# Barton Springs Zone Scientific Inventory

Photograph by Mike Lyday

**City of Austin**
**Watershed Protection Development Review Department**
**Environmental Resource Management Division**

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# WATERSHED CHARACTERISTICS

## Jurisdiction

### Existing Information

- The Barton Springs Zone (BSZ) is within the jurisdictions of at least eight municipalities—City of Austin, Mountain City, City of Buda, City of Sunset Valley, City of Dripping Springs, City of Hays, Village of Bee Cave, and Bear Creek Village, and three counties—Travis, Hays and Blanco.
- The City of Austin has jurisdiction over the largest portion of the recharge zone followed collectively by the other municipalities.
- Counties have jurisdiction over the largest portion of the contributing zone followed by other municipalities and the City of Austin.
- Approximately 29 percent of the Barton Springs Zone is within the City of Austin's jurisdiction, specifically 49 percent of the recharge zone and 23 percent of the contributing zone.
- Municipalities outside of the City of Austin have jurisdiction over 40 percent of the recharge zone and 34 percent of the contributing zone.
- Counties, outside of the local municipalities, have jurisdiction over 11 percent of the recharge zone and 43 percent of the contributing zone, with Hays County having the largest share.

**Jurisdictions in the Barton Springs Zone by Percent**

| | Percent Area | | |
|---|---|---|---|
| | City of Austin | Other Municipalities | Counties |
| Recharge Zone | 49 | 40 | 11 |
| Contributing Zone | 23 | 34 | 43 |

- The TNRCC's jurisdiction extends throughout the contributing and recharge zone.
- New development in the BSZ will be required to adhere to a set of water quality protection measures if they receive water from the LCRA's new waterline.
- The Barton Springs Edwards Aquifer Conservation District's jurisdiction includes the entire recharge zone.
- The Hays Trinity Groundwater District was confirmed by the 77$^{th}$ Texas Legislature, but will still face a confirmation election by the area residents.
    - Its jurisdiction includes only the Hays County portions of the Trinity aquifer, which also encompasses the contributing zone.

- There is no corresponding groundwater district for Travis County's portion of the Trinity aquifer.

# Land Use & Growth

## Existing Information

*Population*

- The BS/EACD (1995) estimated population within its regulatory jurisdiction and for the Barton Springs Sole Source Area.
  - ➢ The Sole Source Area received its federal designation in the 1980s, and refers to an area within the BSZ where groundwater use predominates, i.e. it is the source for at least 50 percent or more of the areas drinking water.
  - ➢ The sole source area roughly approximates the recharge zone portion of the Barton Springs segment of the Edwards aquifer from just north of Slaughter Lane to the District's southern boundary.
  - ➢ Population estimates and projections applied only to the number of people living in the area and were not meant to reflect the number of people that actually use groundwater.

Sole Source Area Population Estimates

| Year | Population |
|---|---|
| 1995 | 44,000 |
| 2000 (est.) | 64,000 |

- The City of Austin and CAMPO disaggregated population projections, made to the year 2040, to the traffic serial zone, which is a unit of geography that is similar to a census tracts. For areas in the BSZ, the projections include all but a small part of the BSZ in Blanco County.
- PBS&J (formerly EH&A) made population estimates and projections for portions of the BSZ as part of a feasibility study for the LCRA, Hwy 290 waterline for that would serve new development in the contributing zone (EH&A, 1996).
- Census 2000 data is available, and allows for small area estimates, including information at the tract, block group and block level.

*Land use*

- The COA makes city-wide land use surveys every five years. Surveys take approximately two years to complete (Poer 2001).
  - ➢ Land use classifications may change from survey to survey making change analysis and comparisons among surveys difficult.
- The COA completed a land use study as part of the Barton Springs Zone Land Use and Traffic Analysis Report (October 2000).
  - ➢ Land uses depict, primarily, the City of Austin's portion of the BSZ.

- The geographic unit under consideration was the traffic serial zone. Because of the traffic model's constraints, staff used whole zones, even if they were only partially contained within the study area. The study area is therefore, larger than the BSZ.
- Land uses for the City of Austin's portion of the BSZ were updated to 1997 with aerial photography and then built out with subdivision and site plan data.
- Hays County provided city staff with GIS subdivision coverages, which were compared against the aerial photography and assumed to be low-density, residential development.
- There was not any information available for Travis County outside of the City of Austin's jurisdiction.
- Blanco County was not included in the analysis.

- The LCRA recently "classified" LANDSAT imagery to characterize, basin-wide, land use/land cover (Charbeneau 2001). The characterization included the BSZ and could be used to analyze land use change.
- The EHA (1996) feasibility study made some general estimates of residential and commercial development in the BSZ.

**Data Gaps**

- Future land use patterns are poorly understood, and models or procedures to analyze them are not readily available.
- We do not know how market and legal/regulatory factors will change current growth assumptions.

**Ongoing Investigations**

- Consultants under contract to the LCRA have recently completed a draft 2000 and 2025 land use map as part of the LCRA's waterline environmental impact study.
  - Consultants used 1995 ortho-photos, which are essentially photographic maps, and information from the City of Austin.
  - Field surveys allowed the consultants to update the land uses to current conditions and fill in the gaps.
  - The maps are being reviewed for accuracy and reasonableness.
- From the Census 2000 the City of Austin will update the area population estimates and can determine population growth rates.
  - Census information can be used to estimate the number of water well users in the BSZ, both those relying on the Trinity and the Edwards.
  - Likewise, the Census information can be used to estimate an assortment of other characteristics that influence water quality, including how many septic systems there are in the BSZ.

- The City has recently acquired population and employment data (current conditions with projections to 2025) for both the Travis and Hays County portions of the BSZ.
- The City completed a color infrared aerial photography project in 2000 that included the entire BSZ. Procedures are being developed to classify land cover types in the watershed.
- The LCRA and the U.S. Army Corp of Engineers are making land use forecasts / projections in the BSZ, as part of two separate projects.
- The USGS is making a new, small scale land use / land cover map for the entire region that is expected to be completed in 2002. Their last LULC map represented conditions in the 1980s.
- The LCRA needs funding, or a project that will justify the expense, to analyze ("join" the 1987 and 1997 GIS coverages) the LANDSAT imagery used to detect change in the basin (Charbeneau 2001).

## Impervious Cover

### Existing Information

- In 1999, the City of Austin estimated total impervious cover in the BSZ using: 1997 aerial photographs , their 1999 updates and case files containing information about permitted development (City of Austin 1999).
  - Researchers directly measured impervious surfaces for areas within the City of Austin's jurisdiction in Travis and Hays County.
  - Outside of the City of Austin's jurisdiction in Travis County, impervious cover was calculated directly from the 1997 aerials and the 1999 update.
  - In Hays County, impervious cover estimates were based on the average size of buildings and roadways identified in the 1997 aerial photographs.
  - Blanco County was not considered in the analysis.

**Current Impervious Cover Estimates for the Barton Springs Zone**

| LOCATION | TOTAL ACRES | IMPERVIOUS COVER (ACRES) | IMPERVIOUS COVER (PERCENT) |
|---|---|---|---|
| City of Austin Jurisdiction | 67,961 | 5,098 | 7.5 |
| Outside of the City of Austin | 168,117 | 2,635 | 1.6 |
| Total | 236,078 | 7,733 | 3.3 |

- Future impervious cover projections were made only for areas of the Barton Springs Zone within the City of Austin's jurisdiction.

**Current and Future Impervious Cover in BSZ in the City of Austin's Jurisdiction**

| BARTON SPRINGS ZONE | TOTAL ACRES | CURRENT IMPERVIOUS COVER | | PROJECTED IMPERVIOUS COVER | |
|---|---|---|---|---|---|
| | | Acres | Percentage | Acres | Percentage |
| Contributing | 44,176 | 2,333 | 5.3 | 5,928 | 13.4 |
| Recharge | 23,785 | 2,765 | 11.6 | 4,164 | 17.5 |
| Total | 67,961 | 5,098 | 7.5 | 10,092 | 14.9 |

- Projections were made using impervious cover estimates found in the unbuilt development permits and by "building out" individual watersheds and subjecting them to the current watershed regulations.

**Data Gaps**

- Impervious Cover estimates are not as refined for watersheds in Hays County outside of the City of Austin's jurisdiction.
  - It will be possible to refine impervious cover estimates once all impervious surfaces throughout the BSZ are represented in a GIS as a polygon, which will allow for direct measurement.
  - Color infrared imagery, such at that acquired by the City in 2000, can be used to estimate impervious cover anywhere in the BSZ watershed.

**Ongoing Investigations**

- LCRA and the U.S. Army Corp of Engineers, with support from the City of Austin, are developing future land use and impervious cover projections in the BSZ, as part of two separate projects: the Northern Hays and Southwestern Travis County waterline and Onion Creek flood study.
- The City completed a color infrared aerial photography project in 2000 that included the entire BSZ. Procedures are being developed to estimate impervious cover from this imagery
- Using locally available information and data sources, WPD will try to determine historical impervious cover for selected watersheds.

# Roadways

## Existing Information

- CAMPO's 2025 roadway plan proposes extensive roadway system upgrades within the BSZ.
  - ➢ The major capacity increases are associated with expansions of existing two-lane arterials, as well as very significant roadway improvements to the State roadway system.
  - ➢ Roadways under consideration in the CAMPO plan include segments of: SH 45 (S), S. Loop 1, Brodie Ln., Fitzhugh Rd., Frate Barker Rd., Southwest Parkway and Thomas Springs Rd/Old Bee Cave Rd./Travis Cook Rd.
- A COA report examined roadway system capacity for the existing system, including improvements that will occur over the next 5-7 years, and for the future system as outlined in the CAMPO 2025 roadway plan (October 2000).
- Only arterials, i.e. not collectors or local roadways, were considered for the near term portion of the study, and these included segments of: US 290 W, S Loop 1, SH 45 and FM 1826.
- The demand created by existing and approved development projects in the BSZ will exceed the capacity of the existing roadways, including their near-term improvements, according to the report. .
- The roadway capacity improvements recommended in the CAMPO 2025 Roadway Plan, and the City's proposed Austin Metropolitan Area Transportation Plan 2025 Update may actually provide capacity beyond that needed by existing and approved development projects in the BSZ.
- Several planned roadway improvements in the CAMPO 2025 plan in the BSZ have not been adopted in the Austin Metropolitan Area Transportation Plan (AMATP). This includes alterations of cross sections and removal of entire planned segments.

## Data Gaps

- It is unknown which roadways removed from the AMATP will be constructed anyway through Travis or Hays County and TxDOT.

## What's Being Done

- The Austin City Council directed that an effort be made to determine the environmental suitability of roadways in the Drinking Water Protection Zone, which includes the BSZ.
  - ➢ A ranking matrix has been developed, and is currently under review by the Urban Transportation Board, Environmental Board and Planning Commission.

# Geology

## Existing Information

- The Edwards Aquifer is a karst limestone aquifer characterized by the presence of caves, sinkholes, large volume discharge springs, and streams that "lose" or recharge large quantities of surface water as it flows across the recharge zone of the Barton Springs segment of the Edwards Aquifer.
- The zones, in downstream order, that make up the BSZ are the contributing, recharge, artesian and bad water zones.
- The composition, distribution and arrangement of the rock types that make up each zone and the environments, or depositional systems, that influenced their formation have been described in great detail (Hill and Vaughan, 1902; Adkins 1933; Fisher and Rodda, 1969; Rose, 1972; Barnes, 1974, 1981; Garner and Young, 1974; Young, 1977; Ashworth, 1983; Baker et al, 1986; Baker et al, 1986; Slade et al, 1986; Slagle et al, 1986; Small et al., 1996).
- The contributing zone is underlain primarily by rocks from the upper Glen Rose Formation.
  - Isolated remnants of the Edwards Group limestones occupy local hilltops.
  - Locally thick deposits of alluvial sediments occur along streams and major tributaries.
  - Weathering and the differential erosion rates of alternating, hard and soft limestone layers and dolomite give the Hill Country its characteristic stair-step topography.
- The recharge zone is underlain by limestones of the Edwards Group (Slagle et al, 1986; Slade et al, 1986; Slade, 1984; Small, et al, 1996; Senger, 1983; Senger and Krietler, 1984; Ashworth, 1983; Baker et al, 1986; Hauwert and Vickers, 1994).
- Faulting complicates the arrangements of rock formations so that, moving eastward, younger rocks cover rocks of the older Edwards Group.
- As they are identified during field work or from surveys and development applications, the City of Austin, the BS/EACD and the Texas Speleological Society catalogue the locations of cave and sinkholes.
- The City of Austin and the BS/EACD catalogue the location of faults and lineaments, from past research articles and, currently, as they are identified from field work or from surveys and development applications.

