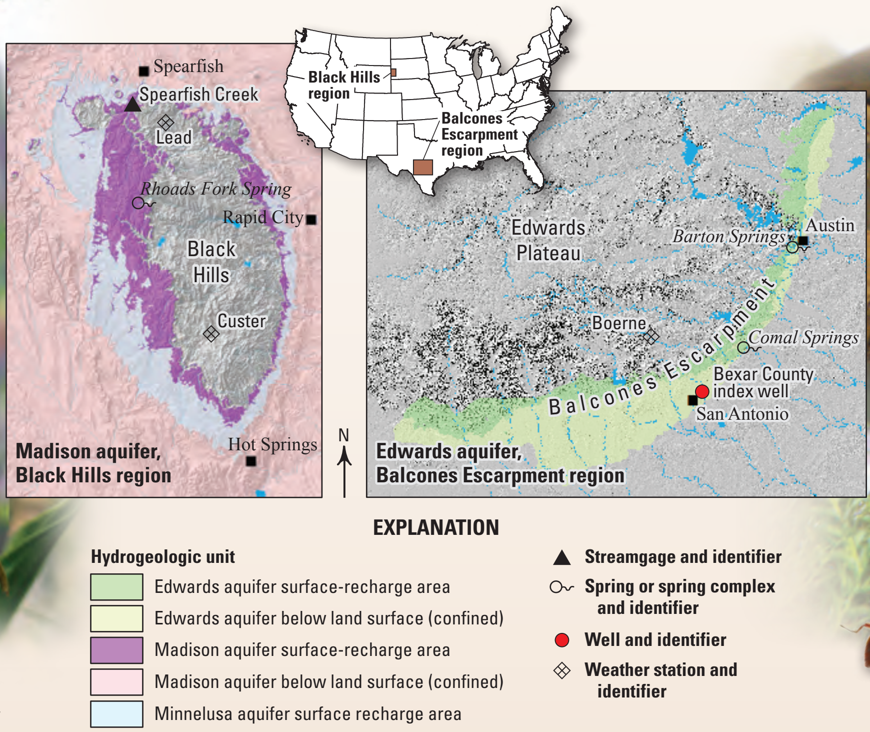
Prepared in cooperation with the Department of Interior South-Central Climate Science Center

Effects of Projected Climate (2011–50) on Karst Hydrology and Species Vulnerability—Edwards Aquifer, South-Central Texas, and Madison Aquifer, Western South Dakota

Karst aquifers—formed by the dissolution of soluble rocks such as limestone—are critical groundwater resources in North America, and karst springs, caves, and streams provide habitat for unique flora and fauna. Springflow and groundwater levels in karst terrane can change greatly over short time scales, and therefore are likely to respond rapidly to climate change. How might the biological communities and ecosystems associated with karst respond to climate change and accompanying changes in groundwater levels and springflow?

Sites in two central U.S. regions—the Balcones Escarpment of south-central Texas and the Black Hills of western South Dakota (fig. 1)—were selected to study climate change and its potential effects on the local karst hydrology and ecosystem. The ecosystems associated with the Edwards aquifer (Balcones Escarpment region) and Madison aquifer (Black Hills region) support federally listed endangered and threatened species and numerous State-listed species of concern, including amphibians, birds, insects, and plants. Full results are provided in Stamm and others (2015), and are summarized in this fact sheet.



Photos, top to bottom: American dipper, by Dave Menke, Fish and Wildlife Service; autumn willow, by Tab Tannery; lesser yellow lady's slipper, courtesy of Smithsonian Institution, Richard A. Howard Image Collection.

Figure 1. Vulnerability of karst-related species to climate change was investigated for the Edwards aquifer, Balcones Escarpment region, central Texas, and the Madison aquifer, Black Hills region, South Dakota.

Photos, top to bottom: fountain darter, by Gregg Eckhardt; Barton Springs salamander, by Lisa O'Donnell, City of Austin; Comal Springs riffle beetle, by Mike Quinn, TexasEnto.net.

Highlights

- Linking global and regional climate models, a hydrologic model, and a species vulnerability index allowed evaluation of the vulnerability of karst-related flora and fauna to climate change.
- An upward trend in air temperature is projected for weather stations near Edwards and Madison aquifer sites during 2011–50; springflow is projected to decrease during 2011–50 at Edwards aquifer sites but not at Madison aquifer sites.
- Of 16 species evaluated for the Edwards aquifer, 1 salamander is projected to be highly vulnerable to climate change, and 9 additional species are projected to be moderately vulnerable.
- Of 8 species evaluated for the Madison aquifer, 4 were predicted to be moderately vulnerable to climate change.
- Inclusion of hydrologic factors that the species depend on was key to evaluating the vulnerability of karst species to climate change.

