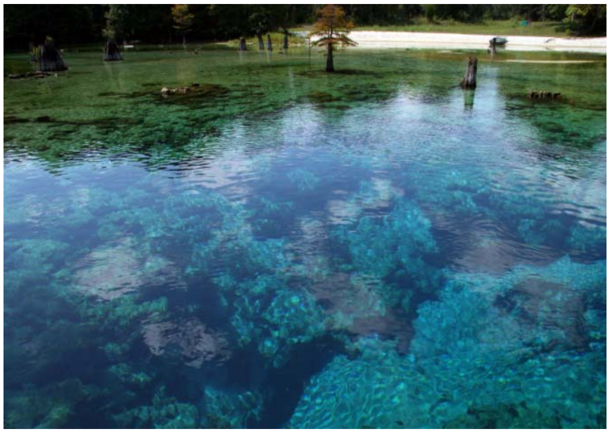
NATIONAL WATER-QUALITY ASSESSMENT PROGRAM—*Report on Factors Affecting Water Quality in Selected Carbonate Aquifers in the United States, 1993-2005*

The National Water-Quality Assessment (NAWQA) Program, implemented in 1991, is assessing the quality of water in principal aquifers across the Nation. A recently released U.S. Geological Survey (USGS) report entitled: Factors Affecting Water Quality in Selected Carbonate Aquifers in the United States, 1993-2005 assesses water quality in 12 carbonate aquifers, mainly in the eastern and central United States, where the NAWQA Program has collected data (see map, page 2). The selected aquifers represent major hydrogeologic and geochemical settings and, therefore, findings are relevant to other carbonate aquifers not studied. Carbonate aquifers are an important water resource and the largest source of drinking water for public supply of any bedrock aquifer, providing over 3 billion gallons per day. This is about 20 percent of the groundwater supplied as drinking water for the Nation. Groundwater samples were collected from more than 1,000 wells and springs representing a variety of uses such as for domestic and public water supply, irrigation, observation, and for livestock. Samples were analyzed for 151 constituents including physical properties, major ions, nutrients, radon, 47 pesticides, and 54 volatile organic compounds (VOCs).

Features of carbonate aquifers

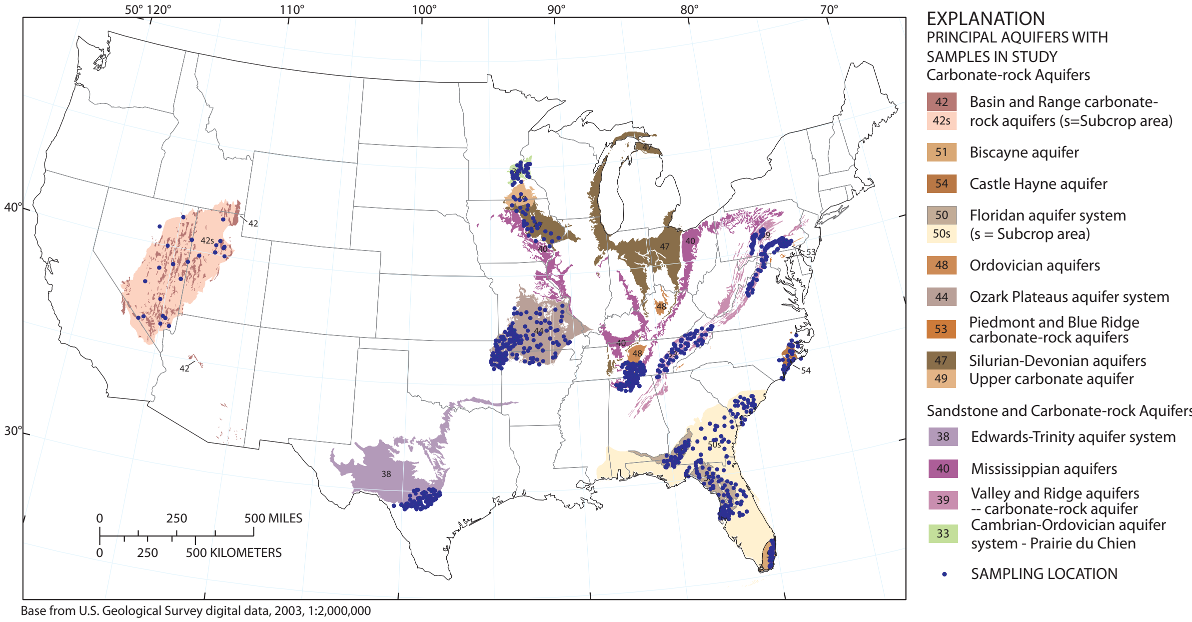
Carbonate aquifers, sometimes associated with karst terranes, have features such as sinkholes and large magnitude springs (see photographs below), as well as caves, sinking streams, and underground drainage systems.