## Data Gaps

- Geologic mapping and interpretation that produced more large-scale maps representing smaller, but more detailed areas of the Barton Springs Zone would augment our current understanding of, and ability to protect the aquifer and Barton Springs.

- BSZ geology is often depicted on relatively small-scale maps representing large areas that may lack the detail necessary to assess impacts from spills or development.
- Major faults that could prevent groundwater flow between Onion Creek and the Blanco River near Kyle have not been observed in recent geological mapping efforts.
- Large scale map elements include: refined local geologic interpretations and the location of faults, fractures, caves and sinks.

- We need more information about the distribution and arrangement of rock units that make up the Glen Rose formation outside of the Austin area. These units are associated with springs and seeps and may be more environmentally sensitive.

**Ongoing Investigations**

- City of Austin staff will continue to check and refine the recharge zone boundaries.
- Karst data—location of caves, sinks and faults—is being compiled by COA staff in cooperation with the BS/EACD and the Texas Speleological Survey.

# Soils

## Existing Information

- The National Resource Conservation Service (NRCS), which was formerly known as the Soil Conservation Service, mapped the range and extent of soil types by county throughout the BSZ onto medium scale soil survey's maps (Batte 1984, SCS 1974, SCS 1979).
  - These surveys were compiled as GIS coverages for Travis County, and are found contained in the NRCS' soil survey geographic database (SSURGO).
- Soils in the BSZ recharge and contributing zones are generally shallow and stony.
  - These soils are comprised mainly of Brackett, Tarrant and Speck-Tarrant soil associations in Travis County (Werchan, et al. 1974) and the Brackett-Comfort-Real, Comfort-Rumple-Eckrant in Hays County (Batte, C.D. 1984).
  - Soils in the Contributing Zone may be locally deeper and more biologically active than has generally been believed. (Woodruff et al. 1993).
- General BSZ soil characteristics include:
  - little to no organic content and high pHs,
  - highly variable infiltration rates and potentially rapid runoff rates, and
  - shallow restrictive horizons depth.
  - these soil characteristics tend to reduce the attenuation of pollutants and reduce the viability of land-based wastewater treatment and disposal systems (Community Environmental Services 1996).
- Other characteristics of BSZ soils include:
  - Forms preferential flowpaths and dissolution channeling along macropores, which reduces residence time of soil water.
  - The soil's low organic carbon content reduces microbial activity.
  - The low residence time and reduced microbial activity reduces the soil's ability to mitigate the impacts from non-point source pollutants that infiltrated the subsurface (Balogh 2001).
- Large scale soil importation is typically practiced in the BSZ when constructing facilities dependant on uniform vigorous turfgrass cover such as golf courses or commercial/residential landscaping.

## Data Gaps

- How do differences in the variability of soil and topography, and the reported existence of localized pockets of deeper native soil profiles, limit our ability to generalize soil characteristics over the entire BSZ.

- How do changes caused by large scale soil importation influence the ability of natural BSZ landscapes to moderate pollutant transport.
- How well do stormwater treatment systems that are designed to infiltrate stormwater, e.g. retention/irrigation systems, moderate the effects of pollutants.
- What is the erosion potential (stability) of stream floodplain soil, especially for soils located in intermittent, BSZ headwater streams.

**Ongoing Investigations**

- More erosion assessments for the Williamson and Onion Creek watersheds are being carried out. These assessments may provide some information about the stability of floodplain soils in the intermittent, BSZ headwater streams.
- Land-based, wastewater treatment systems are being monitored for effectiveness: using grants from the city's water and wastewater utility, by agreements made through TNRCC permit negotiations and because of land development permit settlements.
- Additional sites are being sought out to monitor the effectiveness of SOS compliant development.
- Because of an NRCS project, detailed, Hays County soil survey information is being converted into a GIS ready, SSURGO coverages.

# SURFACE WATER

## Hydrology

### Existing Information

*Stormwater Runoff (uplands)*

- The stormwater runoff characteristics for many of the urban land uses in the Austin area have been well documented (Barrett, et al. 1998, COA 1989).
- The volume of stormwater runoff correlates strongly to impervious cover.
- There are 14, single land use, small watershed monitoring sites in the BSZ (COA 1990a, 1994, 1996a and 1997c).
  - Impervious cover for these monitoring sites range from <3% for undeveloped lands to 95% for commercial areas.
  - Ten sites have sufficient data to accurately quantify pollutant concentrations, e.g. event mean concentration.
  - Ten sites have sufficiently accurate flow data to characterize runoff quantity from the watershed.
  - The average annual pollutant load for most land uses, using traditional development techniques can be quantified.
- The relationship between increases in stormwater runoff and decreases in stream base flow may be attributed to increases in impervious cover, which reduces the amount pervious upland areas and depression storage, and increases the use of engineered-storm sewer systems.

*Stream Flow*

- Historically, stream flow was generally characterized in terms of volume and peak flow using data sets collected over long periods of time by the USGS at gaging stations located in the BSZ. Although a more complete understanding of stream systems would characterize flow in terms of frequency, duration, volume and magnitude.
  - The City of Austin and the USGS have collected base and storm flow data for a number of years in Barton (4 locations), Williamson, Slaughter and Bear Creeks.
  - Onion Creek, upstream of the recharge zone, is also monitored by the USGS (COA 1996a and 1997a).
  - Watershed development changes how water moves through a stream system, even though the volumes of water that moves through the system remains fairly constant (COA 1990, Barrett, et al. 1998, Dartiguenave 1997). Specifically, development increases the amount of “storm” flow and decreases the amount of “base” flow.
- The effects of stream flow changes on aquatic ecosystems and stream stability are best understood in terms of the relationship between the timing of small to large stream flow

events, and in terms of stream flow frequency, duration and magnitude, including the effect of low or no-flow conditions (TNC 1997).

**Data Gaps**

- The pollutant loading rates for roadways, construction sites, golf courses (data being collected) and low density residential development are less well known than other land uses due to more limited data (COA 1996a and 1997a).
- The degree to which a continuous recording system of precipitation and stream flow monitoring stations in all contributing watersheds would complete our understanding of the hydrology of BSZ streams is unknown..

**Ongoing Investigations**

- City of Austin staff have investigated the use of the City's Flood Early Warning Systems (FEWS) stations for their ability to enhance precipitation and stream flow data collection or several streams in the BSZ.
    - Staff are screening and evaluating historical precipitation data collected from existing FEWS throughout the BSZ watersheds for use in an analysis of stream hydrology responses to localized storm events.
    - These data could be useful in calibrating hydrologic, hydraulic and non-point-source pollution water quality models of surface water in the BSZ and result in a better overall pollutant mass balance for the BSEA.
- City staff have begun using specific, and investigating other, stream-flow analysis techniques to evaluate the effects of the stream's flow regime on its biological condition.
    - For example, the Indicators of Hydrologic Alteration's, developed for the Nature Conservancy, usefulness is under investigation.
- Planning is underway for the installation of additional USGS stream flow gages on BSZ streams. The additional gages will be designed to track stream flows into and out of the recharge zone and hence explicitly determine the recharge characteristics of Barton Springs over time.

## Physical Stream Conditions and Stream Habitat

### Existing Information

- An assessment from over 50 sites in the Austin area indicates that channel erosion, or stream channel enlargement, increases as watershed impervious cover increases (RC&A 1997b).
- The stream stability and erosion potential of Barton and Williamson Creeks were assessed from 1996-1999 (RC&A 1997c and 1997d).
  - Barton Creek, which is composed of mostly stable alluvial and rock bed reaches, has been destabilized in a lower reach that includes Gus Fruh Park.
  - Williamson Creek is composed of mostly destabilized, some seriously, alluvial and rock bed reaches.
  - Both Barton and Williamson Creeks have the potential to undergo significant future changes in stream stability due to changes in impervious cover.
- The City of Austin found a relationship between higher impervious cover and poorer stream habitat quality in a study that assessed 37 watersheds in the Austin area (COA 2000).
- From 1996 – 2000, the City of Austin staff characterized stream habitat in the six BSZ creeks (COA 2001b).
  - In general, conditions were found to be Good to Excellent.
  - Williamson and lower Barton Creeks showed signs of impact and were found to be in Marginal to Good condition.
  - Problem sources included: riffle/pool system degradation, riparian vegetation losses and channel alterations.

### Data Gaps

- Habitat quality for the lower order stream segments (smaller tributaries) in the BSZ is poorly characterized because of limited monitoring data.
- The current and future erosion problems for Bear, Little Bear, Little Barton, Slaughter and Onion Creeks have not been assessed.
- It is uncertain whether the lower reaches of Barton Creek will continue to degrade or can return to a stable condition with improved stream habitat, or whether upper reaches will maintain their current good condition.
- How will stream reaches outside of the City of Austin's jurisdiction may be affected by the differences in regulatory requirements.

### Ongoing Investigations

- The City of Austin and Raymond Chan & Associates began an assessment in February, 2001 of the current and future erosion problems for Onion Creek.

- The City of Austin collects stream habitat quality data in the BSZ creeks on one to three year cycles as part of its routine monitoring and special studies programs.

# Stream Biology

## Existing Information

- Streams located in the Central Texas Plateau Ecoregion were characterized as having the highest benthic macroinvertebrate (aquatic insects) and nektonic (fish) integrity the state uses (Twidwell and Davis 1989).
- Perennial reference streams in this region received an exceptional aquatic life rating.
  - Regional stream characteristics that encourage the development of diverse biological communities in the Central Texas Plateau are: good bend and riffle development, tendency for deep pooling, complex substrates, adequate riparian buffers and very clear water.
- Baseline biological data was collected for benthic macroinvertebrates, diatoms and algae cover for streams in the BSZ (COA 1996, 1997 and 2001; Davis 1986 and 1999; Geismar 2001; and Bayer, et al. 1992).
  - These studies included inventories of fauna and flora for several of the streams and calculation of the indices commonly used to assess the health of stream ecology.
- In one such index, contributing zone stream segments rated *good* (Barton, Little Barton, Onion), *fair* (Bear and Slaughter), *marginal* (Little Bear), and *bad* (Williamson) in terms of the quality of benthic macroinvertebrate, community metrics, diatom community metrics, algae coverage, fish presence and primary productivity (COA 2001).
- Researchers have noted that because of inputs to nutrient poor streams from low levels of non-point source pollution, that some BSZ streams exhibit disturbances similar to those outlined in the Intermediate Disturbance Hypothesis (COA 1996 and Davis 1986).
  - According to the hypothesis, intermediate levels of physical and/or chemical (nutrient) disturbance can produce greater diversity and/or higher ecological integrity in the aquatic environment. However, when these disturbances exceed a threshold of frequency, duration or magnitude the hypothesis indicates that the diversity and integrity of the aquatic life will rapidly decline (Reice 1994, Connell 1978, Ward et al 1983).
- TNRCC/COA studies of lotic habitats (perennial pools) in Barton Creek, indicate that impairment to benthic macroinvertebrates communities increase downstream with the more intensely developed areas.
  - Although high or exceptional aquatic life uses are still maintained, TNRCC identified effects of non-point source nutrient enrichment and bottom sediment contamination in the lower portion of the watershed as potential reasons for impaired stream ecology (Davis 1999).
  - Types of benthic community impairment included longitudinal variations of total taxa attributed to instream trophic condition, elevated percent Oligochaeta, elevated percent tolerant taxa, reduced intolerant taxa, reduced EPT taxa, and reduced taxonomic similarity to the seven (7) less developed control sites.