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Model Linkage Provides the Bridge

Linking historical weather-station records, global and regional climate models, and a hydrologic model provides a bridge from global to regional to site-specific scales and provides the metrics needed to assess vulnerability of karst-related species to climate change (fig. 2). Climate variability was derived from historical weather-station observations and climate projections at the regional scale from the Advanced Research version of the Weather Research and Forecasting (WRF) model (Skamarock and others, 2008) downscaled from simulations of global climate from the Community Climate System Model, version 3.0 (CCSM3) (Collins and others, 2004). The Rainfall-Response Aquifer and Watershed Flow (RRAWFLOW) model (Long and Mahler, 2013) was used to simulate springflow or water-table level at sites. Historical and projected climate and hydrologic variability at specific sites was used to quantify species vulnerability using the Climate Change Vulnerability Index (CCVI) (Young and others, 2012).

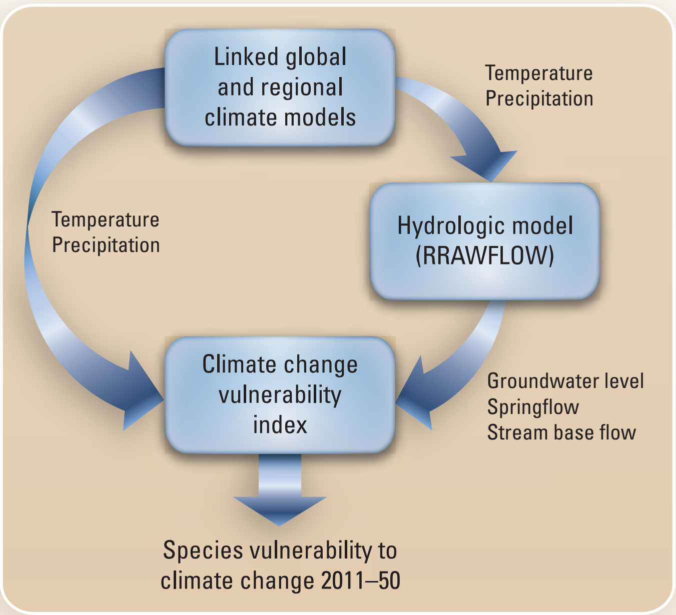

Figure 2. Global and regional climate models, a hydrologic model, and a species vulnerability index were linked to evaluate the vulnerability of selected karst-related species to projected climate change.

Climate—from Global to Regional Scales

The WRF model was used to simulate the projected climate of North America at a 36-kilometer grid spacing, using boundary and initial conditions from the CCSM3 and an "A2" emissions scenario, which is based on the assumption of a world of independently operating nations, continuously increasing population, and regionally oriented economic development (Nakićenović and Swart, 2000). Daily precipitation and mean, maximum, and minimum daily air temperature (at 2-meter height) were extracted for the locations of the Boerne weather station in Texas and the Custer and Lead weather stations in South Dakota (fig. 1).

The linked CCSM3 and WRF models projected (2011–50) a significant upward trend in air temperature for weather stations in both regions, but a downward trend in precipitation for only the weather station in the Balcones Escarpment (Boerne). The distribution of mean monthly maximum and minimum air temperatures for all three weather stations showed a general upward shift in air temperature from 1943–2010 to 2011–50, but not for all months. Monthly anomalies were as large as increases of about 4.9 degrees Celsius (°C) (anomaly for maximum air temperature in May at the Lead weather station) and decreases of as much as 1.1 °C (anomaly for maximum air temperature in October at the Custer weather station and in December at the Boerne weather station).

Hydrology is a Key Variable

The response of local hydrology to climate change was explored for two springs and a well fed by the Edwards aquifer (Barton Springs, Comal Springs, and the Bexar County Index Well), and a spring-fed creek and a spring fed by the Madison aquifer (Spearfish Creek and Rhoads Fork Spring) (fig. 1). The RRAWFLOW lumped-parameter model uses input of air temperature and precipitation to project hydrologic output of groundwater level or springflow or streamflow at specific sites (Long and Mahler, 2013).

Consistent with the projection of a downward trend in precipitation for the Balcones Escarpment, the RRAWFLOW model projected a significant downward trend in mean annual springflow or groundwater level for the three Edwards aquifer sites for 2011–50. Projected mean monthly springflow had downward trends for all months at all three Edwards aquifer sites, and water levels at the Bexar County Index well fell below that observed during the dry years of the 1950s (fig. 3). Consistent with the projection of no significant trend in precipitation at the Lead and Custer weather stations, the RRAWFLOW model projected no significant trend in springflow or streamflow for the two Madison aquifer sites.

