material routes that do not cross the Barton Springs recharge zone, designate them accordingly, and require their use. Measures required by various regulatory agencies to prevent spills from pipelines, underground storage tanks, sewer systems, and other sources should be reviewed, evaluated, and, as necessary, updated. Information gathered from other actions under 1.1.1, 1.1.2, and 1.1.5 of this outline should be helpful in preparing and implementing a catastrophic spill avoidance plan. Methodology for evaluating the effectiveness of this plan should be developed. The effectiveness of this plan should be monitored and evaluated regularly and, as necessary, modified as new information and/or hazardous materials routes become available.

1.1.4. Develop and implement a comprehensive regional spill containment and remediation plan

The potential for a catastrophic spill to occur at or near Barton Springs, or within the recharge zone of the Barton Springs Segment of the Edwards Aquifer, is a concern. A comprehensive regional spill response and remediation plan should be developed to address the potential impacts of on-site and off-site spills using information gathered in other actions in this recovery plan. Once the remediation plan has been completed and a standard set of spill response protocols are developed, annual training sessions and trial runs for mock emergency spills should keep response personnel at an appropriate level of readiness. The effectiveness of the remediation plan should be monitored and evaluated regularly and modified, as necessary.

To effectively address spill response issues, a thorough review of current spill remediation resources and training for on-site and off-site spills should be conducted. A review of resources and training should include the protocols of the Austin Fire Department, the City of Austin Watershed Protection Department's Water Quality Regulation Section (Spill and Response Team), TxDOT, TCEQ, the Texas Railroad Commission, and all jurisdictions within the Barton Springs watershed. Since response time can be the most critical factor for effective containment of a spill, a review of notification and communication protocols is also necessary.

Tracking the type, duration, and quantity of spills, including information on when they were reported, who responded, and how long it took the response team to get to the scene, as well as what actions were taken, will contribute to the effectiveness of the containment and remediation plan. Debriefings should be held after a spill to determine how the plan and response can be improved. The spill response plan and team training should be revised accordingly, following post-response debriefings.

This action (1.1.4) is a logical extension of the mapping and field verification projects described above in actions 1.1.1 and 1.1.2. Data collected during the mapping and evaluation process will provide the framework for the proper location and design of spill containment structures and remediation features. These spill containment structures and remediation features should be placed in locations most needed for the protection of water quality.

1.1.5 Implement effective maintenance procedures for existing and future spill containment structures

Annual inspections of spill containment structures should take place and maintenance scheduled as needed. The need for possible retrofit of containment structures should also be considered.

1.2 Avoid chronic water quality degradation

Information should be gathered and evaluated to design measures that avoid chronic water quality degradation (see discussion under Section 2.1 Recovery Strategy, Protection of Water Quality). Measures and programs to avoid chronic water quality degradation should be developed, implemented, and when needed, modified to ensure their effectiveness.

1.2.1 Develop and implement a regional approach to water quality protection that encompasses the entire Barton Springs watershed

Water quality protection throughout the Barton Springs watershed is currently under the jurisdiction of numerous local, state, and Federal agencies. It is difficult to determine to what extent current local, state, and Federal water protection measures are adequate, especially with rapid development and urban expansion. A regional approach to water quality protection should be developed and implemented. Such an approach should incorporate the best available scientific information and provide recommendations (consistent with those given in Section 2.1 Recovery Strategy, Protection of Water Quality) for new and existing development throughout the Barton Springs watershed to minimize water quality degradation before, during, and after construction. The Regional Water Planning group described in Section 1.7, Conservation Measures has made considerable progress with this effort, completing a final set of water quality protection recommendations in June 2005. Through this regional approach, it should be determined if these recommendations should and can be adopted, implemented, and enforced by a single state entity with jurisdiction over the entire Barton Springs watershed, or if each of the local jurisdictions within the watershed should implement and enforce these regulations independently. An evaluation of these two options should be conducted.

An assessment of the adequacy of existing water quality protection mechanisms should be performed. To accomplish this task, historical water quality data that illustrate both baseflow and stormflow conditions in the Barton Springs watershed should be gathered and compared to new water quality data in this area as it becomes available. Evaluation of water quality data along with toxicity information collected through implementation of Action 1.2.6 may be necessary to assess the efficacy and adequacy of existing protection measures such as TCEQ's Edwards Aquifer Rules and their associated optional water quality protection measures (see Section 1.7, Conservation Measures). The water quality protection recommendations developed for construction activities resulting from the first phase of the LCRA pipeline also should be evaluated. These assessments should provide useful insight for the design and implementation of effective, comprehensive regional aquifer protection measures.

1.2.2 <u>Maintain a comprehensive water quality database for the Barton Springs watershed to house water quality information. Evaluate the data to identify adaptive management actions to ensure long-term water quality protection</u>

Water quality at Barton Springs and in the Barton Springs watershed has been studied for decades by numerous state and local governmental agencies, as well as private and non-governmental groups. The most comprehensive water quality database for the Barton Springs watershed is maintained by the City of Austin and includes data collected by the City of Austin, TCEQ, and the USGS. The available data need to be analyzed and compiled into a comprehensive database available to all agencies, stakeholders, and interested parties. A comprehensive Barton Springs watershed database should provide the information necessary for the development of long-water quality protection. Analysis of the available information should be a coordinated, multi-agency effort with the goal of providing recommendations for long-water quality protection needs.

1.2.3 Design hypothesis-driven monitoring of physical and chemical constituents (sediment, nutrients, and contaminants) present during baseflow and stormflow conditions.

Information should be collected on the physical and chemical constituents of greatest concern during baseflow and stormflow conditions. This information should include the amount of point and non-point source discharges entering the Barton Springs Segment of the Edwards Aquifer and be used to design programs that will minimize pollution.

1.2.3.1 Evaluate sediment quality at specific sites throughout the Barton Springs watershed

Sediment samples collected by the City of Austin from streams in the Barton Springs watershed have contained high levels of various petroleum byproducts including PAHs and heavy metals, as well as various pesticides. These sediments with their adsorbed pollutants may settle in areas of primary salamander habitat, possibly exposing the species to chronic or even acute levels of specific pollutants. The sediment sampling effort should be expanded to locate specific sites that contribute significant amounts of pollutants to the aquifer and the sediments that discharge at Barton Springs.

1.2.3.2 Determine chronic and acute contaminant transport through the aquifer and potential interactions with salamander habitat

Contaminant transport through the aquifer occurs with the movement of groundwater, stormwater, and sediment. The contaminants may enter the aquifer at levels that produce immediate effects resulting in the salamander mortality and acute habitat degradation or more subtle effects resulting in decreased survival and lower reproductive rates among salamanders and their prey base. More information is needed concerning the pathways and rate of contaminant transport within the aquifer. Additional studies should be designed to define major conduits and the rate at which pollutants are either transported or deposited within the aquifer. These studies should include testing during varying flow conditions to determine the effect of aquifer levels on pollutant transport.

1.2.3.3 Conduct baseflow, stormwater, and biological monitoring at the springs and at sites throughout the Barton Springs contributing and recharge zones

Although a vast amount of data is available for the Barton Springs watershed, continued monitoring of surface and groundwater during baseflow and stormflow conditions is vital to further the understanding of the aquifer and the complex hydrogeological and biological mechanisms affecting water quality, water quantity, habitat condition, and ecosystem health for aquatic biota. Continued monitoring from programs will help identify where information gaps may be, the effectiveness of threat management, and how best to address these through the feedback mechanism in the adaptive management process. Existing water quality monitoring methods should be evaluated. If it is found that sampling periods occur at times or frequencies that are insufficient to detect contaminant loads, monitoring programs should be modified.

1.2.4 Gather information needed to assess adequacy of pollution control measures and implement pollution control measures designed to protect water quality at Barton Springs.

Information on pollution control measures such as BMPs, pollution mitigation programs, and riparian buffers should continue to be gathered and evaluated, and the use of such measures should be monitored for compliance and efficacy to ensure adequate water quality for the Barton Springs salamander.

1.2.4.1 Monitor and evaluate the compliance of existing regulations requiring the use of BMPs and the effectiveness of new and existing BMPs on minimizing sediment and other contaminant input into the aquifer and contributing streams

The efficiency of BMPs should also be monitored. Since the early 1980s, City of Austin watershed protection ordinances have required the design and installation of various types of BMPs to aid in the treatment and detention of stormwater runoff from development. TCEQ also requires the implementation of BMPs to comply with the Edwards Aquifer Rules. Hazardous material traps have also been constructed at sites where major highways cross streams that recharge the Barton Springs Segment of the Edwards Aquifer. The design and installation of these stormwater detention, filtration, sedimentation, and hazardous material BMPs have evolved with the monitoring and evaluation of their effectiveness in mitigating the quality and quantity of stormwater runoff. These BMPs and their maintenance schedules should be evaluated for their effectiveness in minimizing sediment and other contaminant input into the aquifer. Developments that were built in accordance with the water quality protection recommendations (such as those receiving water from the first phase of the LCRA pipeline) developed by the Service and other parties in 2000 may provide a starting point in evaluating the effectiveness of BMPs. This monitoring program should be expanded to include all existing BMPs in the Barton Springs watershed. Because poorly maintained BMPs have very little or no effectiveness, new and existing development sites should also be monitored for compliance with TCEQ's Edwards Aquifer Rules and other ordinances or development codes that require the use and maintenance of BMPs. Existing monitoring records should be examined to determine the rate of compliance. Water quality protection programs should incorporate mechanisms to encourage BMP maintenance compliance. Information gathered as a result of monitoring should be used to determine the role and effectiveness of BMPs in the protection of water quality.