- In both Barton and Onion Creeks, analysis of biological data indicates that changes in diatom and benthic macroinvertebrate communities are related to levels of development (impervious cover) in contributing watersheds (COA 1996).
- These data are corroborated citywide by a statistically significant relationship between aquatic life indices and watershed impervious cover (Hiers 2000)
- Anecdotal reports by Durden (1991) regarding the loss of highly sensitive crustacean species such as fairy shrimp (Eubrachiopoda), clam shrimp*(Eulimnadia texana)***,** and the algae *Chara sp.* in Barton Creek due to watershed development.
  - ➢ Although clam shrimp Eulimnadia texana (Packard) specimens were examined from collection in 1998 and Chara sp. is widespread throughout Barton Creek, no verified sightings of fairy shrimp (Eubrachiopoda) have ever been recorded in the ephemeral pools of the Barton recharge area.
  - ➢ Although ecological change may be occurring in the BSZ streams, no documented loss of species has been verified and linked to watershed development to date in the inventory of studies available to the COA.
- The effects of hydrology and physical habitat were compared with the effects of water chemistry in relation to biological indicators for two BSZ creeks (COA 1996b).
  - ➢ The results of this study indicated that flow was the predominant factor in describing biological indicators; however, water chemistry did show a strong relationship with benthic macroinvertebrates in Onion Creek, and diatom community indices in Barton and Onion.
  - ➢ The impact of impervious cover on flow characteristics may be more significant in intermittent streams in the BSZ than the impact on water chemistry pollution due to the almost perpetual state of recolonization and recovery of the benthic and diatom communities.
- An additional study of three Austin creeks including Bear Creek in the BSZ indicated that measures of hydrologic variability differentiate between impervious cover levels, and show strong relationships to biological community indicators in developed and undeveloped streams (Scoggins 2001).
- Analysis by COA staff indicates the correlation of hydrological variability to biological integrity is much stronger in urban drainages (>10% impervious cover) than undeveloped watersheds (<10% Impervious cover), which comprise the majority of the BSZ (Scoggins 2001)

**Data Gaps**

- The macro invertebrate conditions of smaller BSZ stream tributaries beyond the few special investigations conducted by the COA in the BSZ are unknown.
- Little is known about the effects on biota from sporadic changes in water quality due to storm events in combination with habitat and hydrological changes identified to occur in developing watersheds. Monitoring of these events is difficult in isolation, and defining

the contributing impact of chemical exposure through non-point source pollution and habitat and hydrologic cycle alteration has not been achieved with existing techniques.

- The importance of pollutant loads vs. concentrations regarding impacts to aquatic ecosystems is not well understood. It is becoming more evident that research in this area should include an investigation of dose-time responses of organisms to intermittent flows (Horner 1995, WEF/ASCE 1998).
  - This information may be used to supplement current criteria which has been derived from "ambient" studies.
- The intermediate disturbances that result in the current high biological integrity of BSZ creeks have not been quantified. The frequency, duration, and magnitude of the threshold disturbances that would result in rapid degradation of this integrity have not been defined. In other studies of the intermediate disturbance hypothesis, such quantification has been extremely difficult, leaving the protection of such dynamic systems in question.

**Ongoing Investigations**

- The City of Austin is continuing collection of stream biology data in the BSZ creeks every one to five years as part of its routine monitoring and special studies programs.
  - Additional attention is given to the major BSZ creeks Barton and Onion from which biological samples are collected quarterly, and areas where impairment has been reported by other agencies such as Slaughter Creek.
- The City of Austin is working with the national Watershed Management Institute to investigate correlations between aquatic biology, watershed characteristics and BMPs using aerial photography and GIS software.
- City staff are investigating the information available from long term stream flow monitoring in relation to biological data to determine if hydrological variables related to ecological integrity can be better quantified, and used to support protective measures in watershed planning (Scoggins 2001).
- WPDR masterplan projects have the added goal of stream habitat restoration or enhancement to flood, erosion and water quality control. Capital Improvement Projects will be designed to maximize the benefits of major construction projects in all COA creeks including those in the BSZ. These projects will incorporate existing knowledge about stream specific aquatic life and optimal habitats in order to determine design conditions that will approximate natural characteristics.
- City staff will be able to use an index of riparian integrity that is in development to examine relationships between buffer vegetation and biological integrity in all BSZ streams. The index uses GIS software and aerial photography to measure the quantity and quality of vegetative groups within stream corridors, and should provide support for existing and future ordinances and regulations.

## Sediment Quality

### Existing Information

- Stormwater runoff from developed areas is a potential source for many of the toxics found in sediment.
  - ➢ Other potential sources include atmospheric deposition, illegal dumping, illicit discharges, leakage from wastewater systems, spills, abandoned dumps/landfills, residential and commercial lawn care.
  - ➢ All of these human activities are present in the BSZ watersheds and may contribute in varying degree to the sediment results obtained through USGS and COA sampling programs.
- Sediment quality samples collected near the mouths of BSZ streams were ranked as *excellent* (Little Barton), *very good* (Barton, Bear, Little Bear, Williamson) and *good* (Onion and Slaughter) in comparison to the documented toxics effects levels.
  - ➢ Qualitative sediment quality rankings are based on quantitative threshold effects values and are one of the measures that the City of Austin uses as part of an environmental integrity index (EII) to measure stream health.
  - ➢ Some individual sediment samples that were collected from BSZ streams and tributaries contain toxics, which are *priority pollutant* organic chemicals and heavy metals, at levels of *concern* (Geismar 2000, Geismar 2001 and COA 2001).
  - ➢ The results from sediment sampling are highly variable and depend on antecedent storm transport conditions as well as spatially and temporally variable non-point source pollution inputs (COA 1997).
- Large volume suspended sediment (LVSS) samples that exceed *consensus based effects concentrations*, and include several heavy metals, polycyclic aromatic hydrocarbons (PAHs) and pesticides, were collected from Barton Creek and Eliza and Barton Springs following storm events (USGS 2001a).
  - ➢ PAH, LVSS sample concentrations found in Barton Creek are consistent with concentrations found in other impacted urban streams and reservoirs from around the country (Mahler 2001)
- Aldrin, DDD, DDE, DDT, BHC, endosulfan, heptachlor epoxide, heptachlor and lindane have been found in sediment samples collected in-situ from Barton Creek immediately upstream of Barton Springs Pool. (COA 1997b).
- Sediment samples collected in-situ from Onion Creek contained elevated PAH and copper concentrations (COA 2001).
  - ➢ Elevated concentrations are concentrations that exceed method detection limits or background levels.
- In-situ sediment samples have been collected that contain concentrations that were measured at levels above the proposed *consensus based aquatic life-effects levels* for copper and PAHs (COA 2001; MacDonald, et al. 2000).

- Data from more than five years of monitoring indicate that elevated concentrations PAH, copper, lead and arsenic were found in individual sediment samples collected in-situ from Barton Springs Pool (COA 1997b, COA 2000c,COA 2001b).
- Sediment samples that exhibited photo-toxic (toxicity under controlled UV light to simulate sunlight) effects on *Hyalella azteca* were collected from two tributaries to Barton Creek.
  - *Hyalella* is one of many aquatic benthic amphipods used as a food source by the Barton Springs Salamander (USGS 2001).

**Data Gaps**

- It is difficult to determine whether temporal trends exist without enough samples collected over a sufficiently long period of time using consistently comparable sampling methods, sample preparation methods and laboratory techniques.
- We do not know the degree to which differences in sampling techniques and method detection limits account for the current sediment data variability and how they may obscure potential trends.
- Little is known about the in-situ effects of contaminated sediment on aquatic biota in the BSZ given its spatial and temporal variability.
- The sediment quality characteristics of streams throughout the BSZ are poorly understood.
  - LVSS sampling is not currently funded on Slaughter, Bear and Onion Creeks.
- The City of Austin can determine relative PAH concentrations, but other cost-effective techniques that are directly comparable to laboratory analysis or toxicity based criteria are not available.
- The relative contributions from different land uses, semi-point sources and short term activities, e.g. construction disturbances, that cause sediment contamination are poorly understood.

**Ongoing Investigations**

- The USGS collects suspended sediments from streams and from Barton Springs and studies ways that this data might be used to identify sources and impacts to receiving waters.
- The City of Austin collects stream sediment on a routine basis at the mouths of BSZ tributaries for watershed master plan assessments and water quality control prioritization.
- As part of the NPDES program, the City of Austin analyses sediment samples for toxics that are collected quarterly from the main Barton Spring and annually from Eliza, Sunken Garden and Upper Barton Springs.
- Because of the results from previous sediment samples, City of Austin staff proposed additional sediment toxicity testing using the amphipod, *Hyalella azteca*.

- A workplan for this short term study has been submitted to TNRCC and approved for use in the 303(d) listing of BSZ creeks as impaired water bodies due to toxicity at Barton Springs.
- Additional testing may be carried out if the TNRCC considers photo-toxicity in its statewide water quality assessment.

## <u>General Water Quality Issues</u>

**Existing Information**

- General characteristics for streams in the BSZ, as with other streams in the Central Texas Plateau, include a high degree of water clarity, low concentrations of oxygen demanding substances and low available nutrient concentrations (Twidell and Davis 1989).
- Representatives from local, regional, state and federal government have collected large amounts monitoring data for streams in the BSZ.
  - A USGS/COA cooperative monitoring program uses permanent BSZ flow gaging and water quality monitoring stations.
  - The TNRCC, LCRA and the City of Austin conduct, periodic special studies and participate in ongoing, cooperative monitoring programs.
- Baseflow and stormflow water quality have been characterized for each stream with an adequate USGS gage (COA 1997a).
- Samples, collected by the City of Austin, and used in the city's watershed master plan indicate that <u>baseflow</u>, surface water quality by watershed is *very good* (Little Barton and Onion), *good* (Barton, Bear, Slaughter and Williamson) and *fair* (Little Bear) (COA 2000, 2001).
  - Qualitative water quality rankings are based on quantitative water quality sample results and are one of the measures that the City of Austin uses as part of an environmental integrity index (EII) to measure stream health.
- Streams in the BSZ receive, through the TNRCC (because of the federal Clean Water Act), a designated use, e.g. aquifer protection, aquatic life support and/or recreation, and stream standards are based on those uses.
- When uses become impaired, the TNRCC can use a total daily maximum load (TMDL) to improve water quality.
  - A TMDL is the maximum pollutant load from both point and non-point sources that a water body can receive and still be expected to maintain its uses and meet its water quality standards. So far, no TMDL has been determined for any of the streams in the BSZ.
  - TMDLs in Texas are developed only for expressly articulated media and contaminants. Contaminated sediment found in a classified stream segment, for example, will not result in a 303(d) listing for a stream and, therefore, TNRCC has determined that a TMDL is not currently necessary for BSZ creeks.
- Several streams in the BSZ periodically exceed the TNRCC's criteria for fecal coliform and are listed on the 303(d) lists developed by TNRCC as causes for concern. These concerns are associated primarily with non-point source pollution during or immediately following rain events for Barton, Williamson, Onion, Slaughter, and Bear Creeks (TNRCC 1999, 2000).

