Rapid urbanization and a growing population in the semi-arid West have led to the production of large volumes of wastewater effluent and a concurrent decline in groundwater levels. Among the options available for effluent disposal is discharge into stream channels, through which effluent can help recharge the aquifer below.

Effluent discharge into otherwise dry or intermittent streambeds in the Southwest has created new perennial stream reaches. Although these streams cannot be used for recreation, they develop riparian ecosystems and contribute to groundwater recharge. Effluent-dependent streams may provide the benefits of riparian ecosystems, but they also introduce potentially poor-quality water to the environment with the possible presence of organic and microbial contaminants. Therefore, understanding the fate and transport of any pollutants released into the stream and their potential effects on groundwater quality is important.

The Santa Cruz River near Tucson, Arizona, is an effluent-dependent stream that supports vegetation and helps replenish declining groundwater levels in the region. Recently, researchers from the USDA Water Conservation Laboratory in Phoenix, in collaboration with the U.S. Geological Survey, investigated the temporal and spatial occurrence of indicator bacteria and pathogens in surface water along this river and in groundwater from monitoring wells adjacent to it.

E. coli numbers increased with distance from the discharge point, contrary to what might be expected from bacteria die-off.

Surface Water and Groundwater Sampled
Surface water was sampled at four locations along the Santa Cruz River. Sampling sites included the Roger Road Wastewater Treatment Plant (WWTP) outfall, the Ina Road WWTP flume (4.2 miles downstream from Roger Road WWTP), the Santa Cruz River at Cortaro Road (6 miles downstream from the Roger Road WWTP), and the Santa Cruz River at Trico Road (13.1 miles downstream from the Roger Road WWTP). To analyze diurnal fluctuations in concentration, multiple samples were collected over 24 hours to coincide with low, rising, peak, and falling streamflow at each of the four sites. To evaluate the spatial distribution of bacteria, surface water samples were collected from three additional points between the Ina Road WWTP flume and the Cortaro Road site. Groundwater samples were also collected from three monitoring wells adjacent to the Santa Cruz River near three of the surface water sampling points.

All samples were analyzed for total coliforms and E. coli by standard membrane filtration and culture-based techniques. Groundwater samples were analyzed for Legionella by molecular-based techniques. Water samples were filtered, followed by DNA extraction and real-time PCR with Legionella-specific primers. In addition, water samples from two locations were analyzed for Cryptosporidium and Giardia by concentration followed by immunomagnetic separation.

Diurnal Fluctuations Observed
The Ina Road WWTP flume demonstrated diurnal variation in coliform numbers, ranging from more than 800 colony forming units per 100 milliliters (CFU/100ml) at 9:00 pm to less than 100 CFU/100ml in the early morning. E. coli numbers demonstrated similar diurnal variations. The high and low coliform counts were concurrent with the high and
low flows in the channel, suggesting a correlation between bacterial concentrations and treatment plant hydraulics. Samples from the Roger Road WWTP outfall showed similar diurnal fluctuations. These results suggest that when assessing microbial loads for regulatory compliance in effluent-dependent streams, sampling should be conducted during both low- and high-flow periods, with average daily load reported instead of a single daily measurement.

Concentrations Increased Downstream

Results demonstrated that *E. coli* numbers increased with distance from the discharge point, contrary to what might be expected from bacteria die-off. Although the survival capacity of *E. coli* and pathogens in the environment is controversial, this investigation corroborates other studies that suggest *E. coli* survives and can even flourish in the soil profile (Gagliardi and Karns, 2000). Hence, once *E. coli* are introduced and established in the environment, in-situ growth can elevate counts in an affected water supply to levels above what is expected from local sources.

Coliform counts initially increased downstream with distance from the discharge point to Cortaro Road, then decreased farther downstream. Highest coliform concentrations at Cortaro Road (6,900 CFU/100 ml) prompted researchers to investigate further. Samples were collected from three additional points downstream of the Ina Road WWTP and upstream of the Cortaro Road monitoring site. An order of magnitude increase (from about 300 to 3,000 CFU/100 ml) in coliform numbers over a short distance from the discharge to Ina Road was observed. This can be attributed to reactivation of injured bacteria or regrowth in the stream and sediments. Researchers have argued that standard chlorination of municipal wastewater does not completely kill bacteria but may result in injured bacteria that are viable but nonculturable. Therefore culture-based analytical methods may actually underestimate the number of viable pathogens in treated effluent. Such underestimation may contribute to the release of large populations of viable bacteria into stream water.