1.2.4.2 Monitor and evaluate the effectiveness of pollution mitigation programs

With the implementation of structural stormwater controls, the City of Austin and other governmental agencies have developed pollution mitigation programs to minimize the amount of pollutants that enter Central Texas surface and groundwater. These programs include: (1) permit requirements for businesses that generate significant amounts of contaminants, petroleum products recycling, and household hazardous water disposal; (2) citizen monitoring groups; and (3) public outreach and education. The effectiveness of these programs in preventing pollution of the aquifer should be monitored and evaluated. Information gathered as a result of monitoring should be used to determine the effectiveness of pollution mitigation programs. These programs should be modified as necessary to minimize pollution of surface and groundwater.

1.2.4.3 Evaluate buffer zone size and location for sensitive environmental features

Recharge and sensitive environmental features such as caves, sinkholes, and fissures should be protected to maintain a high quality of water in the aquifer. To adequately protect these features, the source areas that drain water into them should be defined. Hydrological assessments and dye-tracing studies may be necessary to determine the drainage areas of caves and other recharge features. Buffer zone sizes, such as those used in the 2000 water quality protection recommendations used in the construction of developments receiving water from the first phase of the LCRA pipeline (see discussion in Section 1.7, Conservation Measures), should be evaluated to determine adequate slope, vegetation, and drainage area characteristics. Buffer areas around recharge features should be part of any water quality protection program in the Barton Springs watershed. These sizes should be modified if warranted by new information.

1.2.4.4 Implement programs to protect critical environmental features (caves, sinkholes, fissures, springs, and riparian zones)

Use of BMPs, buffer zones, impervious cover limits, conservation easements, land acquisition, and other tools are all important ways to protect critical environmental features throughout the Barton Springs watershed and ensure the quality of water recharging to the aquifer and discharging from spring habitats of the salamander. Information gathered as part of other actions in this outline should be helpful in implementing this action.

1.2.4.5 Reduce pollutant loading from existing development and transportation infrastructure

Information should be gathered to determine to what extent existing development and transportation infrastructure contribute to water quality degradation at Barton Springs. This may include a prioritization of the structures that are most in need of retrofitting to minimize the amount of pollutants that enter the aquifer. Sites that lack water quality control mechanisms or have mechanisms that are no longer operational should be retrofitted.

1.2.4.6 Monitor and evaluate the extent and effects of impervious cover

Because of the demonstrated correlation between increasing impervious cover and decreasing water quality (see discussion under Section 1.6, *Factors Influencing Concentrations of Pollutants and Contaminants at Barton Springs*), the effects of impervious cover on water quality within the Barton Springs watershed should be evaluated and monitored. Such an evaluation should include research specific to the Barton Springs Segment of the Edwards Aquifer to determine how increasing impervious cover affects the Barton Springs salamander, its prey base, and its habitat. Studies should also be conducted to determine how other water quality protection measures such as structural BMPs, buffers, and impervious cover limits can mitigate the effects of impervious cover within the watershed. This information should be used to assess the adequacy of existing water quality protection mechanisms and help to develop a regional approach in protecting water quality (action 1.2.1).

1.2.5 Develop, implement, and modify programs to identify and correct problems from point and non-point source discharges

The amount of pollution from point source discharges entering the Barton Springs Segment of the Edwards Aquifer should be minimized. Studies should be conducted to determine which site-specific characteristics influence the amount of impervious cover that should be recommended in an area. Public education about point and non-point source pollution should be expanded. Regulatory agencies should work with stakeholders from development, utilities, transportation, and other appropriate industries to create specific recommendations to minimize potential water quality degradation before, during, and after construction. Additional efforts to reduce the discharge of stormwater pollutants related to the use of pesticides, herbicides, effluent irrigation, and fertilizer should be developed, implemented, and updated regularly.

1.2.6 Use existing information and conduct research to determine the potential effects of different levels of water quality constituents, pollutants, and contaminants on the Barton Springs salamander, its prey base, and its habitat

The survival of the Barton Springs salamander depends on an ecosystem defined by a specific set of water quality parameters such as temperature, dissolved oxygen, saturation of gases, pH, and conductivity. Shifts in these constituents may negatively effect the salamander. Water quality constituent levels that could negatively affect the Barton Springs salamander should be identified with consideration of water quality data from Barton Springs and within the Barton Springs watershed. Pollutants and contaminants such as sediments, nutrients, metals, pesticides, and PAHs should also be monitored within the Barton Springs watershed and evaluated to determine when water quality changes have occurred and how these changes will affect the salamander and its habitat.

A comprehensive literature search and review should be conducted to summarize the available toxicological research on the Barton Springs salamander, its prey base, and other plant and animal species found in the Barton Springs ecosystem. Toxicity studies should be conducted to determine the full range (including the durations, concentrations, and the combinations of these) of potential effects of pollutants and contaminants. Target or threshold levels of water quality constituents needed to ensure long-term protection of the species should also be identified. Research should also evaluate sublethal effects (including those relating to reproduction, egg development, growth, and other metabolic processes) of specific constituents and contaminants and the effects of their interactions with one another (synergistically or in combination) on the Barton Springs salamander. The information collected through the implementation of this recovery action should be used in comparison to water quality monitoring data to help determine when water quality degradation has occurred or if the water quality of Barton Springs is adequate to sustain the populations of the Barton Springs salamander in its natural environment.

1.2.7 Develop and implement a land preservation strategy for the Barton Springs watershed

The preservation of undeveloped land within the Barton Springs watershed provides permanent protection for the Barton Springs salamander by reducing the threat of increased water quality degradation resulting from higher impervious cover and other non-point pollution sources caused by development. A strategy should be developed that outlines the amount of land in both the contributing and recharge zones of the Barton Springs watershed that should be protected and preserved through fee simple acquisitions, conservation easements, or deed restrictions and for evaluating which locations provide the most water quality benefits. Recommendations for maintaining open space in a manner that protects water quality should be developed as part of this strategy.

Such a strategy should also provide a socioeconomic analysis of the costs associated with purchasing land for conservation in comparison to the cost of building and maintaining infrastructure as it is constructed within the Barton Springs watershed. This analysis should include estimates of some of the ongoing costs that may occur as a result of increasing infrastructure such as providing schools, police, and utilities. An evaluation of how land prices are subject to change with increasing infrastructure would also be beneficial in determining how soon land should be purchased. A land preservation strategy also should include proposals for specific funding mechanisms for land acquisition.

2.0 Water Quantity

2.1 Gather and evaluate information necessary to ensure adequate water quantity

Additional information needs to be gathered and evaluated to ensure adequate water quantity in the Barton Springs Segment of the Edwards Aquifer at levels that protect the Barton Springs salamander and its habitat (see discussion under Section 2.1, Recovery Strategy, Sustain Water Quantity at Barton Springs).

2.1.1 Determine aquifer characteristics and recharge patterns

The City of Austin and BS/EACD dye tracing efforts should be continued to further examine groundwater divides (particularly the southern divide), sources and pathways of contamination (action 1.2.3.2), and to more precisely locate the preferred groundwater flow paths along which most of the groundwater transported converges.

2.1.2 Develop Barton Springs watershed models to predict effects of increasing impervious cover, flooding, and groundwater pumping

Due to the complex nature of the interactions between surface and groundwater, and the effects of increasing impervious cover, flooding, and groundwater removal on aquifer pathways and hydraulics, predictive models should be useful tools to evaluate potential effects of future development throughout the Barton Springs watershed. Modeling of the Barton Springs watershed should be expanded to include accurate estimates of flow rates and water quality constituent concentrations under varying development and water pumping scenarios to determine how they might influence quantity and quality of springflow. The models should include results of dye-tracing tests to provide the most meaningful, accurate, and updated analyses of aquifer conditions. The Center for Research in Water Resources Parsimonious Model (Barrett and Charbeneau 1996) provides an excellent starting point for the development of the predictive watershed model.

2.1.3 Monitor aquifer and springflow levels under normal and drought conditions

Continuous data loggers as well as site visits should be used to monitor and assess aquifer and springflow levels under normal and drought conditions to ensure that activities implemented under action 2.2.1 are resulting in adequate flow levels. This information should be used in developing and refining models mentioned in this outline under actions 2.1.2 and 2.1.7.