- TNRCC stream standards and criteria use “ambient” water quality conditions, which do not represent the impacts from a storm event. Compliance is routinely evaluated using ambient conditions rather than using storm event conditions when many non-point source pollutant loads are detectable.
- According to several statewide water quality assessments, Barton Creek has been affected by various nonpoint source pollutants, including fecal coliforms, nutrients, sediment and oil/grease. (TNRCC 1991, 1996).
- Water quality impairments in Barton Creek also include increased nitrate, total dissolved solids, total suspended solids and turbidity (filamentous algae also increases downstream). These water quality conditions occur below existing golf courses and urbanized development in the watershed (COA 1997)
- COA data on Barton Creek has shown a statistically significant, positive correlation between percent cover for algae and nitrate nitrogen concentration along the stream course (longitudinally) in perennial pools from upstream to downstream (COA 1997).
- Water quality in perennial pools downstream of Barton Creek Boulevard was poorer than in pools upstream. Statistically significant differences between several pollutant parameters were found in samples from the upper and lower Barton Creek perennial pools from over five years of monitoring (COA 1997).
- Dye tracing could not verify the source for the high nitrates and TDS found in a spring-fed pool in Barton Creek just below Lost Creek Boulevard. The pool was originally believed to be hydraulically connected to a nearby wastewater irrigation holding pond (Hiers 2001).
- Water quality samples collected in sub-watersheds where golf courses are irrigated with treated wastewater effluent, or where residential developments are sewered with centralized systems, have higher baseflow, nitrate concentrations than samples collected from sub-watersheds without those characteristics (COA 1997).
- Baseflow water quality concentrations in samples collected from tributaries to Barton Creek where residential land uses predominate are significantly different in concentrations for nitrate, ammonia, TDS, TSS and turbidity than they are in samples collected from tributaries where rural land uses predominate (COA 1997).
- Williamson Creek has generally been reported to have overall poorer water quality conditions than other streams in the Barton Springs Zone (COA 1998, Dartiguenave 1997, and COA 1995, 1990 ).
- Onion Creek was listed as a non-point source affected water for fecal coliforms and sediment. The sources were attributed to septic tanks, animal confinement, agriculture and construction (TNRCC 1991, 1996 and 2000).
- Onion Creek was also listed in the 1999 TNRCC statewide assessment of non-point source impaired waterbodies as being impacted by urban runoff and streambank modification resulting in a concern for TDS concentrations throughout the length of the segment (TNRCC 1999).

- Samples from a site in Barton Springs were analyzed for 77 different organic contaminants as part of Central Texas salamander, water quality requirements study (Dwyer, et al. 1999).
    - Analysis detected the presence of 20 contaminants, which in general had concentrations that were somewhat higher than the method detection limit. These contaminants included: five PAHs, two pyrethroids and 13 organo compounds.
    - The 1999 sample study was funded in part by the City of Austin, and designed to determine the average concentrations of bio-available organic contaminants in the Edwards Aquifer using of semi-permeable membrane devices (SPMDs).

**Data Gaps**

- Ongoing monitoring needs to be evaluated in terms of the "gaps" in our monitoring data (Mahler 2001).
    - Historically, monitoring has concentrated on less toxic and less-expensively analyzed parameters such as DO, TOC, nitrate and suspended sediments.
    - But, because these parameters are difficult to run trend tests for, and because they are not always toxic to biota, they may not be the best indicators of impacts from development.
- Soluble pesticides (atrazine, deethyl atrazine, carbaryl, dieldrin and simazine) were detected by the USGS in a pilot study of Barton Springs, Eliza Springs, Barton Creek and Williamson Creek stormwater quality (Mahler 2001).
    - The City of Austin does not have any plans to fund research into occurrence of soluble pesticides; however, more information is needed about: annual loading, their relationship to landuse, and how concentrations of these pesticides may vary in both baseflow and stormflow.
    - Two of these compounds, atrazine and deethyl atrazine, and another pesticide, prometon, were also detected in Barton Springs baseflow.
- Toxic substance concentrations in baseflow or stormflow below routine laboratory detection limits are largely unknown due to the expense and availability of specialized laboratory analysis.
- Aquatic life effects from long-term variable frequency exposure to toxic substances at extremely low levels is also not known.
- Given the potential dependency of Barton Springs and Barton Springs Zone stream biology on intermediate disturbances of a certain frequency magnitude and duration, it is unknown how protective TNRCC stream standards and criteria developed on an equilibrium or steady state basis are for the aquatic resources in these areas .
- The development of "wet weather" standards and criteria has been debated since at least the NURP project, but relatively little progress has been made.

- The water quality characteristics of most tributaries to the six BSZ streams are unknown because routine, consistent monitoring has not been conducted outside of the main stem of the streams with the exception of Barton.
- Baseflow water quality relationships to tributary vegetative buffer characteristics has not been determined due to inadequate riparian vegetation data.

**Ongoing Investigations**

- The City of Austin and the USGS continue to collect and analyze water quality data on a regular basis in Barton and Onion Creeks and less frequently in the other BSZ creeks. Monitoring of Barton, Eliza, Old Mill, and Cold Springs is also performed in accordance with the City's NPDES permit..
- City staff monitors and reviews TNRCC's frequent reevaluation of the methods used to determine impairment of surface water bodies.
- The USGS and City of Austin operate monitoring stations, located in Barton, Onion, Slaughter and Williamson creeks, that measure stream baseflow, stormflow and water quality.
- Evaluations that use the city's Masterplan Watershed Management Areas should generate detailed information about some tributaries in the BSZ areas like middle Williamson Creek that are considered a high priority.
    - Watershed Management Areas are stream reaches that are segmented and prioritized by flood control, erosion control and water quality protection needs according to criteria outlined in the City of Austin's Watershed Masterplan.
- The City of Austin supports and participates in studies carried out by the USGS that measure toxics in BSZ streams using, among other methods, LVSS Large Volume Sediment Sample procedures  in Barton and Williamson Creeks.
- The City plans to reinstall semi-permeable membrane devices (SPMD) in Barton Springs in compliance with its NPDES permit during the current permit period.
- City staff will try to use color infrared aerial photography for streams in the BSZ to create an appropriate riparian index that can relate vegetative buffer widths and characteristics to tributary water quality data.

## Temporal Water Quality Trends

### Existing Information

- Recent interpretations, based on water quality sampling, suggest that in the broadest sense there is a trend  in declining water quality (Mahler 2001).
  - Contaminants that are associated only with human activity can now be found in BSZ streams and in Barton Springs.
  - Their mere presence is indicative es of changes in water quality, i.e. these contaminants would not have been detected 50, 30 or even ten years ago, because in some cases because they did not yet exist,.
- Historically, studies that use USGS data have not identified any statistical, water quality trends. (Santos, et al. 1995, Ross 1995 and COA 1995, 1997 and 2000).
- Using the USGS's BSZ, stream water quality data, the results from a preliminary investigation indicate that dissolved oxygen (DO), turbidity and organic carbon are decreasing and that sulfate and conductivity are increasing during both storm and base flow (COA 2000).
  - Trends in the samples collected from Barton Springs mirror those for the surface water quality trends for DO, sulfate and conductivity.
  - Trends in the samples collected from Barton Springs are in the opposite direction from the surface water quality trends for turbidity and organic carbon.
  - Trends analysis relied on an aggregate of all the stream samples rather than an analysis using individual streams or stations. The number of samples collected and how often they are collected between the different sites can influence conclusions that are made using aggregated data (COA 2000).

### Data Gaps

- The observed surface water trends cannot be correlated to urbanization because of the lack of historical impervious cover estimates.
- We do not know the degree of similarity between temporal trends in the BSZ and in individual streams over the same time period.
- It is unknown whether the temporal trends in the parameters noted above may be precursors to trends in other parameters.

### Ongoing Investigations

- Using locally available information and data sources, WPD will try to determine historical impervious cover for selected watersheds.
- Additional analysis of stream data will be performed using data collected in 2001, and the methods of baseflow/stormflow separation techniques used to categorize data will be reevaluated.

- ➢ If it is deemed that sufficient data exists, then site and stream trends may be evaluated. This effort may be hampered by shorter periods of records in some BSZ streams, and discontinuous stream monitoring station operation.
- The 2001 sample data will be used to examine trends in water quality, and the sample analytical methods will be re-examined.

## Spatial Water Quality Trends

### Existing Information

- Analysis of spatial trends are limited primarily to Barton Creek because it is the only BSZ stream for which multiple, long term water quality monitoring stations have been located.
- Statistical analyses of USGS data in a watershed modeling study of Barton Creek points to increases in pollutant concentrations for most water quality constituents moving downstream from the relatively undeveloped headwaters represented by the areas above the Hwy 71 stream gage to the more developed areas represented by the intervening areas above the Lost Creek Blvd stream gage (COA 1997).
- The contrast between LVSS samples collected from Barton Creek at Hwy 71 and from Barton Creek above the springs illustrates the difference between water quality as it travels downstream from less to more developed areas (Mahler 2001).
    - Samples collected from Barton Creek at Hwy 71 have very low concentrations of PAHs, which is consistent with levels that are expected to occur "naturally," and only one organochlorine compound (DDE) has ever been detected.
    - PAHs concentrations of samples collected from Barton Creek above the springs are 10 to 30 times higher, and often at concentrations exceeding the TEL and/or PEL, than concentrations from samples collected from Barton Creek at Hwy 71.
    - Organochlorine pesticides (chlordane, DDE, DDD, DDT) have been found on numerous occasions in samples collected from Barton Creek above the springs. The chlordane concentrations usually exceed the PEL.

### Data Gaps

- The spatial water quality trends in other BSZ streams are unknown.
- It is also unknown which trends in surface water quality constituents will prove to be statistically significant by site or stream when sufficient data is available under all flow conditions.

### Ongoing Investigations

- The City of Austin is using its GIS software capabilities and aerial photography to characterize a sample-site's, contributing watershed.
    - This will allow researchers to examine differences between certain water quality conditions and the localized human-related watershed impacts within a contributing watershed.
- Because of the City of Austin's development reviews and environmental impact assessments, monitoring agreements with operators and developers are being made to obtain more spatially segregated water quality data linked to potential impacts.

- These include golf course developments, a planned unit development known as the Forum PUD and developments using spray irrigation of treated wastewater for disposal in the BSZ.

- The USGS, in cooperation with COA, continues to monitor BSZ creeks.
- The City of Austin conducts quarterly monitoring at a number of sites on Barton and Onion Creeks.
- The City of Austin collects samples from each of the major BSZ creeks every three to five years.

## Algae Blooms (Streams)

### Existing Information

- Nitrate-nitrogen concentrations are spatially related to the degree of filamentous algae cover when data is averaged over time for each mainstream Barton Creek site.
  - ➢ The City of Austin conducts routine, quarterly algae surveys in perennial pools located on Barton Creek. (COA 1997).
- In several years of monitoring, algae cover has been shown to increase significantly from upstream to downstream in perennial pools along Barton Creek (COA 1997).
- Documented occurrences of unusual and nuisance growth of algae are frequently made in streams in the BSZ, which suggests that there may be impacts beyond the natural cycling of nutrients (COA 1999, McClintock 2001, Geismar 2001, and Jones 2002)
- Several of the documented occurrences of severe algae blooms have been associated with discharges of partially treated wastewater from effluent irrigation facilities (COA 1993, 1997).
- Recent algae blooms—winter/spring 2000/2001—downstream of Lost Creek Boulevard in the mainstem of Barton Creek can be attributed to extremely high nitrate levels found from several urban tributaries in the Barton Creek watershed.
  - ➢ Watershed protection staff conducted a dye-trace study of the Lost Creek Golf Course Pool in 2000. The study did not confirm the suspected hydraulic connection between the effluent holding pond and springs where the high nitrate-nitrogen was detected
- The Lost Creek MUD carried out a series of rigorous smoke tests of wastewater lines in the sub-watershed draining to the spring with elevated nitrogen and found no major sources of exfiltration (outward leaks).

### Data Gaps

- Source of elevated nitrates noted in the pools below Lost Creek Blvd which may be providing nutrient inducement to algae blooms.
- Consistent cause of nuisance algae growth has not been determined because of drought, natural nutrient cycling, and transient nature of non-point source pollution events.

### Ongoing Investigations

- The City of Austin conducts routine, quarterly algae surveys in perennial pools located on Barton Creek.
- Additional testing to determine the source for the high nitrate springs below Lost Creek Boulevard will be undertaken by the Lost Creek MUD, city staff and Lost Creek Golf Course personnel.