(Photos from William E. Kochanov, Pennsylvania Geological Survey and Alan M. Cressler, U.S. Geological Survey)

Karst features form because of the rapid dissolution of limestone and dolomite relative to other types of bedrock. Groundwater flow in solution-enlarged conduits is markedly different than in other types of aquifers. Carbonate aquifers are highly productive, but can be particularly vulnerable to contamination because the open conduits provide relatively rapid downward movement of water and contaminants. However, even among carbonate aquifer systems, some areas are less vulnerable than others because of a variety of natural protective features such as the presence of a confining layer that impedes flow of water and contaminants, and geochemical conditions that enhance the degradation of contaminants. This study found a range of vulnerability to contamination because some of the aquifers had these protective features and others did not. Findings from this study of carbonate aquifers may help improve the prioritization and effectiveness of approaches for monitoring and management of carbonate aquifers in certain geographic areas.

Twelve carbonate aquifers studied



Groundwaters from 1,042 wells and springs were sampled and analyzed. Aquifers represented areas with land uses ranging from highly agricultural to urban to undeveloped and climate ranging from humid to arid. Aquifer characteristics ranged from shallow unconfined to deep confined.

Major Findings

Contaminants were most often detected at concentrations less than human-health benchmarks except for nitrate

- Nitrate was measured at concentrations greater than the U.S. Environmental Protection Agency (EPA) Maximum Contaminant Level (MCL) of 10 milligrams per liter as nitrogen in about 5 percent of wells. The vast majority of the samples that exceeded the MCL for nitrate were from wells in the Piedmont and the Valley and Ridge aquifers (in 63 and 14 percent of the wells, respectively) used for domestic supply and near or in agricultural areas; concentrations exceeded the MCL in less than 1 percent of the wells tapping the remaining aquifers. Homeowners may be unaware of possible contamination because domestic wells are not monitored regularly, as is required for public-supply wells, which points to the importance of greater public awareness. Nitrate can occur naturally, but elevated concentrations usually originate from man-made sources, including fertilizers, manure, and septic systems.

Human-Health Benchmarks Used in this Study

The term human-health benchmark refers to U.S. Environmental Protection Agency (EPA) Maximum Contaminant Levels (MCLs) for regulated compounds and USGS health-based screening levels (HBSLs) for unregulated compounds for which EPA has published toxicity information. Human-health benchmarks were available for 45 of the 47 pesticides analyzed and 38 of the 54 volatile organic compounds (VOCs) analyzed. Comparisons of concentration data to benchmarks provides an initial perspective on the possible significance of contaminants; it is not a substitute for a comprehensive risk assessment, which includes consideration of many more factors, such as additional avenues of exposure.

Major Findings—continued

- o Concentrations of man-made organic compounds, such as pesticides and VOCs, were seldom greater than available human-health benchmarks (about 3 percent). Two insecticides, diazinon and dieldrin, exceeded the benchmarks in 1 and 20 wells, respectively. Concentrations of four VOCs exceeded the benchmarks, including vinyl chloride (in two wells), and tetrachloroethene, trichloroethene, and 1,2-dichloropropane, in one well each. More than half of the wells with exceedances were used for drinking water (domestic or public supply).

- o The most common naturally occurring contaminant was radon, which is part of a decay series of uranium that can occur in trace amounts in aquifer sediments and rocks. Concentrations of radon were greater than the proposed EPA MCL (300 picocuries per liter) in nearly 60 percent of wells, and greater than the proposed alternate EPA MCL (4,000 picocuries per liter) in less than 1 percent of wells. Radon was found at higher concentrations in some areas of the United States than others. The four highest concentrations were found in the Floridan aquifer system, all of which were detected in water from wells used for domestic supply.

Water quality in the carbonate aquifers is controlled by a combination of factors, including chemical use and land use, and natural features, such as geology, hydrology, and aquifer composition.

- o The types and concentrations of contaminants in ground water in carbonate aquifers are closely related to land use and the chemicals that are used, such as fertilizers, pesticides, and VOCs. For example, concentrations of nitrate were significantly higher in ground water underlying agricultural land than in ground water underlying undeveloped or urban land. Herbicides were detected more frequently in wells in agricultural areas, whereas insecticides and VOCs such as chloroform were more frequently detected in wells in urban areas.