2.1.4 Monitor bad water line encroachment under low flow conditions

When aquifer and springflow are in low flow conditions, movement of the "bad water line" (also referred to as the saline water interface) should be monitored. Information gathered as a result of monitoring should be used to implement measures, if necessary, to ensure adequate water quantity and quality.

2.1.5 Investigate aquifer recharge enhancement potential in the recharge and contributing zones

Opportunities exist throughout the recharge and contributing zones to design and construct recharge enhancement features. One proposal is to construct large detention facilities in the Onion Creek watershed. These structures would minimize the level of flooding along downstream sections of Onion Creek and also increase the aquifer recharge potential in the recharge zone. All six contributing streams in the Barton Springs watershed should be evaluated for recharge enhancement potential. These evaluations should analyze the long-term effectiveness the recharge enhancement features would have with regard to aquifer levels.

Aquifer recharge enhancement may be a useful tool in future years to help offset drought, increased surface runoff due to expanding development, and increased pumping from the aquifer. However, careful consideration of these projects should be given because of the potential of introducing poor water quality back into the aquifer, and affecting the native terrestrial biota (for example, karst invertebrates) that may inhabit the recharge features.

2.1.6 Refine understanding of water quantity requirements for the Barton Springs salamander and determine withdrawal volumes and aquifer levels that will maintain adequate springflow

Barton Springs have never ceased flowing in recorded history. However, with increases in the level of development on the watershed it will be more difficult to ensure that flow levels will be maintained. The level of flow required to support the continued existence of the aquatic community at Barton Springs, including the Barton Springs salamander, should be defined. Neither the optimal nor critical flow levels have been determined. These flow levels should be determined, evaluated regularly, and refined, as necessary.

2.1.7 Refine understanding of water balance within the Barton Springs Segment so major sources of recharge and discharge can be located and quantified

Estimates of water balance within the Barton Springs Segment should be refined based on source areas delineated by groundwater tracing, longer continuous flow measurements upstream and downstream of each major creek channel, measurements of evapotranspiration, flow measurements from typical upland drainage sinkholes, rainfall, and pumping levels.

2.2 Design, implement, and when needed, modify measures to provide adequate water quantity to Barton Springs

Droughts are a natural occurrence in Central Texas. The effects of droughts on the Edwards Aquifer, however, may be worsened by development and other human activities on the watershed. To protect the ecosystem at Barton Springs, a comprehensive approach to management in the Barton Springs Segment would be beneficial in protecting water quantity.

2.2.1 Develop and implement a regional Aquifer Management Plan using Barton Springs watershed model predictions to ensure protection of aquifer levels and springflows under normal and drought conditions

Local governments should work together with the public and state and Federal agencies to develop measures to ensure protection of aquifer levels and springflows. Although the BS/EACD continues to manage well pumping, a comprehensive regional plan that addresses water quantity threats to the aquifer should be developed and implemented to provide protection throughout the contributing and recharge zones. Groundwater pumping limits during periods of normal rainfall and drought should be addressed and outlined in this plan. Research may be necessary to determine how much pumping can be sustained during drought conditions while ensuring the long-term survival of the Barton Springs salamander and its ecosystem.

Vegetation management practices such as brush control that can be used to preserve or maintain the native ecological community in the recharge zone of the Barton Springs watershed and allow for the most beneficial effects to water quantity also should be evaluated and addressed in this plan. The BS/EACD would be a good candidate to take a lead role in developing these protection measures.

2.2.2 Develop, implement, and modify measures to protect existing recharge features from plugging and filling

Major recharge features in the creek channels can be plugged by sediment and debris, particularly when they are situated downstream of disturbed areas. While most of the aquifer recharge occurs within the creek channels, some recharge enters the aquifer through sinkholes, caves, dissolution cavities, and other features in the upland areas. Efficient upland recharge is important because the creeks have limited infiltration capacities, causing excess water to leave the recharge zone as downstream runoff. The destruction, plugging, or filling of recharge features and the loss of natural drainage features can have long-term effects on water quantity in the Barton Springs Segment of the Edwards Aquifer. Innovative and nondestructive methods of infiltrating high quality runoff (such as diverting drainages into existing, unused quarries and sinkholes, and opening sediment filled sinkholes in creek bottoms) should be developed, implemented, and, as necessary, modified. A plan detailing protection and restoration measures for these recharge features should be prepared to help sustain continuous spring flows.

3.0 Surface Habitat Management

3.1 Maintain a comprehensive database on the spring habitats of the Barton Springs salamander

The City of Austin maintains a database of monthly salamander survey data. This database should continue to include comprehensive information about the spring ecosystem, such as substrate composition, plant/animal composition, salamander survey information, and the effects of management practices on the spring sites. The Service and City of Austin should conduct an annual review of this database and adapt salamander or spring ecosystem management (action 3.4) as necessary.

3.2 Monitor the health and stability of the salamander prey base

Data exist on the food habits of the Barton Springs salamander, but additional information is needed to assure adequate management of the species and its habitat. The distribution, abundance, and microhabitat preferences of potential prey items should be studied, as well as the nature and degree of prey selection by the Barton Springs salamander.

3.3 Implement research programs to further study the habitat requirements of the Barton Springs salamander

The City of Austin, Service, and other appropriate parties should continue monitoring and research to determine the reproductive, nutritional, and ecological requirements of the Barton Springs salamander. Data on habitat features necessary for survival and reproduction will improve long-term management of the species. Although general habitat features are known, more information is needed about the characteristics and breadth of the niche occupied by these salamanders, their position in the food web and their interaction with the aquatic ecosystem as a whole.

3.4 Continue to monitor, manage, and provide protection for existing spring habitats, and modify management actions when new information warrants changes

The City of Austin should continue its efforts to protect, manage, and restore the four spring sites using information maintained in the database described in action 3.1, primary scientific literature, and salamander research. Monitoring data also should be used to modify the current measures to protect salamander habitat if warranted.

4.0 Salamander Monitoring and Research

4.1 Implement research programs to determine the life history characteristics (for example, fecundity, mortality, longevity, age/size at maturity, and growth rate) that govern population dynamics (such as, intrinsic rate of increase/decrease and population viability) of the Barton Springs salamander

Additional life history and demographic data are needed to accurately assess the status and long-term trends of Barton Springs salamander populations and to effectively manage captive populations. Studies should include determining if subsurface movement occurs among the four springs sites; accurately estimating effective population size, extinction probabilities, sex ratios in the wild, fecundity ratio (percent of females producing offspring at any one point in time), and percent of breeding males; and determining if breeding is density-dependent. This information will be useful in conducting a population viability analysis of the salamander.

4.1.1 Monitor Barton Springs salamander populations in the wild to ensure long-term stability and viability

Information on the number of juveniles and adults found at each spring site should continue to be collected during the City of Austin's monthly surveys. Although population estimates are not feasible, surveys might provide valuable trend information. These data should be analyzed and the results used to determine whether adequate reproduction is occurring and whether the objective of maintaining a stable or increasing population has been obtained.

4.1.2 Explore and develop marking techniques and conduct mark/recapture research

Mark and recapture methods are useful in identifying and tracking individual salamanders in the wild population. These data can be used to estimate population size, growth rates and mortality, and document territorial behavior or migration events between different spring sites. The ability to track and identify animals as small as the Barton Springs salamander poses unique challenges. Standard methods used for larger animals such as radio-tracking and PIT (passive integrated transponder) tagging are currently not feasible for the salamander. City of Austin biologists have developed an identification technique based on photographing external pigment patterns. The technique appears to be feasible in the field, but is time-consuming. Existing and new marking techniques such as the use of visible implant elastomers should be explored and evaluated for utility and efficiency in studying the Barton Springs salamander.

4.1.3 Determine gene flow and migration between the four spring sites and genetic variation within and among the sites

Using information developed from genetic research (action 4.1.6) and mark/recapture (action 4.1.2) studies, salamander migration among the four spring habitats should be evaluated to determine if the populations are discrete or part of a larger population linked by dispersal. If salamanders are found to move between sites, efforts should be made to determine what influences preference for one site over another (for example, seasonal changes, water quality, or gas saturation). This information is also needed to determine how to manage captive populations to optimize genetic diversity. For example, should captive populations be maintained separately or pooled?

4.1.4 Investigate effects of various flow levels, especially low flows, on the salamander and spring ecosystem

The City of Austin should continue monthly monitoring of salamander populations at all four spring sites and quantify changes in the composition of the ecosystem. The relationship of changes to flow conditions should be analyzed and the potential long-term effects of water quantity on salamander abundance should be evaluated. This information should be used to develop and implement management practices that will ensure adequate water quantity to support a stable salamander population and ecosystem.

4.1.5 Investigate the reproductive and other life history characteristics of the Barton Springs salamander

Information on the reproductive characteristics of the salamander is needed to better understand the dynamics of population change and to evaluate the positive or negative effects of environmental factors in species recovery. Fecundity, fecundity ratio (the number of females in the population that are gravid at any one time), reproductive seasons, if any, oviposition (egg-laying) behavior and site selection, factors influencing egg hatching, larval growth characteristics, influence of nutrient availability on reproductive success, and others are important aspects of reproduction that will contribute to effective management of wild populations and further the development of the Captive Propagation and Contingency Plan (action 5.1).