Focus on the Species—Vulnerability to Projected Climate and Hydrologic Response

Species vulnerability to climate change was assessed using the CCVI, which is based on three components: exposure (character, magnitude, and rate of change in climatic parameters), sensitivity (physiological, biological, and ecological factors particular to a species), and adaptive capacity (the ability of the species to cope with climate change effects). For each species, 1 or more categorical scores are assigned to 6 measures of exposure and 16 measures of sensitivity and adaptive capacity. Sixteen species from the Balcones Escarpment and eight species from the Black Hills that span the range of broad taxonomic groups (such as mammal, bird, plant) were selected for assessment.

The 16 Balcones Escarpment species assessed occurred in either Comal or Barton Springs. All of the species that were scored as moderately to highly vulnerable are aquatic cave or spring species (table 1). Many of these species are negatively affected by extremely low flows that lead to decreased dissolved oxygen concentrations and increased water temperature (Woods and others, 2010; Gillespie, 2011; BIO-WEST, Inc., 2011; RECON Environmental, Inc., and others, 2012), or by extremely high flows that lead to habitat loss (RECON Environmental, Inc., and others, 2012). As a result, the use of projected springflow and water-table level was key for scoring

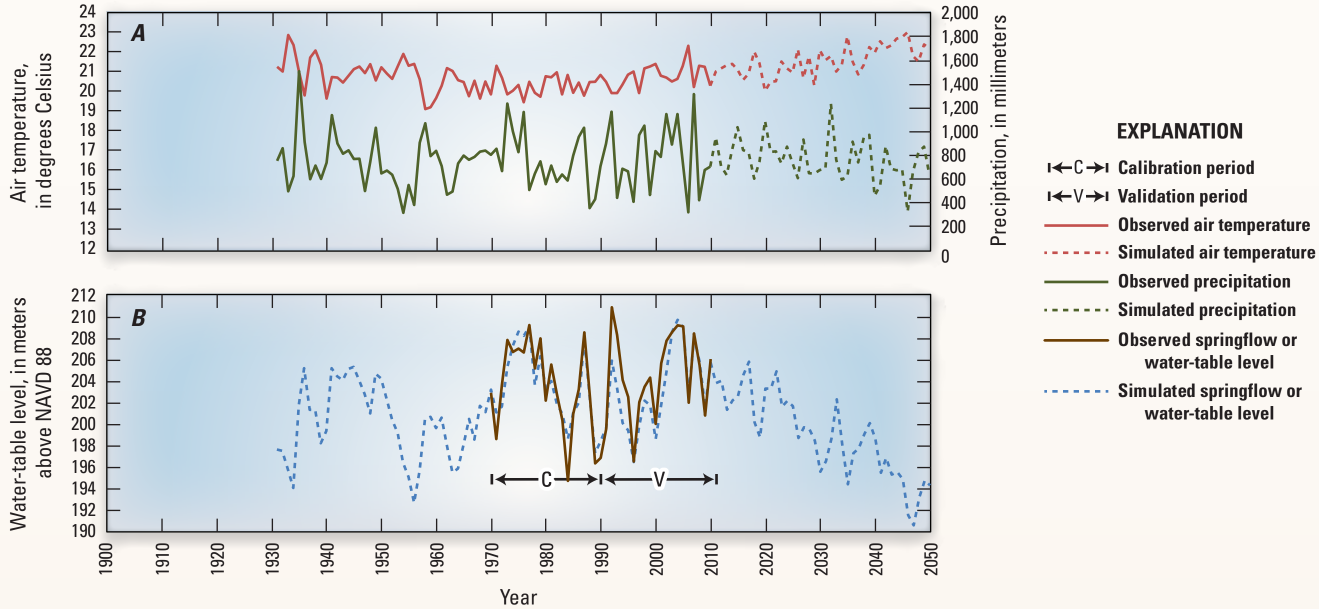

Figure 3. Climate and hydrologic projections are exemplified for the Bexar County Index Well, Texas. *A*, The climate model for 2011–50 projects that air temperature in the area will increase and precipitation will decrease. *B*, Using the projected air temperature and precipitation, the hydrologic model projects an overall decrease in water level at the well from 2011 through 2050. The ability of the RRAWFLOW model to simulate observed hydrologic response is indicated by the close match of the solid and dashed lines.

vulnerability of these species. For example, species with narrow thermal tolerance—such as *Etheostoma fonticola*, the endangered fountain darter in Comal Spring (U.S. Fish and Wildlife Service, 2013)—were scored with higher vulnerability where decreasing springflow was linked to higher water temperature.