## Contaminant Sources

### Existing Information

- Because no significant point source wastewater discharges are permitted by TNRCC in the BSZ, non-point source (NPS) pollution concerns outweigh point-source concerns.
- Stormwater runoff pollutant concentrations and loading rates are correlated to site imperviousness.
- Sources of NPS pollution include: stormwater runoff that washes off pollutants linked to urban/suburban development and atmospheric deposition from the land surface, leaking or poorly constructed and maintained septic systems and centralized wastewater collection systems, disposal operations and landfills, mining and the extractive industries, illicit discharges and accidental spills.
- At the site level, the water quality characteristics of stormwater runoff from many land uses are reasonably well documented in the Austin area (COA 1989, CRWR 1995a). Limited data exist for some of the more toxic pollutants (e.g., PAHs, oil and grease, pesticides).
- Stream channel erosion increases stream sediment loads and TSS concentrations in water samples (COA 1990, Dartiguenave 1997).
  - Increases in sediment load and TSS concentrations are greater than increases that may be attributed to wash-off from upland areas.
  - Changes in stream hydrology and sediment loads can cause stream channels to readjust by cutting down into the streambed or out into the stream bank.
  - Changes that induce in-stream erosion may be caused by increases in impervious cover.
- Another source of sediment and TSS, construction site runoff, can also be significant.

### Data Gaps

- Contaminant sources associated with some land uses have not been well characterized, these include golf courses, undeveloped land, roadways and construction sites.
- While it is generally acknowledged that suburban development is a significant source of concern, the relative importance of other sources is poorly understood or quantified.

### Ongoing Investigations

- Additional stormwater and surface water monitoring stations have been set up on golf courses, through development settlement agreements with operators, or TNRCC permit negotiations.
- Database development for the Permitting and Spills and Complaints programs is underway to more accurately track releases in the BSZ and other watersheds and identify commercial/industrial contaminant sources.

- Residential turfgrass monitoring, through an interlocal agreement with TAMU, is planned for FY02. Monitoring will help quantify subsurface and runoff releases from homowner applied fertilizers and pesticides.
- Masterplan WMA studies and other integrated planning projects are being designed to incorporate evaluation of stream channel geomorphology to reduce channel enlargement impacts thus moderating TSS and associated pollutant loadings from this source.
- Under NPDES, dry weather flow screening and abandoned landfill inspections are being conducted to identify contaminant sources.
- Construction runoff regulated by EPA NPDES general permit is proposed to incorporate significant BMPs in the BSZ through consultation initiated by USFWS. Implementation of these BMPs will be tracked through coordination with local USFWS office.

## Surface Water Modeling

### Existing Information

*CRWR/WPD Watershed Water Quality Planning Model(1997):*

- This model was developed for the city's master plan and is a simple watershed, water quality model, combined with a GIS, that researchers can use to determine average annual loads, flows and the concentrations of various water quality constituents. The model was used for the 17 Phase I watersheds and included some BSZ streams.
- The model was designed to provide information about current and future conditions at any location in the watersheds using city stormwater data and correction factors that are based on long term USGS data.
- Current impervious cover was used in combination with event mean concentrations, runoff coefficients, average annual rainfall, and took into account the effect of stormwater controls to predict current uplands pollutant contributions.
- Future impervious cover estimates used traffic serial zone (TSZ), population and land use projections.
- The model allowed researchers to simulate and predict upland loads, flows and concentrations on the basis of impervious cover; however, even with a channel erosion based calibration factor, it was not possible to determine average annual, in-stream pollutant loads that consistently match those observed at USGS stations. Hydrologic changes induced by development can affect stream dynamics and increase in-stream pollutant loads that are difficult to account for.

*Barton Creek Watershed Model (1997):*

- A continuous-simulation model using EPA's SWMM 4.1 was constructed to more accurately predict development impacts to recharge water quality from specific parcels of property in Barton Creek watershed.
- This model subdivided the watershed of Barton Creek above the recharge zone into a number of tributary watersheds and segmented the mainstem of the creek to allow predictions at a number of locations.
- The hydrologic components of the model simulated stream flow at USGS gages adequately, but the water quality model failed to accurately predict concentrations at the gages or in individual models of stormwater monitoring stations in single land use watersheds (Charbeneau and Barrett 1998).
- Researchers made numerous attempts to calibrate the model with limited success before resorting to an empirical model that simulated historical data, but that could not be used to predict future responses to development.
- The Barton Creek Watershed Model showed that streams that recharge an aquifer would be more difficult to model than expected and that a more parsimonious approach would be beneficial for planning level estimates of pollutant loads.

## Data Gaps

- Because of the way land uses are allocated within a TSZ, it is difficult to geographically locate increases in pollutant loading.
- We do not have a proven method to adequately estimate initial concentrations in stormwater runoff without use of conventional, contaminant buildup models that are based on antecedent dry periods (Charbeneau and Barrett 1998).
- A new way to accurately predict event loads in small watersheds may permit researchers to calibrate a deterministic, surface water quality model for BSZ using USGS data. Continuous simulation using these models would allow researchers to predict the frequency and duration of water quality impacts in creeks recharging Barton Springs.

## Ongoing Investigations

- The CRWR model is being refined using improved model data and methods.
- The City of Austin is working with Raymond Chan & Associates to develop a predictive stream erosion model for Onion Creek.
- LCRA contractors are working on a pollutant loading model for the BSZ, as part of an LCRA sponsored environmental impact study for the Northern Hays County and Southwest Travis County waterline.
- The U.S. Army Corp of Engineers in coordination with the City of Austin is trying to develop an improved flood model for Onion Creek.

# GROUNDWATER AND BARTON SPRINGS

## Recharge

### Existing Information

- Recharge originates in the contributing zone as stream flow that is predominated by the baseflow leg of the hydrograph.
- Streams crossing the recharge zone provide most of the water to the Barton Springs segment of the Edwards Aquifer.
- Recharge can also be attributed to direct rainfall on the recharge zone (Barrett and Charbeneau, 1996; City of Austin, 1995).
  - This upland area recharge makes a smaller contribution, and originates as overland flow that infiltrates directly into soils or drains to sinks, caves, faults and fractures.
- Stream flow stations continuously monitor bulk recharge loss across the major stream channel of Barton and Williamson Creeks. These stations are maintained by the USGS under contract to the City of Austin.
- Slaughter, Bear and Little Bear Creeks are not monitored for recharge losses. Automated flow gauges are now located on the upstream end of the Recharge Zone in Slaughter, Bear, and Onion Creeks.
- Onion Creek is monitored on the downstream side of the Recharge Zone by the LCRA, but data quality collected at the monitoring station has not been evaluated.
- Baseflow from streams originating in the contributing zone begins as rainfall that infiltrates in uplands and discharges into the streams from springs and seeps (COA, 1997b; Woodruff et al, 1993).
- Onion Creek contributes the largest amount of groundwater recharge, followed in order by Barton, Bear and Little Bear, Slaughter and Williamson Creeks (Slade, et al. 1986; COA 1995, Barrett and Charbeneau 1996).
  - Evaluation of tracing results may change our understanding of the stream contributions.
  - Contributions are closely related to watershed drainage area.
- Barton Creek has the greatest maximum recharge rate followed in order by Onion, Bear and Little Bear, Slaughter and Williamson Creeks (Barrett and Charbeneau 1996).
- Stormwater related recharge is related to watershed imperviousness,
  - The most impervious creek is Williamson followed by Slaughter, Barton, Bear and Little Bear and Onion. (Barrett and Charbeneau 1996)
- Groundwater that "leaks" from the Trinity Aquifer, which is adjacent to the Barton Springs segment, may be another source of groundwater (Slade, et al. 1986, Woodruff 1984; Barrett and Charbeneau 1996).

## Data Gaps

- We need more information about the location of significant stream recharge features.
  - These locations would help isolate areas where recharge occurs.
  - Flow loss studies have identified creek reaches with high rates of water loss, but specific features responsible for the loss have not been found.
- We have not determined how much recharge occurs in specific areas, or the proportion of upland to stream-channel recharge to Barton and Cold Springs.
- It is unknown how droughts affect the southern boundary of the Barton Springs segment of the Edwards Aquifer. Water level measurements or dye tracing could be used to assess boundary movements during a drought.
- Because of dye-tracing, we believe that the spring-shed for Cold Springs now includes areas of Barton and Williamson Creeks. We need to re-evaluate how much water, both in terms of volume and as a percentage of total Barton Springs discharge, each stream contributes to recharge. This may change our understanding of the upland area recharge contributions.
- We do not understand the mechanism governing groundwater exchanges between the Trinity and the Edwards Aquifers.
- We do not know how groundwater use from the Trinity Aquifer in the contributing zone will affect baseflow in streams originating in the contributing zone,
- We do not how recharge rates change during individual storm events, or over time during periods of either extended baseflow (months), or as a result of changes in land use (years).
- The degree to which changes in land use affect, e.g. block, recharge features is unknown.

## Ongoing Investigations

- COA and BS/EACD staff collect and analyze stream flow data, manually and from automated stations, on recharge streams to increase our understanding of where recharge occurs.
- Relative recharge contributions by watershed may be reevaluated by a university graduate student doing research for their dissertation.

## Flow Paths and Travel Times

### Existing Information

- Each of the six major streams crossing the recharge zone are hydrologically connected to Barton Springs. Barton and Williamson Creeks, also make contributions to Cold Springs too (Hauwert, et al. 2001).
- Dye-tracing and groundwater level maps have been used to identify major groundwater flow paths where water rapidly migrates through the subsurface (Hauwert, et al. 2001).
- Dye tracing and groundwater level maps have been used to estimate travel times between many recharge points and springs (Hauwert, et al. 1998 and 2001).
  - The groundwater flow rate may exceed five miles per day near preferred groundwater flow paths during moderate and high water-level conditions.
  - During a drought conditions and during moderate to high water-level conditions in the western side of the recharge zone, the fastest component of groundwater flow can vary from a rate of about one mile per day to one-half mile per day.

### Data Gaps

- All of the major, groundwater flow paths have not been identified. Nor do we know how to track or monitor water quality pollutants, or mitigate spills along major groundwater flow paths.
- We have not quantified the relationship between stormwater runoff and certain recharge points and Barton Springs. The relationship would include an examination of how long stormwater from specific recharge features takes to reach the springs, and how much of it reaches the springs.
- We do not fully understand how groundwater levels affect groundwater travel times, especially at greater distances from the major springs.
- We have not determined the areal extent of the recharge source areas for the major groundwater users, including large residential water supply systems, and other springs like Backdoor Springs.

### Ongoing Investigations

- Additional groundwater dye trace studies may be carried out by the BS/EACD.
- Plans are being made to install additional stream monitoring stations that will be used to measure flow rates above and below the recharge zone. Quantifying flow rates will enable researchers to accurately determine a water balance for the aquifer.

# Discharge

## Existing Information

- Main, Old Mill, Eliza and Upper Barton Springs, known collectively as Barton Springs, are the largest springs in the Barton Springs Edwards Aquifer followed by Cold Springs on the Colorado River (Rodda et al. 1970, Brune 1975, 1981, Slade and others 1986).
- We have quantified the long-term spring flow discharges at Barton Springs: average, minimum and maximum values.
- The BS/EACD and, to a lesser extent, the TNRCC and Texas Water Development Board, have collected groundwater use information since 1989; records from before 1989 were collected for only some of the major users and by the TNRCC for public water supply wells.
- Elevated discharge at Barton Springs is related to prolonged periods of heavy rainfall and sustained stream flow (USGS, 1976-1999).
- Many of the springs in the contributing zone have been mapped, especially in Barton Creek (City of Austin, 1997).
- City of Austin staff have, on a limited basis, documented sub-watershed stream flow contributions in Barton Creek (City of Austin, 1997; COA, unpublished data).

## Data Gaps

- The effect of groundwater use on Barton Springs flow during droughts is unknown.
    - ➢ The BEG reports that Barton Springs flow could be reduced to approximately 1 cfs under record drought conditions and at 1998 groundwater pumping levels, which averaged 6.3 cfs (BEG, 2000).
    - ➢ Barton Springs discharge during the drought of record in 1956 was 9.6 cfs (USGS, 1999).
- The amount of groundwater discharged at Cold Springs and from other BSZ springs along the Colorado River is not known.
- The spring flow contributions from each individual spring—Main, Old Mill, Eliza and Upper Barton Spring—to the Barton Spring total under different conditions are not known.
- The location of the major Onion Creek springs, and what their individual sub-watershed stream flow contributions are, is unknown.