Other life history characteristics of the Barton Springs salamander should be researched so that the population dynamics of the species are better understood. Such characteristics may include fecundity, mortality, longevity, age/size at maturity, and growth rate.

Information on these characteristics would be beneficial in conducting a population viability analysis to assess the success of the recovery program for the species.

4.1.6 Investigate the genetic characteristics and variation in the Barton Springs salamanders at the individual and population level

Genetic analyses will help determine the effective size of the current population of the Barton Springs salamander and its potential to adapt to changes in the environment. This type of information will also contribute to understanding the movement patterns between the four springs sites and whether individuals from different sites interbreed. The City of Austin should continue to work closely with salamander and captive breeding experts to further understand the genetic diversity of the species and foster cooperative research with other institutions to increase knowledge of the species. Continued research is also essential in designing the CPCP (action 5.1) and a reintroduction program so that captive populations adequately represent the genetic characteristics of the wild population.

4.1.7 Conduct a population viability analysis of the Barton Springs salamander

Information collected through the implementation of other actions such as 4.1.2, 4.1.3, 4.1.5, and 4.1.6 should be used to conduct a population viability analysis for the Barton Springs salamander. Such a comprehensive analysis of environmental and demographic characteristics should provide extinction probabilities for the species in its natural ecosystem. This will help assess the success of the recovery program for the salamander.

4.2 Investigate the prevalence, character, and cause of gas saturation in the water of spring habitats in the Barton Springs watershed

Evidence of gas supersaturation of water at all four spring sites was noted in 2002 after the discovery of salamanders with gas bubble trauma. Supersaturation levels were particularly pronounced at Upper Barton Springs (which lies along a more urbanized flow path). Baseline data on the temporal and spatial variation of dissolved gases at Barton Springs and other springs in the Edwards Aquifer, including the Northern Segment and San Antonio Segment, should be collected and analyzed. Weekly collection of temperature, pH, gas saturation, and gas composition data should continue as part of the City of Austin's monitoring program. Data should be collected from within the Edwards Aquifer including wells that lie along the flowpath of Upper Barton Springs. Information collected through the implementation of this action should be conducted to help determine the causes, effects, and prevention of gas bubble trauma (actions 4.3 and 4.4).

4.3 Determine the short and long-term impacts of gas bubble trauma on the Barton Springs salamander

Salamanders and other animals affected by gas bubble trauma in Barton Springs were first observed and documented in February 2002. The majority of affected animals were found at Upper Barton Springs, which had the highest supersaturation among Barton Springs salamander sites. Multiple species were affected and veterinary pathologists found no evidence of a pathogenic cause. However, it is unclear to what extent the condition may have been in the population previously because affected salamanders may be difficult to find due to predation or decomposition. Laboratory experiments should be conducted using similar species to determine the acute and chronic effects of gas bubble trauma on Barton Springs salamanders. Searches of the spring areas for salamanders and other aquatic animals with gas bubble trauma should be conducted. Any live salamanders found in bloated condition should be maintained in the City of Austin's captive breeding facility and monitored for improvement or complicating factors. Whenever possible, dead salamanders should be preserved for use in pathology studies, genetic research (action 4.1.6), or investigations into the potential causes of gas bubble trauma.

4.4 Develop and implement actions that prevent, avoid, or minimize the effects of gas bubble trauma on the Barton Springs salamander and other aquatic life in the spring ecosystem

After the cause(s) and prevalence of gas bubble trauma are determined, the City of Austin and other appropriate entities should use this information and that from action 4.2 and 4.3 to develop and implement measures that prevent, avoid, or minimize gas bubble trauma in Barton Springs salamanders and other aquatic life in the spring ecosystem.

5.0 Captive Breeding

5.1 Develop a comprehensive Barton Springs salamander captive propagation and contingency plan consistent with the Service's *Policy Regarding Controlled Propagation of Species Listed Under the Endangered Species Act*

A comprehensive CPCP should be developed to establish captive maintenance and breeding programs and a reintroduction strategy for the Barton Springs salamander. The goal of the captive propagation portion of the CPCP will be to outline the steps necessary to provide a representation of the genetic characteristics of the wild population should reintroduction be necessary. Although holding individuals in captivity is not a substitute for maintaining the species by protecting the ecosystem on which it depends, a captive maintenance program is important for this species for maintaining stock should a large scale die-off take place in the wild. Additionally, the development of captive breeding techniques will provide an opportunity to identify additional information on the biology of the species, including early life stage characteristics.

The contingency portion of the CPCP also will establish the collection targets and protocols needed to respond to crisis situations. Contingency planning should not be delayed until the completion of genetic, breeding, and reintroduction studies, but should be updated as these studies are completed. The CPCP should be developed in coordination with agencies that would likely be involved with the collection efforts, including the City of Austin, Texas Parks and Wildlife Department, Service, and experts from academic institutions with expertise in determining collection levels that will represent enough genetic diversity to keep the population viable. City of Austin biologists are developing a “salamander rescue” plan to be used in the event of a catastrophic spill and will modify this plan as new information becomes available.

The CPCP needs to address four situations: (1) captive rearing of animals during non-crisis times in the event of a rapidly developing crisis when there is no time to collect wild animals; (2) collection and captive rearing of animals as a response to a rapidly developing crisis in which there is time to collect additional wild animals; (3) collection and captive rearing of animals in response to a slowly developing crisis; and (4) captive rearing of animals during non-crisis times without a developing crisis (standard operating procedures). A commitment to long-term management of a captive population is needed due to the limited range of the species and the on-going potential of a catastrophic event occurring at the spring sites that could decimate the wild salamander population.

The City of Austin has established a captive breeding program for the Barton Springs and Austin blind salamanders and is committed to its continued funding and operation. Longhorn Partners Pipeline L. P. has provided funds for the establishment and maintenance of a captive breeding facility at the NFHTC in San Marcos, Texas. City of Austin biologists are working with the American Zoo and Aquarium Association to develop a plan to manage the breeding of the species to maintain a viable population that is both genetically diverse and demographically stable. City of Austin biologists should work with Service biologists, once the captive breeding program is operational at NFHTC, to ensure a viable population is maintained at the new facility.

Identifying facilities interested in participating in both the captive propagation and contingency portions of the CPCP is necessary for its success. Because the City of Austin operates, manages, and monitors the springs, any salamander collection efforts would need to be coordinated with the City of Austin. Institutions involved in collection efforts would need to hold appropriate state and Federal permits. For each facility, a Participation Plan should be developed in coordination with the Service and City of Austin that outlines the level of commitment to cooperate (long-term versus short-term holding facilities), personnel willing to collect and transport animals, research to be conducted, and level of information to be collected. The CPCP and Participation Plans should be periodically re-assessed (for example, annually) and altered as necessary.

5.2 Develop dependable captive breeding and reintroduction techniques

Although the Barton Springs salamander has been bred in captivity, dependable techniques for controlled captive breeding have not been developed. These techniques need to be developed to ensure that offspring will be available for reintroduction should it be necessary. City of Austin biologists and other participants in the CPCP should continue to explore breeding techniques as well as detailed records on egg-laying events and salamander courtship behavior.

Consideration should also be given to post-release survival of individuals that are reintroduced into the wild. Techniques should be developed to maximize the ability of captive-reared salamanders to survive in the wild after they are reintroduced. Such techniques should address predator avoidance, foraging, interactions with members of the same species, and interactions with other species. Salamanders that are reintroduced into the wild should be monitored closely in perpetuity to ensure the population is viable. A plan to monitor salamanders reintroduced back into the wild should be in place prior to their release.

5.3 Establish, maintain, and monitor captive breeding populations to maintain adequate captive populations

At least two captive breeding facilities should be established as quickly as possible in accordance with the CPCP. Maintenance of captive breeding facilities will likely be needed even if the species is delisted, to serve as back-up should a catastrophic spill or other event threaten to decimate the species. A commitment to fund and maintain an adequate captive breeding program for the long term is necessary. The number of individuals in captivity and effectiveness of captive breeding programs should be monitored. Each captive breeding site should track the collection site (or collection site of parentage, if born in captivity), sex, reproductive condition, egg laying events, hatching, survivorship, and mortality information for each salamander. Captive salamander populations should be monitored closely for disease and other health concerns. If reintroduction is deemed necessary, precautions should be taken to ensure the individuals to be introduced are not bringing disease or other harmful agents into the wild.