Understanding the microbial loads and the physiological state of microbes in streams is just one aspect of developing effective control strategies; understanding how the environment affects survival is another. While the temporal results indicate the need for sampling during a range of flows, the spatial results stress the need to better understand how environmental factors such as nutrient availability (nitrogen, phosphorus, total suspended solids, total organic carbon), pH, temperature, and the presence of organic contaminants, particularly antibiotics, in the effluent affect the survival, reactivation, and regrowth of bacteria in streams and sediments.

Groundwater Impacted by Effluent

Total and fecal coliforms have been used for many years as water quality indicators. However, some pathogens, including protozoa, have higher resistance to chlorine disinfection than indicator bacteria and can survive long enough to percolate into groundwater. Hence, groundwater samples were collected from shallow wells adjacent to the Santa Cruz River near Ina, Cortaro, and Trico roads and tested for total coliforms, *E. coli*, and *Legionella*. Low numbers of coliform bacteria were detected in two of the wells (Ina and Trico) whereas *E. coli* was detected in only one of the wells (Trico). *Legionella*

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organic compounds (VOCs), nutrients, chloride, and elements such as arsenic and lead, according to the results of a five-year water quality study by the USGS.

**Rivers and Streams**

More than 80 percent of the samples collected from streams affected by agricultural and a combination of mixed land uses had phosphorus concentrations that exceeded the U.S. EPA desired goal of 0.1 milligrams per liter (mg/l) to prevent nuisance plant growth in streams. Although nutrients occur naturally in streams, additional and potentially elevated sources include agricultural and urban runoff and wastewater discharge.

In many streams near the mountain front, aquatic communities have been impacted by increased water temperature and nutrient and dissolved-solid concentrations as a result of water diversion, mainly for irrigation. Continued drought conditions and increasing demands for water in the areas surrounding the Great Salt Lake make this an ongoing water-quality issue, said Thiros.

At least one pesticide was detected in all but one of the 24 streams sampled. Insecticides — most commonly carbaryl, diazinon, and malathion — were detected more frequently in urban streams than agricultural streams. Diazinon was detected in about 90 percent of 42 samples from the urbanized Little Cottonwood Creek, but in only about 4 percent of 26 samples from Cub River, classified as agricultural. Thiros suggested that this is most likely because nutrients, pesticides, and VOCs accumulate between storms on impervious surfaces in urban areas and then are transported to streams in storm runoff. During the winter of 1999, for example, chloride concentrations in Little Cottonwood Creek often exceeded the EPA aquatic-life guideline following winter storms and the application of salt to area roads.

Aquatic-life guidelines for arsenic, cadmium, copper, lead, mercury, silver, and zinc were exceeded in sediment samples from streams that were affected by mine-tailing deposits and smelters (including some in urbanized streams). In areas with little mining or urban influence, such as the Bear River basin, trace-element concentrations were low compared to those measured in other parts of the nation.

**Groundwater**

The USGS study revealed that the median concentration of nitrate (6.8 mg/l) in shallow groundwater underlying residential and commercial land in Salt Lake Valley was almost five times the national median (1.4 mg/l) for groundwater studies in similar urban areas and was the highest measured in 34 urban studies across the nation. Thiros said that although nitrate does occur naturally in groundwater, elevated concentrations in urban and agricultural areas could result from leaking septic systems and sewer pipes, as well as from fertilizer applications. Even though this shallow water is not currently used for drinking, Thiros said the potential exists for contaminated water in the shallow aquifer to move downward to the underlying aquifer that is used as a public supply.

VOCs and pesticides were detected in water from 23 of 31 public-supply wells sampled in Salt Lake Valley, mostly at very low concentrations. The widespread occurrence of the VOC chloroform in Salt Lake Valley is likely a result of chlorinated public-supply water used to irrigate lawns and gardens in residential areas that then recharges the deeper aquifer. Although the concentration of these compounds measured in groundwater used for public supply is not a known health concern according to current standards, the occurrence of these compounds in the deeper groundwater presents the possibility that water with a higher concentration may enter this aquifer in the future.


**Broader Implications**

Results of the Santa Cruz study underscore the need for further research to assess impacts of effluent-dominated streams on groundwater quality, as well as the need for better understanding of the processes affecting bacterial concentration in these types of streams. Taking a broader view, the results also have implications for other situations. In Southern California, for example, the Orange County Water District (OCWD) has constructed recharge basins and injection wells that receive highly treated wastewater effluent that meets drinking water standards to recharge the groundwater basin. Similar projects undertaken in the Southwest may use water that is less highly treated, for which the consequences remain unclear.

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