## Ongoing Investigations

- Staff will continue monitoring Barton Springs discharge.
- Data collected from existing and new, or proposed, stream monitoring stations located on recharging creeks over a range of flow conditions, will make it possible to establish a more explicit representation of recharge/discharge relationships.

## Spring And Groundwater Quality

### Existing Information

- Baseline water quality in the aquifer and springs is generally good although isolated results from some more urbanized area wells have indicated concerns about water quality (USGS 1976-1999, Brune and Duffin 1983, Andrews et al. 1984, Slade et al. 1986, COA 1991, Hauwert and Vickers 1994, Johns 1994, COA 1997).
- Storm water runoff causes a temporary deterioration of water quality in Barton Springs, and begins within hours of a rainfall and generally lasts for a day for small storms, or several days for larger storms (COA 1991; COA 1997; Johns 1994; Mahler and Lynch 1999; USGS 1976-1999).
    - Increased turbidity, suspended solids, and bacteria are indicative of the poorer storm water related water quality.
    - Other changes include decreases in specific conductance (and dissolved solids), nitrates and other dissolved constituents and increases in dissolved oxygen. Changes in temperature depend on the season.
- TNRCC has listed the aquifer as a non-point source pollution impaired ground water resource and identified problem causes/stressors as priority organics, non-priority organics, metals, radiation and oil and grease. The aquifer has a “High” vulnerability rating, based on the DRASTIC Index methodology (TNRCC 1999).
- Suspended sediment, storm sampling has detected several contaminants discharging from the springs, including organic compounds and metals. Several soluble pesticides have also been detected in the spring discharge (Mahler 2001, Mahler and Van Metre 2000).
- Aquifer monitoring has identified several individual wells in urban areas where poorer quality water is present (Hauwert and Vickers 1994, COA 1997, USGS 1976-1999).

*Trend Analysis*

- An analysis of historical USGS data in Barton Creek indicated significant differences in average Barton Springs water quality data (total organic carbon, fecal coliform and TDS) depending on flow conditions at Barton Creek at Loop 360 using standard statistical comparison s(ANOVA). However, no significant trends were found using linear regression with time (Ross 1994).
- Trend analysis identified increases in nitrate-nitrogen, specific conductivity, sulfate, turbidity and organic carbon concentrations in Barton Springs discharges over time. Concentrations of dissolved oxygen were found to be decreasing. (COA 2000, Turner and Johns 2000).
    - Historical USGS data for the period of record from the Barton Springs monitoring station from all sources was analyzed.
    - Data was grouped into storm, non-storm, recharge and non-recharge categories.

- ➢ Linear regression over time and flow indicated statistically significant trends in several parameters.
- ➢ Increases in sulfates, total organic carbon, total dissolved solids and decreases in dissolved oxygen were found under various flow conditions.
- ➢ These changes may be precursors to additional changes in parameters more commonly associated with non-point source pollution. Significant trends were not noted in other parameters that are commonly considered pollutants, such as nutrients and total suspended solids. (COA 2000).

- Previous statistical analyses of Barton Springs water quality did not use separate flow conditions of recharge, non-recharge, storm and non-storm and did not detect a temporal trend in the Main Barton Springs water quality (Barrett 1996; Ross 1994).

*Contaminants (USGS)*

- New analytical techniques made known the presence of pesticides (atrazine, simazine, prometon, diazinon, diethylatrazine), which—because of analytical limits in the detection methods—were previously unknown in water samples from the Main Barton Springs (Mahler 2000).
- Metals and organics (arsenic, zinc, several PAHs) are found in suspended sediment samples in measurable amounts at the Main Barton Springs (USGS 2001a).
- Regular sampling of Eliza, Old Mill, and Upper (Barton) Springs began in 1995. Little analysis has been conducted on the last five years of data for Eliza, Old Mill and Upper Barton Springs. Most references to Barton Springs analysis refer to the Main Barton Spring, located in the pool, which has been sampled regularly since 1978.
- Higher TDS concentrations are found in Barton Springs when the pool is lowered for cleaning. This phenomenon was discovered using continuous in-situ water quality probes and data recorders (COA 1997).

**Data Gaps**

- The source for previously undetected and increasing nitrate-nitrogen trends at Barton Springs has not been determined. The source is also unknown for relatively high nitrate levels that are consistently present in the Upper Barton Spring and a narrow line of wells through the Sunset Valley/Brodie Lane area.
  - ➢ Groundwater modeling required large assumed inputs of nitrogen from upland sources to account for and balance nitrogen loads discharged at Barton Springs.
  - ➢ Septic and centralized systems portion of this load remains unaccounted for.
- The source of pesticides and trace metals found on sediments in spring discharge has not been determined and how their concentrations differ from sediments that discharge from the spring during a storm is unknown.
- The source of, and the mechanism for, the observed high total dissolved solids slug/seepage affecting BS during pool drawdown is unknown.

- We do not know the degree and extent of pesticide and organic contamination across the aquifer.
- We do not know whether or how contaminants are stored in the aquifer or on sediment in the aquifer.
- Contaminant levels, aquifer-wide are unknown because of the limited number of constituents we have sampled for.
- Few groundwater samples have been collected from the springs or wells over the discharge hydrograph when its raining, which is when—according to recent research—a significant part of the contaminant load moves through the aquifer.
  - The samples that have been collected were analyzed for a limited set of parameters (some nutrients and inorganics), thus leaving the behavior, presence, persistence, and potential sources of a large number contaminants (including metals and organics) unknown.
- What is the quality of upland area recharge as it enters the aquifer, particularly from developed areas or from stormwater treatment systems like the irrigation spray from a retention-irrigation system.
- We do not fully understand the effects from air-fall deposition of contaminants associated with areas adjacent to roadways on ground water quality.
- The available water-quality information for all the Barton Springs may not include all contaminates, and the level of contaminant tested for may only be known for the time which the sample was collected.

**Ongoing Investigations**

- Spring discharge, water quality trends will be reexamined using data collected in 2001, and the methods used to analyze that data will also be reevaluated..
- The USGS, in cooperation with the COA, collects suspended sediment samples from BSZ streams and Barton Springs following storms.
- The USGS, in cooperation with the COA, has written a sampling plan for Barton Springs and wells in BSEA using NAWQA protocols (ultra low detection limits).
- City staff collect samples from springs in the BSZ, including main Barton, Old Mill, Eliza, Upper, High, Backdoor and Cold Springs.

# Barton Springs Salamander

## Existing Information

*General Information*

- The Barton Springs salamander (*Eurycea sosorum*) was listed as endangered in 1997 because of its highly restricted range in a rapidly urbanizing watershed (62 Federal Register 23377).
- The salamander has one of the smallest known ranges of any vertebrate in North America.
- The salamander is known to occur only at Barton Springs, located in Zilker Park, Austin, Texas. It has been found at each of the four spring sites that collectively make up the Barton Springs complex – Barton Springs Pool, Eliza Springs, Sunken Garden (Old Mill) Springs, and Upper Barton Springs.
- The salamander has not been found at other springs in the vicinity of Barton Springs, such as Cold Spring, Backdoor Spring or Campbell's Hole.
- Although gravid females and small juveniles are found year-round, eggs have never been found in the wild (City of Austin, unpublished data) and are assumed to be deposited in the aquifer and/or spring upwellings below the surface.
- The salamander is neotenic, meaning it retains its larval gill-breathing morphology as an adult. The salamander lives in water its entire life, does not metamorphose, and never develops lungs.
- Wild and captive salamanders are often found in aquatic moss (*Amblystegium riparium*) and other aquatic plants and under gravel and small rocks.
- The salamander is predatory and feeds on small invertebrates. Based on gut content analyses, prey items include amphipods, copepods, ostracods, mayfly larvae, midge larvae, and snails (City of Austin, unpublished data).
- Salamander counts at the springs fluctuate widely. For example, monthly surveys in Barton Springs Pool, numbers have ranged from as few as one after a major flood in January 1995 to as many as 82 in September 1999 (City of Austin, unpublished data).
- Anecdotal information indicates that salamander numbers have declined. Local scientists reported seeing "dozens or hundreds" of salamanders at Eliza Spring during the 1970s (62 Federal Register 23377). Few, and often no salamanders have been seen at this site in recent years (City of Austin, unpublished data).
- The formal description of a second salamander species discovered in Barton Springs was published in 2001 (Hillis et al. 2001). The Austin blind salamander (*Eurycea waterlooensis*) has eyespots and lacks functioning lenses.
  - Typically, only small (less than one inch total length) Austin blind salamanders have been found in the wild, and no adult females have been found. Thus, it is thought that the Austin blind salamander spends most of its life in the aquifer.

- Austin blind salamanders are most frequently found in Sunken Garden, but have also been seen in Eliza Spring and Barton Springs Pool. To date, it has not been found at Upper Barton Springs.

*Tolerances & Threats*

- Primary threats to the salamander include degradation of water quality and quantity from urban expansion over the Barton Springs watershed (62 Federal Register 23377).
- Localized threats are related to recreation and management at Barton Springs.
  - The three perennial springs (Barton Springs Pool, Eliza Springs, Sunken Garden) were impounded during the early 1900s, altering surface drainage patterns and water levels.
  - A bypass tunnel constructed in the 1970s diverts creek flow from Barton Creek around Barton Springs Pool, which lies within the creek channel. Aquatic plants disappeared from the deep end of the pool in the 1980s.
  - In the early 1990s, the City discontinued the use of chemicals to clean the pool. Frequent pool lowerings, which were discontinued in 1998, resulted in documented salamander mortalities (City of Austin, unpublished data).
- The salamander has evolved in a thermally and chemically stable clean, clear, flowing water with little silt or sediment deposition.
- The salamander appears to be highly sensitive to environmental changes.
  - Captive breeding biologists have observed behavioral and physiological anomalies in salamanders following changes in their environment. A common physiological response to changes in temperature, flow regimes, and increased physical activity levels is the formation of gas bubbles in the throat and body cavity (Chamberlain and O'Donnell 2002).
  - The gas bubble phenomenon has been observed in one individual in Barton Springs Pool following drawdown in August 2001 (Chamberlain and O'Donnell 2002) and in seven individuals from Upper Barton Spring in January-March 2002. The condition severe enough to cause mortality in four salamanders from Upper Spring (City of Austin, unpublished data).
  - Although rare and sporadic, courtship and egg-laying activities have occurred in captivity; however, no clear patterns of behavior/reproduction have been discerned. Stress can be a major factor inhibiting reproduction in captive animals and may explain the unpredictable reproductive success in captive salamanders (Chamberlain and O'Donnell 2002).
  - Other common signs of stress in captive salamanders include restlessness, where salamanders are constantly moving throughout their environment and a reduction in or absence of feeding (Chamberlain and O'Donnell 2002).
  - Young salamanders are more difficult to keep alive in captivity than adults, and survival rates from the egg to adult stage are generally low (Chamberlain and O'Donnell 2002).

- Contaminated sediments and water quality degradation from urban runoff have been documented in Barton Springs and Barton Creek (City 2000, U.S. Geology Survey 2000).
- The salamander is rarely found in heavily silted areas (City of Austin, unpublished data).
  - Siltation/sedimentation appears to be detrimental, resulting in the degradation or loss of habitat.
  - Sediments act as a sink for many organic and inorganic contaminants and can accumulate these contaminants to levels that may impact aquatic ecosystems (62 Federal Register 63377).
- Ingersoll et al. (1996) investigated toxic effects on the amphipod, *Hyallela azteca*, from sediments contaminated with heavy metals and polycyclic aromatic hydrocarbons (PAHs).
  - The amphipod is found at Barton Springs and is a known food item for the salamander.
  - Sediments collected from the main stem of Barton Creek and in Barton Springs have contained several PAHs that were above levels shown to always have a toxic effect to the amphipod.
- Other salamander prey items and aquatic plants are known to be sensitive to contaminants (62 Federal Register 23377, USFWS 2000, Fairchild et al. 1998).
- Based on travel time determined by dye injection, pollutants from a large tanker spill or pipeline rupture could travel quickly to the springs and result in the extirpation of the salamander in the wild before diversion or remediation could be implemented (Radian Inc. 2000).
- Because the salamander is fully aquatic and unable to escape degradation of its habitat, a single incident (such as a contaminant spill) has the potential to eliminate the entire species (62 Federal Register 23377).
- The Austin blind salamander faces similar threats from declining water quality and quantity as the Barton Springs salamander.