In addition to requiring reliable breeding success, other factors to be considered in determining a long-term viable population include diseases, genetic variability in the wild, age at first reproduction, percent of females producing young, percent of males in the breeding pool, clutch size, fecundity, factors influencing egg hatching and juvenile survivorship, and whether breeding is density-dependent. A general rule of thumb commonly obtained from conservation biology literature prescribes a minimum short-term effective population of 50 individuals to prevent a level of inbreeding that could result in decreased fitness of the population (Soulé 1980) and a minimum long-term effective population of 500 to maintain overall genetic diversity (Franklin 1980). Effective population size generally refers to individuals that contribute offspring to a population. Thus, if only 10 percent of the individuals in a population reproduce, the 50/500 rule would translate to a short-term minimum viable population of over 500 individuals. Adequate space, equipment, and water are critical to supporting a viable captive population. New information should be reviewed and new study techniques should be implemented. Captive breeding programs should be modified when new information becomes available.

6.0 Public Outreach and Education

6.1 Develop, evaluate, and update education and outreach programs and materials to increase public awareness about the Barton Springs salamander and its habitat

The Austin Science and Nature Center operates the "Splash!" Exhibit and other programs designed to educate the public on the salamander and the Edwards Aquifer. The programs should focus on a variety of topics such as the biology and ecology of the Barton Springs salamander and its sympatric species, the ecosystem of the Edwards Aquifer, the hydrology of the Edwards Aquifer region, and the natural and cultural histories of the Edwards Aquifer region. These efforts should be continued and modified as new information becomes available. Efforts to develop new outreach materials on the salamander, the aquifer, good land-use and watershed protection practices, and water quality should be encouraged and supported.

6.2 Develop, evaluate, and disseminate information about how to avoid spills and other sources of water quality degradation within the Barton Springs watershed

Whether it is information about responsible recycling of potentially hazardous household materials like engine oil, batteries, and pest control substances or information about new technology available to be used by dry cleaners or oil and gas companies, continued education on how individuals and corporations can do their part to ensure spills and other contaminants do not reach the aquifer is important. Outreach efforts by the City of Austin, TCEQ, local businesses, and others should be encouraged, supported, and expanded where possible.

7.0 Post-delisting monitoring

7.1 Develop a post-delisting monitoring plan for the Barton Springs salamander

Section 4 (g) (1) of the ESA requires that the Service monitor the status of all recovered species for at least five years following delisting. In keeping with this mandate, a post-delisting monitoring plan should be developed by the Service in cooperation with Texas Parks and Wildlife Department, the Barton Springs Salamander Recovery Team, Federal agencies, academic institutions, and other appropriate entities. This plan should outline the indicators that will be used to assess the status of the Barton Springs salamander (considering population numbers and threat monitoring), develop monitoring protocols for those indicators, and evaluate factors that may trigger consideration for relisting.

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4.0 IMPLEMENTATION SCHEDULE

The Implementation Schedule that follows outlines actions and estimated costs for implementing this recovery plan. It is a guide for meeting the objectives discussed in the recovery section (Section 2.0) of this plan. This schedule indicates action priorities, action numbers, action descriptions, duration of actions, potential partners, and estimated costs. These actions, when complete, should accomplish the objectives of this plan. The Service has identified agencies and other potential partners to help implement the recovery of this species. This plan does not commit any partners to actually carry out a particular recovery action or expend the estimated funds. Likewise, this schedule does not preclude or limit other agencies or parties from participating in the recovery program.

The estimated cost of recovery, according to each priority, is provided in the Executive Summary. The Implementation Schedule contains the estimated monetary needs for all parties involved in recovery for the first 10 years only. Estimated funds for agencies include only project specific contract, staff, or operations costs in excess of base budgets. They do not include budgeted amounts that support ongoing agency staff responsibilities.

Cost for some actions in the recovery plan are not yet determinable, because they depend on the nature of the strategies selected for use. These actions where expenses cannot yet be calculated are represented in the costs column with the designation NYD for “not yet determinable.”

The term “continuous” is used to denote actions that are expected to require constant attention throughout the recovery process, and therefore have an indefinite duration. The term “ongoing” is used in the recovery plan to identify actions that have already been started, but are not yet complete.

Priorities in column one of the following implementation schedule are assigned using the following guidelines:

Priority 1(a) - An action that must be taken to prevent extinction or to prevent the species from declining irreversibly in the *foreseeable* future.

Priority 1(b) - An action that by itself will not prevent extinction, but which is needed to carry out a Priority 1(a) action.

Priority 2 - An action necessary to prevent a significant decline in species population/habitat quality, or some other significant negative impact short of extinction.

Priority 3 - All other actions necessary to meet the recovery objectives.

Actions and action numbers are taken from the Recovery Action Outline and Recovery Action Narrative (sections 2.3 and 2.4). The terms and acronyms used for the potential partners for implementation are listed below:

BS/EACD	Barton Springs/Edwards Aquifer Conservation District
CoA	City of Austin
EPA	U.S. Environmental Protection Agency
HCo	Hays County
LCRA	Lower Colorado River Authority
NRCS	Natural Resource Conservation Service
TxDOT	Texas Department of Transportation
TXSt	Texas State University-San Marcos
TCEQ	Texas Commission on Environmental Quality
TCo	Travis County
TPWD	Texas Parks and Wildlife Department
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UT	University of Texas at Austin

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s) (2 year totals)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
1(a)	1.1.3	Develop and implement a catastrophic spill avoidance plan	2 to develop; continuous	TxDOT, TCEQ, EPA, HCo, TCo, CoA, and other jurisdictions, USFWS	80	40	10	10	10	10	
1(a)	1.1.4	Develop and implement a comprehensive regional spill containment and remediation plan	2 to develop; continuous	CoA and other jurisdictions, TCEQ, EPA, TxDOT, HCo, & TCo	110	30	20	20	20	20	
1(a)	1.1.5	Implement effective maintenance procedures for existing and future spill containment structures	continuous	CoA and other jurisdictions, TCEQ, EPA, TxDOT, HCo, & TCo	70	30	10	10	10	10	
1(a)	1.2.1	Develop and implement a regional approach to water quality protection that encompasses the entire Barton Springs watershed	2 to develop; continuous	CoA and other jurisdictions, HCo, TCo, LCRA, BS/EACD, TxDOT, TCEQ	280	200	20	20	20	20	

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s) (2 year totals)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
1(a)	1.2.4.4	Implement programs to protect critical environmental features (caves, sinkholes, fissures, springs, and riparian zones)	continuous	CoA and other jurisdictions, TCEQ, EPA, USFWS	175	75	25	25	25	25	
1(a)	1.2.4.5	Reduce pollutant loading from existing development and transportation infrastructure	continuous	CoA and other jurisdictions, HCo, TCo, LCRA, TxDOT	250	50	50	50	50	50	
1(a)	1.2.5	Develop, implement, and modify programs to identify and correct problems from point and non-point source discharges	3 to develop; continuous	CoA and other jurisdictions, TCEQ, EPA, USFWS, USGS	225	90	45	30	30	30	

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s) (2 year totals)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
1(a)	1.2.7	Develop and implement a land preservation strategy for the Barton Springs watershed	2 to develop; 10 to implement	CoA, HCo, TCo, and other appropriate entities	60	60					estimated cost is given only for strategy development; does not reflect cost associated with acquiring land
1(a)	2.2.1	Develop and implement a regional Aquifer Management Plan using Barton Springs watershed model predictions to ensure protection of aquifer levels and springflows under normal and drought conditions	3 to develop; continuous	BS/EACD, TCEQ, CoA, USFWS, and other jurisdictions	300	100	50	50	50	50	

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s) (2 year totals)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
1(a)	3.4	Continue to monitor, manage, and provide protection for existing spring habitats, and modify management actions when new information warrants changes	ongoing	CoA, TPWD, USFWS	250	50	50	50	50	50	
1(a)	5.3	Establish, maintain, and monitor captive breeding populations to maintain adequate captive populations	ongoing; continuous	CoA, USFWS, Longhorn Partners Pipeline, and other appropriate entities	375	75	75	75	75	75	should be performed in accordance with action 5.1
1(b)	1.1.1	Identify, field verify, and map stream crossings and major recharge features and potential sources of catastrophic spills	3	TxDOT, TCEQ, EPA, HCo, TCo, CoA, and other jurisdictions	200	150	50				supports actions 1.1.3 and 1.1.4

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s) (2 year totals) Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	Comments
1(b)	1.1.2	Develop a comprehensive database to track potential sources of spills that occur in the Barton Springs watershed	2 to develop; continuous	TxDOT, TCEQ, EPA, HCo, TCo, CoA, and other jurisdictions, USFWS	130	50	20	20	20	20	supports actions 1.1.3 and 1.1.4
1(b)	1.2.2	Maintain a comprehensive water quality database for the Barton Springs watershed to house water quality information and evaluate the data to use in adaptive management actions to ensure long-term water quality protection	continuous	TCEQ, EPA, USGS, USFWS, TPWD, UT, CoA and other jurisdictions	100	20	20	20	20	20	supports actions 1.2.1 and 1.2.5