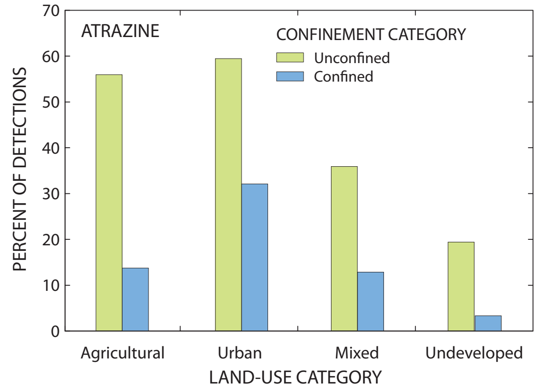
- o Natural protective features can control the transport of contaminants and therefore result in different contaminant concentrations among carbonate aquifers that have similar land-use settings and chemical use. For example:
  - •The presence of confining layers can affect the concentrations by limiting the mobility and transport of nitrogen and pesticides commonly applied in agricultural areas (see inset, page 4).
  - • Presence of dissolved oxygen can control concentrations of other chemicals in groundwater through chemical processes called reduction and oxidation (redox) reactions (see inset, page 4).

Water-quality results show importance of aquifer characteristics

- o Although carbonate aquifers have the karst features which can make these systems vulnerable to contamination, protective features can limit contamination. Examples of confinement and geochemical conditions illustrate that contaminant sources at the land surface do not always result in elevated concentrations in the aquifer. However, in aquifers lacking protective features and having a large contaminant source at the land surface, elevated concentrations of contaminants is likely. In carbonate aquifers without these protective features and a high contaminant source at the surface, concentrations of contaminants are among the highest in the nation.

Aquifer confinement is an important factor affecting water quality:

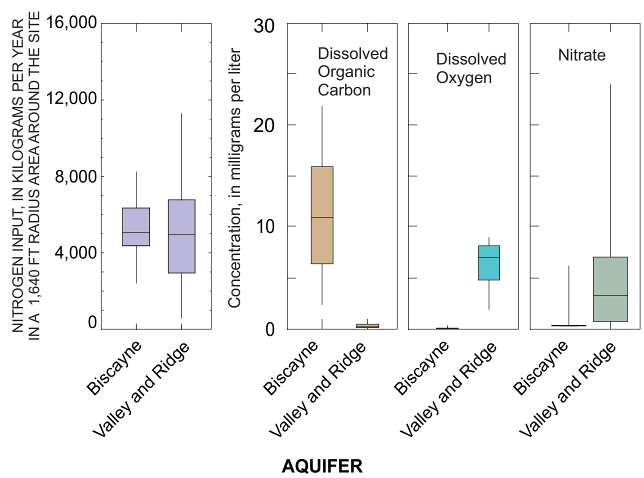
Aquifer confinement is a physical characteristic of an aquifer that affects the mobility of water and contaminants, and thus, affects water quality. A confined aquifer has relatively impermeable materials between the land surface and the aquifer. Water travels very slowly through this confining layer, thus allowing contaminants time to degrade. If there is no confining unit, it is unconfined and is sometimes referred to as a water-table aquifer.



In the example to the right, the detection frequency of atrazine was much greater in groundwater from unconfined aquifers than from confined aquifers, even when the land use was the same. In a similar comparison, median nitrate concentrations were highest in samples from wells in unconfined aquifers, and only a single sample from a confined aquifer exceeded the MCL of 10 mg/L for nitrate. A single sample from a well completed in a confined aquifer exceeded the human-health benchmark for a pesticide; however, all other cases where man-made contaminants (nitrate, pesticides, and VOCs) exceeded human-health benchmarks were in samples from wells in unconfined aquifers.

Redox conditions control the presence of nitrate

The presence or absence of dissolved oxygen can play a major role in controlling the occurrence and transport of contaminants in an aquifer. Groundwater low in oxygen (or "reduced"), for example, can, through a series of chemical reduction and oxidation (redox) reactions, decrease concentrations of nitrate. The role of redox reactions depends on the availability of reactive organic carbon and on groundwater flow from different parts of the aquifer that can transmit oxygenated water to reduced parts of the aquifer.The Biscayne and Valley and Ridge aquifers are both shallow, unconfined aquifers with relatively high inputs of nitrogen, and yet concentrations of nitrate vary in these two carbonate aquifers. Specifically, the median concentration of nitrate in the Biscayne aquifer was less than the detection limit of 0.05 mg/Land the median concentration of nitrate in the Valley and Ridge aquifers was 3.7 mg/L. Low concentrations in the Biscayne aquifer are tied to low concentrations of oxygen and high concentrations of dissolved organic carbon, contributing to anoxic conditions that allow the transformation of nitrate to innocuous, gaseous forms. Nitrate remains more stable in well oxygenated systems, such as the Valley and Ridge aquifers.



This briefing sheet highlights findings from the USGS Scientific Investigations Report, “*Factors affecting water quality in selected carbonate aquifers in the United States, 1993-2005*”, which is available online (http://pubs.usgs.gov/sir/2008/5240/). Supplementary information on this and related studies is available online *(*http://water.usgs.gov/nawqa/pubs/carbonate/*).* This USGS study was implemented by the National Water Quality Assessment (NAWQA) Program, which was initiated in 1991 to support national, regional, state, and local information needs and decisions related to water-quality management and policy (http://water.usgs.gov/nawqa).

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