## Data Gaps

*General*

- We do not know the extent of the salamander's range within the aquifer.
- Genetic markers and techniques to safely and reliably mark individual salamanders need be developed to estimate population size, demographic patterns (birth, death, migration, survival), space use (such as home range) patterns, and whether salamanders move between spring outlets.
- The mechanisms or cues that trigger egg-laying are unknown.

*Tolerances & Threats*

- Additional research is needed to determine more specific information regarding the salamander's tolerances to changes in water quality and quantity, including effects on salamander reproduction and development, feeding, and behavior.
- Specific pool cleaning and management activities at Barton Springs that benefit the salamander and its ecosystem need to be developed, monitored, and adapted as needed to ensure successful implementation.

**Ongoing Investigations**

- The City of Austin carries out the following activities in compliance with its federal 10(a)(1)(B) permit governing the operation and maintenance of Barton Springs Pool:
  - monthly salamander counts at all four spring outlets,
  - developing and maintaining a captive breeding program, and
  - promoting conservation and research activities through the City's Barton Springs Salamander Conservation Fund.
- The *Splash! Into the Edwards Aquifer* exhibit is used to educate people about the Barton Springs segment of the Edwards Aquifer.
- In addition, the City is developing other public outreach efforts, including additional signs and restoration of the Sunken Garden and Eliza Springs enclosures.

## Algae Blooms at Barton Springs

### Existing Information

- Filamentous algae blooms occurred in 1994 and in 1995.
- Blue green algae blooms (primarily *Oscillatoria*) occurred in the Summer and Fall 2000.
- The 2000 blooms may have had multiple causes including: extended drought and low spring flow, higher air temperatures, more sunlight, limitations on pool cleaning and maintenance practices in salamander habitat and surrounding areas and a substantial reduction of the more diverse ecosystem that existed in the pool prior to the 1990s.
  - Until the early 80's the deep end of Barton Springs pool was covered by aquatic macrophytes (similar to the San Marcos River). Since then, the macrophytes have slowly disappeared.
  - Their disappearance may be attributed to the construction of the Barton Creek bypass in 1975, which diverted Barton Creek and its biological input around the springs, and from the continuance of pool maintenance practices such as dredging the deep end and the use of chlorine.

### Data Gaps

- It is not known what caused the 1994 and 1995 algae blooms.
- The degree to which efforts to minimize the frequency and severity of algae blooms will work (APAI 2000).
- The frequency and severity of algae blooms in the pool before 1993.

### Ongoing Investigations

- Implementation of the APAI short-term recommendations for skimming the pool surface by PARD Aquatics staff.
- Prioritization of pilot studies to determine the effectiveness of long-term solutions recommended by APAI in the algae bloom report.

## Contaminate Sources

### Existing Information

- Sources of NPS pollution for groundwater are largely the same as those for surface water, and include: stormwater runoff that washes off pollutants linked to urban/suburban development and atmospheric deposition from the land surface, leaking or poorly constructed and maintained septic systems and centralized wastewater collection systems, disposal operations and landfills, mining and the extractive industries, illicit discharges and accidental spills.
- How these sources affect groundwater varies from source to source and is, in some cases limited by the amount of available data.
  - For example, the diffuse recharge produced by septic systems are believed to be a potentially significant source of groundwater pollution in the Barton Springs segment of the Edwards Aquifer; however, the data that would support this characterization is limited.
  - Organized sewer collection systems are also expected to leak to some extent, although the extent of sewer line leakage over the recharge zone is unknown.
- The TNRCC listed the aquifer as being nonpoint source impaired, with contaminant sources of petroleum activities, land disposal, hazardous waste, waste storage/storage tank leaks, and unknown. Urban runoff and construction were not listed as problem sources (TNRCC 1999)
- Reductions in spring flow, baseflow in streams, and declines in groundwater for consumption are a concern as a result of continued population growth in the area.

### Data Gaps

- Unknown contaminant sources were identified in the Surface Water section.
- The sources of nitrogen entering the aquifer system are not well understood.
- The sources listed by TNRCC are not well understood.
- The amount of future groundwater use is not known.

### Ongoing Investigations

- All activities listed in previous sections that pertain to monitoring of Barton Springs, other Edwards springs and wells will help characterize sources of groundwater contamination.

# Groundwater Modeling

## Existing Information

- Groundwater models may be able to predict recharge and discharge for the Barton Springs segment of the Edwards aquifer as long as the assumptions and information they are based on are accurate. (Slade, et al. 1985, Barrett and Charbeneau 1996, Scanlon, et al. 2000).

*USGS Model (1985)*

- The USGS is a two dimensional, finite difference porous media model with 318 active cells designed to estimate localized aquifer levels.
- 1981 annual groundwater use was estimated at 3,800 acre feet per year; however, only 2,900 acre feet per year was used in the simulation because private and irrigation wells were not included in the model. This may artificially inflate the impact of additional pumpage.
- Projected pumpage (9,000 acre feet/year) was capable of drying about 5 square miles of the southwestern Recharge Zone over a three month simulation.
- Using a projected pumping rate of 9,000 acre feet / year and simulated recharge enhancement on Onion Creek, the model predicted groundwater increases of 50 feet in the southwestern portion and large water-level declines in the southeastern portion of the Barton Springs segment.

*CRWR Parsimonious Model of Barton Springs (1996)*

- The CRWR model was designed to predict nitrogen concentrations in Barton Springs discharge under selected development scenarios.
- Several types of modeling approaches were tried to show how well the system could be simulated.
- The model predicted that relatively intense development reduced Barton Spring discharge and elevated nitrogen concentrations dramatically.
- Using a turbulent pipe model approach researchers simulated springflow well, but overestimated water levels in the simulated aquifer.

*BEG Water Availability Modeling (2000)*

- The BEG developed a two dimensional, finite difference MODFLOW porous media groundwater flow model with more than a ten year simulation period.
- Using 1998 groundwater withdrawals averaging 6.3 cfs over the year and climatic conditions representing the drought of the 1950's, the model predicted that Barton Springs would decline to about 1cfs (after correcting for a 10 cfs bias.

- Note: In 2000 groundwater withdrawals increased to an average 9.3 cfs, and since then large requests for additional pumping permits have been requested from BS/EACD. .

- Barton Springs was predicted to run dry using a pumping rate of 10,000 acre feet/year and recreating the drought conditions found in the 1950's.
- The model verified the USGS's predictions for portions of the southwest area of the BS segment, which were subject to complete drying.

**Data Gaps**

- At present, all of the BSEA groundwater models are porous media models, which assume that the aquifer is composed of granular material such as sand. Because of the complexity of karst aquifers like the BSEA, the existing models may share these limitations:
  - each model was completed before more detailed information on the actual groundwater flow paths and recharge source area was determined directly through dye tracing and detailed stream-flow measurement (still in progress); and
  - the existing models cannot accurately simulate travel times of groundwater measured in dye traces; therefore, the models may not accurately assess the actual transport of contaminants and other constituents.
- Additional limitations to specific modeling efforts which constitute "unknowns" are outlined below:

*USGS Model (1985)*

- Since the model requires an assumption of a constant head elevation at Barton Springs in its calculations, it cannot be used to assess potential impacts to Barton Springs flow.
- The model simulated average conditions, not drought conditions.

*CRWR Parsimonious Model of Barton Springs (1996)*

- The model cannot be used to predict impacts to Barton Springs water quality from individual parcels of property.
- The nitrogen balance proposed for model requires the assumption of a large undetermined diffuse nitrogen loading in order to match monitored water quality at Barton Springs
- The model did not effectively simulate water-levels in the recharge zone.
- Because the cells used in segmentation of the aquifer are vary large, the model will not estimate the effects of pumping or water quality contamination locally . In general, models with a smaller cell size could provide more detailed local predictions of water levels and transport.
- The model did not provide an estimate of the aquifer-wide effects of pumping but only average water levels for each major tributary basis cell under two development (pumping) scenarios.

- There is a weak relationship present between the estimated groundwater volume and estimates from other sources.
  - BEG estimates of 180,000 acre feet of groundwater in the BS segment (with a Barton Springs flow of 24 cfs) compared to USGS (1986) estimates of 275,000 to 306,000 acre-feet (10-50 cfs) and BS/EACD (1997) estimates of 300,000 acre-feet (17-35 cfs)
  - BEG estimates of 45,000 acre-feet above the elevation of Barton Springs compared to USGS (1986) estimates of 204,000 acre feet and BS/EACD (1997) estimates of 94,000 acre-feet
- Modelers assumed that flow losses between Lost Creek and Loop 360 on Barton Creek flowed to Barton Springs.
  - Recharge from this segment of Barton Creek are now known to flow to Cold and other springs on the south bank of the Colorado River.
- Modelers ignored flow losses downstream of Loop 360.

*BEG Water Availability Modeling (2000)*

- The model relies on underestimates of Cold and other springs discharges along the south bank of the Colorado River.
  - Cold Springs discharge was estimated at an average of 3 cfs.
  - However, over 10 years worth of data from flow losses studies on the Barton Creek section that feeds Cold Springs and other springs on the south bank of the Colorado River suggests that these springs averaged at least 14 cfs (Hauwert 2000).
- Modelers did not take into account how differing hydraulic conductivity values influence model predictions.
- The southwest section of the study area, which completely dried in the USGS simulation, was removed from the BEG model because it also completely dried in the simulations. Some cells even dried under 1989 simulated pumpage, which was considered steady state (background) conditions in the BEG model. This occurrence represents a poor calibration in these areas, and less confidence in water level predictions.
- Modelers did not take into account how differing groundwater use estimates affect model predictions.
  - BEG estimates differed from the BS/EACD estimates.
  - For domestic wells, the BEG used TWDB county-wide estimates, then divided by the percentage of area of the study area in the county.
  - The BEG method may not accurately reflect that wells are focused in areas with sufficient amounts of potable water, and are not uniformly distributed throughout the county.
  - The BS/EACD estimates used 1990 census data as the basis for their projections. BEG (1995) estimated a total groundwater use of about 3,800 acre-feet, while BS/EACD estimated almost 5,000 acre-feet.

- For the steady state simulation, recharge for the model was assumed to be equal to the average Barton and Cold Springs discharge of 55 cfs, and five cfs for 1989 pumping (60 cfs total). To accurately reflect steady state conditions, the flows should have included::
  - (1) a long-term Barton Springs flow of 53 cfs (it may decrease through time with increased pumping),
  - (2) an average flow of Cold Springs (and other Colorado River springs) of at least 14 cfs, and
  - (3) five cfs pumping, or a total of at least 72 cfs.
- The model cannot simulate transport and would, likely, be a very poor way of simulating dye tracing results.
- The model has trouble simulating low flow conditions, because it is essentially a porous media (sand) model and the sand drains slower than conduits
- The model cannot simulate conduit groundwater flow through caves.
- Each of the above models probably underestimated the discharge of Cold Springs, which was generally assumed to average about 3 cfs. However, over 10 years worth of data from flow losses studies on the Barton Creek section that feeds Cold Springs and other springs on the south bank of the Colorado River suggests that these springs average at least 14 cfs.

**Ongoing Investigations**

- The BS/EACD is currently modifying the BEG 2000 porous media model.
- German and Canadian university researchers are developing groundwater models that can better simulate karst conduit flow.