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s) (2 year totals)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
1(b)	1.2.3.1	Evaluate sediment quality at specific sites throughout the Barton Springs watershed	continuous	USGS, TCEQ, EPA, LCRA, TxDOT, CoA	125	25	25	25	25	25	supports actions 1.2.1, 1.2.5, and 3.4
1(b)	1.2.3.2	Determine chronic and acute contaminant transport through the aquifer and potential interactions with salamander habitat	2	USGS, TCEQ, EPA, LCRA, TxDOT, CoA, TPWD, BS/EACD	50	50					supports actions 1.2.1 and 1.2.5
1(b)	1.2.3.3	Conduct baseflow, stormwater, and biological monitoring at the springs and at sites throughout the Barton Springs contributing and recharge zones	continuous	USGS, TCEQ, EPA, LCRA, TxDOT, CoA, TPWD, BS/EACD	100	20	20	20	20	20	supports actions 1.2.1 and 1.2.5

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s) (2 year totals)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
1(b)	1.2.4.1	Monitor and evaluate the compliance of existing regulations requiring the use of BMPs and the effectiveness of new and existing BMPs on minimizing sediment and other contaminant input into the aquifer and contributing streams	continuous	TCEQ, EPA, CoA and other jurisdictions, LCRA, TxDOT, USGS	125	25	25	25	25	25	supports actions 1.2.1, 1.2.5, and 3.4
1(b)	1.2.4.2	Monitor and evaluate the effectiveness of pollution mitigation programs	continuous	TCEQ, EPA, CoA and other jurisdictions, LCRA, USGS	100	20	20	20	20	20	supports actions 1.2.1, 1.2.5, and 3.4
1(b)	1.2.4.3	Evaluate buffer zone size and location for sensitive environmental features	2	TCEQ, EPA, CoA and other jurisdictions, LCRA, USGS	60	60					supports actions 1.2.1, 1.2.5, and 3.4

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s) (2 year totals)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
1(b)	1.2.4.6	Monitor and evaluate the extent and effects of impervious cover	continuous	CoA and other jurisdictions, TCEQ, EPA, USFWS, USGS	175	75	25	25	25	25	supports actions 1.2.1 and 1.2.5
1(b)	1.2.6	Use existing information and conduct research to determine the potential effects of different levels of water quality constituents, pollutants, and contaminants on the Barton Springs salamander, its prey base, and its habitat	3	CoA, EPA, TCEQ, USFWS, HCo, TCo, and other jurisidictions	150	100	50				supports actions 1.2.1 and 1.2.5
1(b)	2.1.1	Determine aquifer characteristics and recharge patterns	ongoing; 2 to complete study	BS/EACD, CoA, USGS	30	30					supports action 2.2.1

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s) (2 year totals)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
1(b)	2.1.2	Develop Barton Springs watershed models to predict effects of increasing impervious cover, flooding, and groundwater pumping	3	TCEQ, EPA, BS/EACD, CoA, USFWS, TPWD, USGS	150	100	50				supports actions 1.2.1 and 2.2.1
1(b)	2.1.3	Monitor aquifer and springflow levels under normal and drought conditions	ongoing	TCEQ, EPA, BS/EACD, CoA, USFWS, USGS	100	20	20	20	20	20	supports action 2.2.1
1(b)	2.1.6	Refine understanding of water quantity requirements for Barton Springs salamander and determine withdrawal volumes and aquifer levels that will maintain adequate springflow	3	USGS, BS/EACD, CoA, TCEQ, EPA, TPWD, USFWS	90	60	30				supports action 2.2.1

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s) (2 year totals)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
1(b)	2.1.7	Refine understanding of water balance within the Barton Springs Segment so that major sources of recharge can be better located and quantified	3	USGS, UT BS/EACD, CoA, TCEQ, EPA	90	60	30				supports actions 2.2.1 and 2.2.2
1(b)	3.2	Monitor the health and stability of the salamander prey base	ongoing; continuous	CoA, USFWS, TPWD, TCEQ	100	20	20	20	20	20	supports action 3.4
1(b)	3.3	Implement research programs to further study the habitat requirements of the Barton Springs salamander	5	CoA, USFWS, TPWD, UT	200	75	75	50			supports action 3.4
1(b)	4.1.4	Investigate effects of various flow levels, especially low flows, on the salamander and the spring ecosystem	continuous	CoA, BS/EACD, UT, USFWS, TPWD	125	25	25	25	25	25	supports action 2.2.1

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s) (2 year totals)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
1(b)	5.1	Develop a comprehensive Barton Springs salamander captive propagation and contingency plan consistent with the Service's *Policy Regarding Controlled Propagation of Listed Species Listed Under the Endangered Species Act*	2	CoA, UT, TXSt, USFWS, TPWD	150	150					supports action 5.3
1(b)	5.2	Develop dependable captive breeding and reintroduction techniques	ongoing	CoA, UT, TXSt, USFWS	200	40	40	40	40	40	supports action 5.3
2	2.1.4	Monitor bad water line encroachment under low flow conditions	continuous	USGS, CoA, TCEQ, EPA, BS/EACD	150	30	30	30	30	30	supports action 2.2.1

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s) (2 year totals)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
2	2.1.5	Investigate aquifer recharge enhancement potential in the recharge and contributing zones	3	USGS, BS/EACD, CoA, TCEQ, EPA	90	60	30				supports action 2.2.1
2	2.2.2	Develop, implement, and modify measures to protect existing recharge features from plugging and filling	2 to develop; continuous	BS/EACD, EPA, TCEQ, CoA, USFWS	110	50	15	15	15	15	
2	3.1	Maintain a comprehensive database on the spring habitats of the Barton Springs salamander	ongoing; continuous	CoA, USFWS, TPWD	100	20	20	20	20	20	supports action 3.4
2	4.1.1	Monitor Barton Springs salamander populations in the wild to ensure long-term stability and viability	ongoing; continuous	CoA, USFWS, TPWD, UT	100	20	20	20	20	20	supports action 3.4

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s) (2 year totals)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
2	4.1.2	Explore and develop marking techniques and conduct mark/recapture research	ongoing; 4 to complete	CoA, USFWS, TPWD, UT	50	25	25				supports action 3.4
2	4.1.3	Determine gene flow and migration between the four spring sites and genetic variation within, and among, the sites	2	CoA, USFWS, TPWD, UT, USGS,	50	50					supports action 3.4
2	4.1.5	Investigate the reproductive and other life history characteristics of the Barton Springs salamander	ongoing; 4 to complete	CoA, USFWS, TPWD, UT	80	40	40				supports actions 3.4 and 5.1
2	4.1.6	Investigate the genetic characteristics and variation in the Barton Springs salamander at the individual and population level	4	CoA, USFWS, TPWD, UT	80	40	40				supports actions 3.4 5.1

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s) (2 year totals)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
2	4.1.7	Conduct a population viability analysis of the Barton Springs salamander	1	USGS-Biological Resources Division, USFWS, CoA, TPWD	80	80					
3	4.2	Investigate the prevalence, character, and cause of gas saturation in the water of spring habitats in the Barton Springs watershed	4	TCEQ, EPA, UT, CoA, USFWS, TPWD, USGS, BS/EACD	100	50	50				supports action 3.4
3	4.3	Determine the short and long-term impacts of gas bubble trauma on the Barton Springs salamander	2	TCEQ, EPA, UT, CoA, USFWS, TPWD, USGS,	40	40					supports action 3.4

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s) (2 year totals)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
3	4.4	Develop and implement actions that prevent, avoid, or minimize the effects of gas bubble trauma on the Barton Springs salamander and other aquatic life in the spring ecosystem	3 to develop; continuous	CoA, EPA, TCEQ, TPWD, USFWS	90	40	20	10	10	10	supports action 3.4
3	6.1	Develop, evaluate, and update education and outreach programs and materials to increase public awareness about the Barton Springs salamander and its habitat	ongoing continuous	CoA and other jurisdictions, USFWS, TPWD	125	25	25	25	25	25	

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s) (2 year totals)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
3	6.2	Develop, evaluate, and disseminate information about how to avoid spills and other sources of water quality degradation within the Barton Springs watershed	ongoing continuous	TCEQ, EPA, LCRA, NRCS, USDA, USFWS, TPWD, CoA and other jurisdictions, HCo, and TCo	250	50	50	50	50	50	
3	7.1	Develop a post-delisting monitoring plan for the Barton Springs salamander	2	USFWS, CoA, BS/EACD, TPWD, USGS, TCEQ, HCo, TCo, and other appropriate entities	50	25	25				

Appendix A - Degradation of selected water quality constituents at Barton Springs (City of Austin 2000, 2005).