Of the eight species assessed in the Black Hills region, four were scored as not vulnerable and four as moderately vulnerable to effects related to climate change (table 1). For species in this area, biological factors that make them sensitive to moisture-related climate changes are generally balanced by little projected change in moisture, and moderate air temperature changes ameliorate the physiological sensitivity of the species to heat. However, for one species with a low tolerance for high air temperatures—American dipper (*Cinclus mexicanus*)—the increasing frequency of days with a maximum air temperature greater than a thermal threshold (36 °C) increased its vulnerability.

The vulnerability of species in the two regions differs for at least two reasons. First, the Edwards aquifer has one of the most diverse and unique karst groundwater and cave faunas in the world (Longley, 1986) with a high level of endemism (the ecological state of being unique to a defined geographic location); of the 233 species considered for inclusion in this study, 75 percent were endemic. In contrast, of the 25 species in the Madison aquifer area considered for inclusion in this assessment, only 1 species (4 percent) was endemic. Endemic species tend to have highly restricted range, habitat, and thermal tolerances. Second, the hydrologic effects of climate change were projected by the climate models to be more severe for the Balcones Escarpment region than for the Black Hills region. The hydrologic data produced by the RRAWFLOW model led to increased vulnerability scores for 12 of the 16 Balcones Escarpment species scored.

Evaluation of the Approach

The CCVI species assessment was enhanced by the detailed climate and hydrologic information produced by the coupling of the CCSM3, WRF, and RRAWFLOW models. The high spatial resolution of the WRF model climate projections is particularly important for regions, like the Balcones Escarpment and the Black Hills, that have strong climatic gradients over relatively small distances. The inclusion of hydrologic projections in the vulnerability assessment added critical information for assessing the effects of climate change on aquatic species.

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Table 1. Species assessed with the Climate Change Vulnerability Index (CCVI), the vulnerability determined, and the confidence in that assessment.

Aquifer	Major taxonomic group	Taxon	Climate vulnerability assessment	Confidence
Edwards	amphibian	*Eurycea sosorum* Barton Springs salamander	Highly vulnerable	Moderate
Edwards	amphibian	*Eurycea waterlooensis* Austin blind salamander	Moderately vulnerable	Very high
Edwards	arthropod	*Stygobromus pecki* Peck's Cave amphipod	Moderately vulnerable	Very high
Edwards	arthropod	*Heterelmis comalensis* Comal Springs riffle beetle	Moderately vulnerable	Very high
Edwards	fish	*Etheostoma fonticola* fountain darter	Moderately vulnerable	Very high
Edwards	amphibian	*Eurycea rathbuni* Texas blind salamander	Moderately vulnerable	Moderate
Edwards	amphibian	*Eurycea* sp. 8 Comal Springs salamander	Moderately vulnerable	Moderate
Edwards	arthropod	*Haideoporus texanus* Edwards Aquifer diving beetle	Moderately vulnerable	Moderate
Edwards	arthropod	*Stygobromus flagellatus* Ezell's Cave amphipod	Moderately vulnerable	Moderate
Edwards	arthropod	*Stygoparnus comalensis* Comal Springs dryopid beetle	Moderately vulnerable	Low
Edwards	vascular plant	*Ehretia anacua* anacua	Not vulnerable	Very high
Edwards	vascular plant	*Taxodium distichum* bald cypress	Not vulnerable	Very high
Edwards	vascular plant	*Cabomba caroliniana* Carolina fanwort	Not vulnerable	Very high
Edwards	mollusk	*Stygopyrgus bartonensis* Barton cavesnail	Not vulnerable	Moderate
Edwards	arthropod	*Calathaemon holthuisi* Purgatory Cave shrimp	Not vulnerable	Low
Edwards	vascular plant	*Platanus occidentalis* American sycamore	Not vulnerable	Low
Madison	bird	*Cinclus mexicanus* American dipper	Moderately vulnerable	High
Madison	vascular plant	*Cypripedium parviflorum* lesser yellow lady's slipper	Moderately vulnerable	High
Madison	vascular plant	*Equisetum scirpoides* dwarf scouringrush	Moderately vulnerable	Moderate
Madison	vascular plant	*Salix serissima* autumn willow	Moderately vulnerable	Low
Madison	mammal	*Zapus hudsonius campestris* Bear Lodge meadow jumping mouse	Not vulnerable	Very high
Madison	vascular plant	*Asplenium trichomanes-ramosum* green spleenwort	Not vulnerable	Very high
Madison	mollusk	*Oreohelix cooperi** Black Hills mountainsnail	Not vulnerable	Low
Madison	mammal	*Castor canadensis* American beaver	Not vulnerable	Low

*See Stamm and others (2015) for a discussion of taxonomy of the genus *Oreohelix*.

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