GROUNDWATER POLLUTION: POINT SOURCES

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Gunn, J., (editor) *Encyclopedia of Caves and Karst Science*, Fitzroy Dearborn, NY.

Point source pollution is contamination that originates from any discernable or discrete source such as a pipe, ditch, channel, well, container, concentrated animal feed operation, landfill, or industrial storage area. This is in contrast to dispersed or non-point sources such as contaminants in storm water runoff from agricultural or urban lands (see Groundwater Pollution: Dispersed). Many contaminants commonly occur as both point and non-point sources. For example, salt used for road de-icing and spread along roadways may be considered a non-point source, whereas contamination from a road salt storage facility would be considered a point source. Other contaminants that commonly occur as both point and non-point sources are fertilizers, herbicides, and pesticides: from broad application in agricultural and residential areas or as point sources from manufacturing, formulation, and disposal sites.

Point sources may enter the karst groundwater system by either an allogenic or an autogenic source. Allogenic point sources originate in a non-karst area from the discharge of contaminants into surface streams. These then flow onto karst and sink into the bedrock, where they impact groundwater. Autogenic point sources occur on the karst landscape and directly enter the groundwater system as a liquid, such as from a leaking underground storage tank, or may be carried by rainwater runoff (leachate) from an industrial storage or disposal site.

Point sources have been responsible for the most serious cases of groundwater contamination, affecting both human consumers of groundwater and the aquatic fauna. Contaminants detected in groundwater in karst systems have included a wide range of volatile organic compounds (benzene, TCE, PCE), heavy metals (lead, mercury, arsenic), pesticides (DDT, atra-zine), and polychlorinated biphenyls (PCBs) (Crawford, 1998; Crawford & Groves, 1995). Particular problems are posed by non-aqueous phase liquids (NAPLs), which may be either dense (D) or light (L) depending upon their specific gravity. DNAPLs descend to, and accumulate at, the base of an aquifer whereas LNAPLs accumulate at the water table. Both DNAPLs and LNAPLs may act as a continuous source of karst groundwater contamination and may be transported relatively rapidly depending upon groundwater velocity and conduit morphology. LNAPLs may accumulate in conduits containing air as water flows from conduit-full to non-full conditions; in essence, the roof of the conduit acts as an oil / water separator. Accumulation of petroleum LNAPLs in conduits has created toxic and even explosive conditions in caves, homes, and schools, with some of the best documented cases occurring in the Bowling Green, Kentucky (United States) area. DNAPLs may collect in low areas in the bottom of active cave streams (or even dry conduits) and then be remobilized when groundwater velocities increase due to storm events.

Pathogens from human or animal waste frequently enter karst as a point source, both deliberately, such as where raw or inadequately treated sewage is discharged into a "soakaway" or drains from inadequate septic tanks, and accidentally such as from leaking sewer pipes. Numerous pathogen outbreaks have occurred in karst as little or no natural filtration occurs in the groundwater system. The Hidden River System in Horse Cave, Kentucky, was contaminated for many years with sewage discharged into a doline from a poorly designed and operated wastewater treatment plant. Most naturally occurring fauna were killed and sewage odours discharging from the cave made the downtown business district intolerable at times. Upon completion of a regional sewage treatment plant and piping of effluent to a surface stream, water quality in Hidden River Cave greatly improved and the cave has been reopened for tourism and recreational use (Gee & Heavers, 2002). More serious incidents in terms of human health include a *Cryptosporidium* (protozoa) outbreak in Braun Station (San Antonio, Texas) in 1984 which caused more than 200 people to become sick (D'Antonio et al., 1995). The acute bacterial contamination (*E. coli* 0157:H7) of karst groundwater in Walkerton, Ontario (Canada) in May 2000 resulted in over 2000 people becoming sick and nine dying (Worthington, Smart & Ruland, 2002). While the impacts of pollution on humans are clear, impacts on cave fauna can easily go unnoticed. In Castleton, Derbyshire (England), leachate entering a doline dramatically reduced the abundance and diversity of aquatic invertebrate taxa although surface sites downstream of the cave resurgence were much less obviously affected (Wood, Gunn & Perkins, 2002).

Many factors control the occurrence and persistence of contaminants in groundwater once the source has been identified and controlled. If contaminants are introduced to groundwater through a thick column of soil, the soil may store the contaminant and release it slowly over time, or in large quantities during storm events. If the contaminant is directly injected into a conduit, little of the material may be held in storage in either the rock matrix or fill; therefore, the site may return relatively quickly to pre-contamination conditions in relation to non-karst aquifers (see also Groundwater Pollution: Remediation).

In the United States, point source contaminants have a long history of regulation through a number of federal and state programs, including:

- Clean Water Act (CWA)—including the national pollution discharge elimination system (NPDES) program which regulates end of pipe discharge for municipal and industrial waste into surface and groundwater systems through a state or federal permit system. A number of states regulate the disposal of wastes into sinkholes (dolines) through the NPDES program.
- Underground Injection Control (UIC) Program—regulates the disposal of hazardous materials into the ground through injection wells. Modified sinkholes may qualify as injection wells under the UIC program. Some cities, such as Bowling Green, Kentucky, are located on rolling sinkhole plains, and utilize injection wells to control storm water runoff in the urban environment. However, the injection wells commonly flush urban non-point runoff into the karst groundwater systems beneath the city.
- Safe Drinking Water Act (SDWA)—includes the source water protection program to protect public drinking water supply wells and springs through control of human activities around well and spring heads as well as in recharge areas. Development in the recharge zone of the Edwards Aquifer, Texas (see separate entry), is controlled through a state water quality protection program. This program requires the identification of all significant karst features and places design criteria such as minimum spacing requirements between karst features and potential pollution sources.
- Resource Conservation and Recovery Act (RCRA)—includes regulation of the transportation, storage, and disposal of hazardous wastes as well as municipal solid waste disposal. A number of hazardous waste sites and solid waste landfills exist in karst areas of the eastern United States and have resulted in widespread contamination in some aquifers and related surface water systems.
- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund Act)—regulates abandoned hazardous waste sites. These are sites where the

owner either can not be found or does not have the resources to either investigate or remediate soil and water contamination at the site. Generally, parties that have been identified as contributors to site contamination can be held liable for the site.

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