		Normalized period median values			
Water quality Constituent	**Flow Condition**	**1975-1979 or 1980-1984**	**1995-1999**	**Change From Early to Late Period**	**Percent Change**
Specific conductance (microsiemens per centimeter)	Baseflow without recharge	655	677	22	+3%
	Baseflow with recharge	590*	646	56	+9%
	Storm flow	624	642	18	+3%
Dissolved oxygen (parts per million)	Baseflow without recharge	6.8	5.7	-1.1	-16%
Total organic carbon (parts per million)	Storm flow	1.5	3.4	1.9	+127%
Sulfate (parts per million)	Baseflow with recharge	28.3*	38.8	10.5	+37%
Turbidity (nephelometric turbidity units)	Storm flow	5.3	7	1.7	+32%

*Note: Data for 1981 and 1982 removed from analysis because of effects due to sewer line break

Appendix B - Median concentrations and densities of selected water quality constituents during the rising and falling stages of stormflow for four development classifications within the Barton Springs watershed (Veenhuis and Slade 1990).

Impervious Cover	**Dissolved Solids (mg/l)**		**Suspended Solids (mg/l)**		**Biochemical Oxygen demand (mg/l)**		**Total Organic Carbon (mg/l)**	
	Rising Stage	**Falling Stage**	**Rising Stage**	**Falling Stage**	**Rising Stage**	**Falling Stage**	**Rising Stage**	**Falling Stage**
<1%	not detected	245	not detected	6	not detected	0.95	not detected	4
2 to 7%	160	200	508	120	2.7	1.6	14	7.6
9 to 20%	200	180	1280	236	6.2	4.1	29	13
>40%	140	130	1690	410	15	6	38	18

Impervious Cover	**Total Nitrogen (mg/l)**		**Total Phosphorus (mg/l)**		**Fecal Coliforms (colonies/100 ml)**		**Fecal Streptococci (colonies/100 ml)**	
	Rising Stage	**Falling Stage**	**Rising Stage**	**Falling Stage**	**Rising Stage**	**Falling Stage**	**Rising Stage**	**Falling Stage**
<1%	not detected	0.5	not detected	0.02	not detected	1000	not detected	1200
2 to 7%	1.6	1.15	0.12	0.05	22000	3700	29000	7600
9 to 20%	3.6	2	0.56	0.26	24500	30000	54000	48000
>40%	4.3	2.15	1.35	0.45	110000	42000	180000	75000

Appendix C
Comments on the Draft Recovery Plan and Responses

Public Review

A draft of this recovery plan was published and distributed for review by all interested parties. The Service published a notice in the Federal Register on January 25, 2005 (70 FR 3548-3550) to announce that the document was available for public review and comment. The comment period lasted for 60 days and closed on March 28, 2005. An electronic version of the draft recovery plan was posted on the Service's Southwest Region website and national website. In addition, we posted a fact sheet, questions and answers document, and a press release on the regional website. Over 100 post cards were mailed to interested parties announcing the availability of the document. We distributed the press release to local news organizations. We mailed out several hard copies of the plan as requests were received.

Peer Review

We asked 10 individuals to serve as peer reviewers of the document. Three provided comments. Depending on their expertise, peer reviewers were asked to review and comment on: (1) issues and assumptions relating to the biological or hydrological information in the plan's Background section; (2) scientific data regarding the proposed recovery activities in the Recovery Criteria and Recovery Action Outline sections; and (3) technical feasibility of the proposed recovery activities in the Recovery Criteria and Recovery Action Outline sections. The qualifications of the peer reviewers are in the administrative record for this plan.

Public Comments Received

We received six responses during the comment period from interested parties.

Responses to Comments

Some comments provided were outside of the scope of the recovery planning process. For example, some comments pertained to the recovery priority number of the species or encouraged the Service to fund or enforce the recovery actions recommended in the recovery plan. Other comments pertained to collaborative efforts or biological consultations between the Service and other agencies or addressed previous drafts of the recovery plan that were not made available for public review and comment. Some commenters suggested editorial changes to the text of the Recovery Plan, and the final Recovery Plan has been revised to incorporate many of these suggestions. Some commenters suggested clarifications, and where possible, we tried to clarify the document. The remaining substantive comments were taken into consideration in this final version of the Recovery Plan, and specific responses are provided below. Several of the comments were similar in nature and were combined and summarized for brevity. Comments are arranged into five categories based on the related topics of the comments: threats; recovery strategy, criteria, and recovery actions; implementation schedule and priorities; miscellaneous technical comments; and general comments.

A. Threats

A.1 Comment: The plan maintains an implicit non-degradation of water quality standard for recovery of the salamander despite the fact that the primary reason for listing the species in 1997 was then existing water quality degradation. There should be an explicit recognition of at least the possible need to *improve* certain water quality parameters. Also, wording in the Recovery Criteria should be changed to "The Barton Springs watershed is sufficiently protected to achieve and maintain adequate water quality."
Response: The plan acknowledges some documented changes in water quality in Barton Springs. It also specifically calls for the need to "protect" or "maintain" water quality at Barton Springs to ensure the long-term survival of the Barton Springs salamander. The Service believes that this terminology describes the need that water quality at Barton Springs must be adequate before the species is delisted. However, because there is not enough information to indicate if the current water quality conditions at Barton Springs are affecting the salamander, downlisting criterion 1 under Objective 1 was changed to specifically state that water quality may need improvement.

A.2 Comment: The LCRA's existing and proposed water pipelines should be described under the water quality threats sections due to their facilitation of sprawl over the recharge and contributing zones.
A.3 Comment: The threats section should include a discussion of the LCRA waterline and the Longhorn Pipeline. Both of these projects surfaced as major issues after publication of the Final Rule listing the Barton Springs salamander as endangered.
Response: The Service evaluated the Longhorn Pipeline project and determined that it was "not likely to adversely affect" any federally-listed species. Also, the LCRA has completed a biological opinion with the Service and have been issued an incidental take permit for their effects to the Barton Springs salamander. To mention either of these projects specifically in the recovery plan as major threats to water quality degradation would be inconsistent with the Service's earlier determinations.

A.4 Comment: Specific criteria for watershed protection such as impervious cover limitations and buffer zone sizes should be incorporated into the plan. Without these, the plan is not consistent with the ESA's mandate for providing objective, measurable criteria.
A.5 Comment: Add an objective that calls for the establishment and implementation of a land acquisition program that ensures impervious cover levels in the recharge and contributing zones not to exceed 15 and 20 percent.
Response: The Service believes that decisions regarding these types of recommendations could more effectively be determined during a regional approach specifically directed at achieving water quality for the Barton Springs Segment of the Edwards Aquifer that allows for more extensive stakeholder and expert participation. Recovery actions in the plan call for the evaluation of buffer zone widths and impervious cover limits to determine their adequacy to protect water quality in the Barton Springs watershed. Further, the Service has provided recovery criteria in Section 2.2 of the recovery plan that are objective and measurable. Delisting criterion 1A recommends that the mechanisms set forth to protect water quality at Barton Springs must be shown to be effective; therefore, no matter what specific water quality mechanisms are

in place, their effectiveness in protecting the salamander must be demonstrated before the species can be delisted.

A.6 Comment: The threats section states that changes to the Edwards Aquifer Rules were implemented in 1999 after the Barton Springs salamander was listed. This gives the impression that the inadequacies of the Edwards Aquifer Rules that were presented in the Final Rule listing the salamander as endangered have all been adequately addressed. However, the only change mentioned in this discussion is a requirement that permanent BMPs remove 80 percent of the increase in post-construction sediment loads that, as discussed elsewhere in the recovery plan, present a significant threat to the Barton Springs ecosystem. Further, the Edwards Aquifer Rules still do not address other threats identified in the Final Rule (such as lack of regulations to address land use, impervious cover limits, non-point source pollution, application of fertilizers and pesticides, and retrofitting).
Response: The statement that changes were made to the Edwards Aquifer Rules in 1999 was not meant to imply that their inadequacies, which were presented in the 1997 Final Rule, have been addressed. It was intended to help describe the current rules and show that this program is still evolving. In fact, the narrative for recovery action 1.2.1 specifically calls for an evaluation of the adequacy of all existing water quality protection programs including the Edwards Aquifer Rules.

A.7 Comment: I believe that having the Barton Springs Pool open for human recreational use is at odds with salamander protection, and wonder if it should be closed to human use.
Response: The Service has historically supported the view that public use of the Barton Springs Pool does not threaten the continued existence of the salamander if the pool's operation and maintenance activities are consistent with conservation needs of the salamander. The City of Austin has taken many precautions to minimize the risk of harm to salamanders by human use as part of their HCP.

B. Recovery Strategy, Criteria, and Recovery Actions

B.1 Comment: The spill response plan needs to be coupled with more and intensive dye-tracer studies to determine which likely spill areas will result in contaminant flows to specific springs. These studies need to be done at different aquifer levels since the velocity of contaminant movement, dilution and dispersion of contaminants, and springs that discharge contaminants may change with aquifer conditions.
Response: This suggestion was incorporated into recovery action 1.1.1.

B.2 Comment: Recovery action 2.1.7 should be changed so that the current understanding of water balance within the Barton Springs watershed be refined to include sources of recharge *and* points of discharge.
Response: This suggestion was incorporated into recovery action 2.1.7.