# WATER QUALITY CONTROL

## Regulatory Controls

### Existing Information

*Non-City of Austin*

- Municipalities in the Barton Springs Zone administer a range of water quality regulations. These regulatory strategies differ in their approach to water quality protection: the City of Austin uses non-degradation (SOS), while the city's of Bee Cave and Sunset Valley use approaches that allow for incremental increases in pollution, also known as anti-degradation.
- Statutorily, the potential exists for municipalities to enact or strengthen their water quality regulations.
- Counties do not have explicit water quality rule making authority; however, they can regulate drainage and road construction, regulate and license on-site sewage systems and administer flood-plain development regulations.
  - Hays county uses lot sizing criteria that depend on source of water, waste management and location with respect to areas within the Barton Springs Zone.
  - These criteria also contain stream set-back requirements.
  - Road construction requires the use of temporary erosion controls.
- Counties may pass rules to comply with habitat plans. And, with regard to water use, counties may require developers to "prove-up" their water systems helping homeowners ensure an adequate water supply.
- The Lower Colorado River Authority has enacted an anti-degradation rule for the Highland Lakes. While not applicable to the Barton Springs Zone, it is indicative of their water quality rule-making authority.
  - A US Fish & Wildlife Service / LCRA MOU that applies to the Barton Springs Zone requires new developments to comply with non-degradation water quality protection measures as a condition of water service.
- There are two groundwater conservation districts in the Barton Springs Zone, The Hays Trinity (awaiting voter approval) and Barton Springs Edwards Aquifer groundwater conservation districts.
  - Groundwater district water quality authority has been historically limited and poorly articulated in the Water Code; however, SB 2 ($77^{th}$ legislature) revised the water code and made explicit references to water quality authority.
  - Groundwater districts have more explicit authority with regard to water use and they may in some cases augment the state's well construction standards and require setbacks around wells.

- The TNRCC enforces state water quality protection rules and administers several programs to protect water quality.
- State water quality protection rules target, primarily, surface water and affect point and non-point sources of pollution. These rules are rooted in federal regulations and establish designated uses for, among others, aquatic life support and aquifer protection in classified stream segments, which include Barton and Onion Creeks. Designated uses are either supported or not supported depending on whether a stream segment meets objective criteria established by the state. Unclassified stream segments have less stringent statewide criteria applied to them.
- The TNRCC's Edwards Aquifer Protection Program (EAPP) uses an anti-degradation strategy for development in the recharge and contributing zones. The program also regulates or prohibits discharges, sewage collection systems and underground and aboveground storage tanks. Other regulations administered by the TNRCC require larger lot sizes in the recharge zone for septic systems and also stipulate well construction standards.
- The EPA and USFWS are responsible for administering federal regulations which affect water quality in the Barton Springs Zone, particularly through the Clean Water Act (CWA) and the Endangered Species Act (ESA).
- The CWA affects programs that the City of Austin, and eventually other municipalities and counties in the Barton Springs Zone, administer.
    - National Pollutant Discharge Elimination System (NPDES) permits affect industrial and municipal stormwater programs and, through the general construction permit, constructions sites.
    - The Total Maximum Daily Loads program may be used to address water quality issues in Onion Creek, which could result in the development of water quality protection measures.
- The Endangered Species Act is being used to develop water quality protection measures through the Section 7 consultations, which requires consultation between federal agencies. In a similar fashion, the EPA could be required to consult with the Service because of the general construction permit to develop measures that could be used to protect the salamander.

*City of Austin*

- Water quality and land development ordinances are codified in the city's Land Development Code.
- Zoning, subdivision and site plan can be used to protect water quality.
- Zoning is applicable within the city's full and limited purpose annexation areas and can be used to limit or disallow land uses that may threaten water quality.
    - City policy provides for zoning of floodplains as Rural Residence (RR) category with low density (1 house / acre).

- Subdivision and site plan requirements enable the city to enforce various water quality protection measures, that include:
  - Restrictions on where development occurs;
    - Stream setbacks (Critical Water Quality Zone and Water Quality Transition Zone)
    - Steep slope construction limits
    - Critical environmental feature buffers
  - Restrictions on amount of development (impervious cover);
    - 15% of the net site area (NSA) in the recharge zone
    - 20% NSA in the Barton Creek contributing zone
    - 25% NSA in all other watersheds in the contributing zone
- Stream setbacks and steeper slopes are excluded from the calculations of a sites total developable area and results in a further reduction in impervious cover.
- Requirements for an erosion and sedimentation control plan (ESC) enable the City of Austin to help protect water quality.
  - ESC controls are part of the site "Water Quality Plan"
  - The ESC plan designates a site project manager
- Requirements that disallow increases in the average annual pollutant load from a site establish the goal of non-degradation for the BSZ.
  - Nonstructural (pollutant prevention) measures are required by code to address specific pollutants that result from human activities and to reduce the potential for accidental discharges. The Code also includes provisions for education.
  - Structural controls must capture and treat 2-year storm runoff *volume* to show no increase in annual loads for designated pollutants. This requirement has additional benefits: maintains hydrologic (in-stream) conditions closer to natural condition, reduces total volume of runoff leaving the developed site, reduces potential stream erosion caused by hydrologic changes resulting from development.
- Raymond Chan and Associates (1997a) assessed the City of Austin's ability to control stream erosion
  - The study concluded that the City's current water quality regulations in the Barton Springs Zone should provide a high degree of protection against future stream erosion.
  - The study also refuted a commonly held belief of stormwater managers that the control of the *peak flow* rate from the 2-year design storm constitutes an effective stream erosion control strategy.
  - A *volume* control approach is needed as *peak flow* control does not adequately manage the frequency and duration of the range of small-to-large erosive flow events.

*State Law (1704)*

- As this time, major state legislation allows projects to continue under regulations in effect when the project started, which is treated as the time of the first permit application.
- The city may only impose new regulations related to an imminent threat to public health and safety.
- A number of projects have been completed or are proceeding under earlier city regulations that allowed higher impervious cover and the use of less effective storm water treatment systems. The City of Austin has quantified the number of older projects.
- Many of these "grandfathered" projects have been permitted or have had issues decided through lawsuit settlements, e.g. Gary Bradley Properties. Other projects are under negotiation, e.g. Stratus Properties projects in Circle C, Lantana and Barton Creek Properties.

*Other Exemptions*

- City development regulations do not apply to State of Texas development projects. Of particular concern are road and highway projects constructed without water quality controls or with controls that do not meet the City's standards for the Barton Springs Zone. (State road projects must meet the Edwards Aquifer Rules of the TNRCC, but these are not designed to meet a non-degradation standard).
- There is no assurance that county or federal projects will meet the City's regulations.

**Data Gaps**

- The number and type of water quality controls put into operation in the BSZ is not well known because no single entity tracks this information in a consistent manner. Likewise, the degree to which these controls are inspected and maintained is poorly known, thus their continued operating effectiveness cannot currently be verified.
- How well the Service / LCRA water quality protection measures will protect water quality and the salamander.
- The results of consultations between the EPA and the US Fish & Wildlife Service regarding the nationwide Construction General Permit.
- The extent to which local jurisdictions will participate in regional planning opportunities.
- The extent to which centralized wastewater systems will serve new development in the BSZ.
- The success that Land Trusts, counties and other entities will have in preserving undeveloped land.
- The ability of cities to exercise their authority into watersheds outside of their jurisdiction in order to comply with federal regulations.
- The extent to which counties could use their authority to adopt rules to comply with habitat conservation plans.

- The ability of groundwater district to protect groundwater from over use or pollution.

**Ongoing Investigations**

- The City's Watershed Protection Department may create stream headwater protection zones. Protection zones would require buffers on first and second order streams (those highest in the watershed) that do not already receive a critical water quality zone designation. Buffers may be 100 feet from the centerline of an unclassified stream and may include the following development incentives.
  - Buffers would be counted in the net site area for impervious cover calculations.
  - Buffers may be used for water quality credit if stormwater can be spread as overland flow across native grassy filter strips (stream buffers).
  - Headwater protection zones may replace the wetland critical environmental feature rule.
- Buffers are recognized by the USFWS as an effective watershed protection tool. The Services BSZ water quality protection measures offer criteria to protect streams with 5 acre drainage areas or larger.

## Structural Controls

### Existing Information

- The City of Austin evaluates water quality pollution controls (BMPs) effectiveness.
- The effectiveness of sand filters has been well documented, and some data also exist for sedimentation basins, wet ponds and oil/grit separators (COA 1990a, 1990b, 1996b, 1997a and 1997c, Glick and Chang 1998a and 1998b).
- The effectiveness of sand filters, wet ponds and traditional oil/grit separators effectiveness are well documented (COA 1990a, 1990b, 1996b, 1997a and 1997c, Glick and Chang 1998a and 1998b).
- The higher standards of treatment for storm water runoff required to meet the City of Austin's non-degradation goal in the BSZ have resulted in more complex treatment systems.
  - These systems rely on mechanical components such as pumps, controllers, valves and irrigation systems, which have a higher risk of failure than simpler gravity-driven water quality controls.
  - These systems are also more costly.
  - The complexity of these systems requires more skilled operators and more frequent maintenance – also at a higher cost.

### Data Gaps

- Several types of BMPs have not been evaluated locally including low impervious cover development, retention/irrigation, vegetative swales (data being collected), bio-retention and other new/innovative BMPs.
- Additional monitoring will be required to more fully assess the City of Austin's wet pond design criteria effectiveness (COA 1996b, 1997a and 1997c, Glick and Chang 1998a and 1998b).
- The effectiveness of the improved sand filter designs needs to be monitored (COA 1996b, 1997a and 1997c, Glick and Chang 1998a.)
- The overall, combined effects of BMPs on stream processes is unknown or poorly understood at this time (COA 1996b and 1997a, Glick and Chang 1998a).
  - However, a study conducted by Raymond Chan & Associates (1999) for Walnut Creek indicated that sand filters could be highly effective at reducing future stream enlargement, stating that "*The reduction in anticipated enlargement by 43 to 59% through the use of sand filters … represents a significant benefit*."

### Ongoing Investigations

- Several retention-irrigation sites are being evaluated for potential monitoring of non-degradation controls.

## Barton Springs Zone Retrofit Program

### Existing Information

- There is a large amount of existing development that may adversely affect water quality in the Barton Springs Zone, including Barton Springs. Retrofitting existing development with water quality controls is a way to prevent further water quality degradation.
- Most of the intensely developed areas are in older parts of Austin like Barton Hills and Oak Hill, and are relatively close to Barton Springs in areas with significant recharge.
- Because of the rapidity with which pollutants are recharged and transported, these developed areas are important to Barton Springs water quality. Accidental spills or discharges would have little chance of being mitigated prior to entering the aquifer.
- A large number of cost effective retrofit sites may not be available (Santos, et al. 1995).
- Because there is a limited amount of land available for retrofits sites in developed areas, open space for controls is frequently located in or near waterways.
- Retrofits located near waterways may result in collateral impacts to the streams—e.g. loss of riparian woodlands and wetlands, construction sediment loads; habitat alteration—that must be weighed against the benefits of pollutant load decreases downstream and in receiving waters.

### Data Gaps

- Because it requires a super majority to modify the SOS ordinance, a BSZ water quality regulation, it is uncertain whether the Austin City Council would be able to approve large scale retrofits.
    - The best sites (those that remove the greatest amount of pollutants at the lowest cost) are found in or near waterways, frequently in the Critical Water Quality Zones (CWQZ).
    - SOS prohibits water quality controls in CWQZs (LDC Section 25-8-514(B)).
- Even though they may be easier to locate, it is not known how cost effective small scale retrofits are compared to larger facilities.
- Because of a lack of suitable sites for structural retrofits in some areas, public education programs to change human behavior that negatively affects water quality may be the only feasible option for water quality improvement.
    - While recognized as an important watershed protection plan tool, the long term benefits of public education have not been well quantified, locally or nationally.
    - The level of commitment for retrofit and public education programs is uncertain. Funding for education programs must be ongoing as well as funding for an appropriate level of operation and maintenance of water quality controls.

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