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title: **The effects of urbanization on the sustainability of urban groundwater systems**

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The urban and industrial development of Austin, Texas, USA, has affected its streams and groundwater systems. The latter include the karstic Edwards Aquifer and its significant groundwater dependent ecosystem, Barton Springs. Groundwater recharge is impacted by increased "impervious" cover, leakage from utility systems (water mains, sewage lines, storm sewers, and storm water retention/detention ponds), and irrigation systems. These impacts threaten water quality and important groundwater dependent ecosystems, including Barton Springs. The urban hydrological cycle is also altered significantly.

Water budget analyses show a significant increase in recharge in the last 50 years. In addition, double ring infiltrometer studies on pavements show that their secondary permeability is increased with an areal average of 6×10^{-5} cm/sec (Wiles, Sharp, 2008). Preliminary data on storm sewers show leakage rates above commonly-accepted design criteria. Consequently, it is hypothesized that urbanization: 1) increases groundwater recharge by increased localized and artificial recharge; 2) decreases evapotranspiration by native vegetation that is cleared during development; and 3), therefore, increasing recharge with urbanization is probable. This is confirmed by analyses of systems worldwide.

In karstic systems, increasing flow to losing streams adds to the increase of recharge. Recharge rate trends were tested by comparing springflow versus precipitation. Site-specific hydrogeologic data since 1917 in the Barton Springs segment of the Edwards Aquifer were collected and analyzed to develop a relationship between precipitation and discharge. Increased urban recharge has lead to an increase in discharge at Barton Springs relative to precipitation. Trend analyses of monthly-mean springflow and precipitation data demonstrate that Barton Springs discharge is increasing relative to precipitation since 1923 (Sharp et al., 2009); this most noticeable since the 1960s concomitant when the major growth in population and urban area commenced (Garcia-Fresca, Sharp, 2005). This implies that additional sources of recharge are contributing to the overall water budget and that these correlate with the temporal trend of urban sprawl.

Water quality in the streams and groundwater has remained relatively stable, but several trends raise questions about sustainability. In the most urbanized areas of Austin, small streams at low flows have been demonstrated by Sr-isotopic analysis to consist mostly of water that was processed in the City's water treatment plants (Sharp et al., 2006). Leaky utility systems and excess irrigation of lawns maintain the stream low flows (Garcia-Fresca, Sharp, 2005). Barton Springs, which are the main discharge of the Edwards Aquifer, harbor two endangered salamander species. Time trends show increasing levels of anthropogenic contaminants. These include more fertilizers, pesticides, and other organic chemicals. After heavy rains, fecal coliform bacteria concentrations increase significantly. Concerns have been raised that accidental spills or gradual increases in contaminants that come with urbanization might cause extinction of the endangered species.

Detailed spatial management of urban groundwater systems might be the key to their future maintenance and utilization on a sustainable basis. The effects on groundwater, surface waters, and groundwater dependent ecosystems can be managed by a combination of hydrogeologic analyses, urban planning, and engineering design.

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