B.3 Comment: Few dye-tracing studies have been done to define drainage areas in shallow caves and more are needed.
Response: This suggestion was incorporated into recovery action 1.2.4.3.

B.4 Comment: The reduction of pollutant loading from existing infrastructure should include a prioritization of the infrastructure according to need and threat.
Response: This suggestion was incorporated into recovery action 1.2.4.5.

B.5 Comment: Models of groundwater flow in the aquifer should include and account for the results of dye-tracing tests conducted to date if they are to provide meaningful, accurate, and up-to-date analyses of aquifer conditions.
Response: This suggestion was incorporated into recovery action 2.1.2.

B.6 Comment: Recharge enhancement plans must first answer the question of how much of an effect such enhancement structures (such as detention facilities) will have on aquifer levels.
Response: This suggestion was incorporated into recovery action 2.1.5.

B.7 Comment: It is too presumptuous of the Service to make the statement "…after the species is delisted" in recovery action 5.3 given the problems associated with protecting the species from multiple threats in the urban area of Austin. Delisting is a goal, not a certainty.
Response: Although the Service believes that if the recovery criteria presented in this plan are met, the protections of the ESA will no longer be necessary, we agree that delisting is not a certainty. The language in recovery action 5.3 was changed to "…if the species is delisted."

B.8 Comment: The cost of constructing infrastructure for development over the recharge and contributing zones and the ongoing costs of servicing these areas such as schools, police, and utilities far exceed the costs of purchasing land for conservation. It should be stated that land costs will increase over time and as infrastructure is built over the aquifer. It is vital to have current estimates of the cost of land acquisition needs now and projections for how much it will cost if land acquisition is delayed or follows additional infrastructure development.
Response: The Service agrees that cost estimates for land acquisitions versus construction of infrastructure over the aquifer should be examined, but believes this can be conducted during the implementation phase of the plan. This suggestion was included as part of recovery action 1.2.7.

B.9 Comment: Deletion of action 2.1.5 is recommended because aquifer recharge enhancement measures have serious drawbacks and consequences.
Response: Deleting this action would be counter to several technical experts' recommendations to include it. However, the narrative for this action cautions that care should be given when conducting these studies, especially with regard to other native biota inhabiting recharge features and the possibility of water quality degradation. No specific concerns were identified by the commenter.

B.10 Comment: We believe Objective 4, Downlisting Criteria 4B should be based on life history information from wild populations and population viability analyses.
Response: The Service agrees that this information should be used to determine if the salamander populations at Barton Springs are self sustaining; therefore this comment was incorporated as suggested.

B.11 Comment: Because impervious cover poses a significant threat to water quality, under action 1.2.4 add a subtask to monitor and evaluate the extent and effects of impervious cover.

Response: A new action (action 1.2.4.6) was added to address this comment.

B.12 Comment: At one point, the recovery team was working to summarize the available water quality data according to historic and current baseflow and stormflow conditions and compiling toxicity data for a wide range of parameters to estimate acceptable tolerance limits for the salamander. The recovery team members that represented different local, state, and Federal agencies were to evaluate whether or not the existing rules and regulations were adequate to achieve recovery. We recommend these tasks be included as recovery actions in the recovery program for the salamander.
Response: Although the Service agrees that these actions are important to the recovery of the salamander, no changes to the recovery plan was warranted because these actions were already included in the narratives of recovery actions in the plan such as 1.2.1 and 1.2.6. Also, it is important to note that these types of recovery actions can be accomplished by both recovery team members and other partners.

B.13 Comment: If captive salamanders are reintroduced back into the wild, these individuals should be carefully monitored. This monitoring should continue in perpetuity.
Response: The suggestion that captive salamanders repatriated to the wild should be monitored was incorporated into the narrative of recovery action 5.3.
B.14 Comment: I agree that mark-recapture work is essential, and I would strongly recommend that elastomers might be used for this purpose.
Response: This suggestion was incorporated into the narrative of action 4.1.2.

B.17 Comment: Although the plan includes extensive monitoring of many indicators of water quality, I did not see regular monitoring for pesticides, a plan for testing whether pesticides play a role in salamander declines, or any plan to address this problem. There has been much recent concern about the effects of some pesticides on reproduction of amphibians as well as effects of pesticides on other aspects of behavior that influence survival.
Response: Pesticides are specifically discussed in the threats section of the recovery plan. The narrative for recovery action 1.2.6 was re-written in response to this comment. More emphasis was given to monitoring and research needs regarding all pollutants and contaminants that could affect the salamander. This action addressed the need to modify water quality protection programs as a result of toxicity testing and water quality monitoring.

B.18 Comment: If captive breeding is to be used for reintroductions, it is important to raise salamanders in as natural habitats as possible, including the opportunity to forage on natural prey, to interact with other salamanders, and to experience some of the stresses involved in predation by natural predators. Otherwise, post-release survival may be low.
Response: The narrative for recovery action 5.2 was revised to suggest these considerations for captive bred salamanders and recommend the need for studies that will increase the survivorship of repatriated individuals.

C. Implementation Schedule and Priorities

C.1 Comment: We believe actions 2.1.6, 2.1.7, and 4.1.4 are all Priority 1(b) actions

Response: Because these actions supported other Priority 1(a), changes to the priorities of these actions were made as suggested.

C.2 Comment: I do not believe that gas bubble trauma is a pressing concern for salamanders in the wild.
Response: The recovery action regarding investigating causes of gas bubble trauma was reassigned a lower recovery priority (of 3).

D. Miscellaneous Technical Comments

D.1 Comment: Tracer studies show that much of the discharge in Upper Barton Spring is recharged in the Williamson Creek watershed. Upper Barton Spring has the highest level of nitrates of the Barton Springs group, which therefore correlate to the high level of development in the Williamson Creek watershed. This is a direct measure and means of monitoring potential impact of development on the springs and species and should be discussed in the recovery plan.
Response: The commenter did not provide any studies as references for these statements, so they weren't used specifically in the plan. However, the Service supports the need for monitoring water quality impacts and their effects to the Barton Springs ecosystem caused by all potential pollution sources. Such monitoring activities are called for in the recovery program for the Barton Springs salamander.

D.2 Comment: Different types of structural stormwater treatment filters are efficient at removing specific water quality constituents, and only when the filters are properly maintained. These points and the maintenance record for existing BMPs within the Barton Springs watershed should be addressed in the plan.
Response: The point regarding the efficiencies of stormwater treatment filters at removing only certain water quality constituents was incorporated into Section 1.6, "Best Management Practices". The point regarding the need for proper maintenance of best management practices was addressed in the same section. The Service agrees that the maintenance record for existing BMPs should be examined, but believes this can be conducted during the implementation phase of the plan. This suggestion was included as a part of recovery action 1.2.4.1.

D.3 Comment: The discussion of BMPs needs to include the requirement for regular maintenance and stiff fines for lack of compliance.
Response: Although the plan cannot *require* maintenance of BMPs or fines for lack of compliance, language was incorporated into recovery action 1.2.4.1 to suggest that BMP maintenance compliance be encouraged throughout the Barton Springs watershed.

D.4 Comment: The City of Austin's current water quality program (consisting of quarterly, semiannual, and annual analyses) is a poor way to monitor water quality in a karst aquifer. Widely spaced random sampling works better in porous media aquifers because it allows for monitoring when the groundwater is most likely to have its highest contaminant loads.
Response: The narrative in recovery action 1.2.3.3 was changed to suggest that current water quality monitoring programs be evaluated to determine if sampling periods occur at times or frequencies that are insufficient to detect contaminant loads.

D.5 Comment: Several sources for information on the effects of PAHs and other contaminants of reptiles and amphibians were provided.
Response: The sections of the recovery plan that discuss PAHs and other contaminants provide descriptions of the known effects of these substances on reptiles and amphibians; however, the information provided there was reorganized for clarity.

D.6 Comment: The recovery plan cites many water quality studies that were written between 1995-1998, prior to the implementation of new TCEQ regulations, such as BMPs for sediment control to be used in construction, stormwater control maintenance requirements, and the regulation of activities in the contributing zone. Many of the conclusions about various threats have not been revisited since the listing of the species to evaluate the effect of the new regulations. We encourage the Service to conduct these evaluations as part of the implementation of the recovery plan and as part of its evaluation of the status of the Barton Springs salamander.
Response: The Service agrees that an evaluation of all of the water quality protection mechanisms currently in place within the Barton Springs Segment of the Edwards Aquifer should be evaluated for their adequacy in protecting the salamander; however, no change to the recovery plan is warranted, as this action is already recommended as part of the narrative for recovery action 1.2.1.

E. General Comments

E.1 Comment: We urge the Service to finalize the recovery plan for the salamander with great haste. This plan has been too long in coming and the salamander urgently needs recovery actions to begin.
Response: The Service also believes that finalization of the recovery plan is of the utmost importance, but notes that implementation of actions directed at protecting the Barton Springs salamander have already begun. Section 1.7 of the recovery plan references many actions that are ongoing or completed to protect this species.

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