

*“In the spring of the year 1780, the earth at the bottom of this sink suddenly gave way and fell into the cavity below, forming a circular aperture about the ordinary circumference of a common artificial well... There being no artificial or natural means to prevent the earth immediately about the well from falling in, the aperture is greatly enlarged, forming a sloping bank, by which a man on foot can easily descend within eight or ten feet of the water... The whole depth of the cavity is thirty or thirty-five feet” (Kercheval, 1850, p. 273).*

In Virginia, the formation and modification of sinkholes is a natural process in areas underlain by limestone and other soluble rock. The location and rate at which sinkholes form can be affected by man's activities. Sinkholes are basin-like, funnel-shaped, or vertical-sided depressions in the land surface. In general, sinkholes form by the subsidence of unconsolidated materials or soils into voids created by the dissolution of the underlying soluble bedrock. The rock exposed in a collapsed sinkhole is usually weathered and rounded, but some sinkholes contain freshly broken rock along their steep sides. Freshly broken rock may indicate that the sinkhole has formed by the collapse of a cave (naturally occurring) or a mine (man-made). Where sinkholes and caves have formed by the dissolution of soluble rock, such as limestone, dolomite, and gypsum, surface water is uncommon and streams may sink into the ground. This type of topography, formed by dissolution, is referred to as karst terrain. In karst terrain, sinkholes are input points where surface water enters the groundwater system.

## POTENTIAL SINKHOLE PROBLEMS

There are three types of potential problems associated with the existence or formation of sinkholes: subsidence, flooding, and pollution. Sinkholes are the result of differential subsidence of the land surface. The term subsidence is commonly used to imply a gradual sinking, but it also can refer to an instantaneous or catastrophic collapse.



Figure 1. Sinkhole in Russell County, Virginia

Sinkholes result from various mechanisms (Sowers, 1976), including consolidation from loading, consolidation from dewatering, hydraulic compaction, settling as materials are removed by groundwater flow, stoping or raveling of materials into a void, and instantaneous collapse into a void. Although the formation of sinkholes is a natural process in karst terrains, man-made modifications to the hydrology of these areas commonly results in the acceleration of this process.

The lowering of the water table in unconsolidated materials or soils, especially near the soil-bedrock interface, can result in the draining of voids caused by the dissolution of bedrock or the removal of soil by groundwater flow. The soil at the top of a recently dewatered void, the soil arch, is subject to increased force (effective stress) because of the loss of the “buoyant” support of the water. Wet soil weighs more and has less strength than if it were dry. If the strength of the wet soil is insufficient, the soil arch will fail.

A number of adjacent voids may coalesce to form a large void. If the strength of the dry soil is sufficient

to support the soil arch, the wet soil failure will proceed only to the dry soil above the former water level. Subsequent periods of extended heavy rainfall may wet the soil sufficiently to reduce its strength below that necessary to support the soil arch and failure would propagate to the surface and form a steep-sided collapse feature.

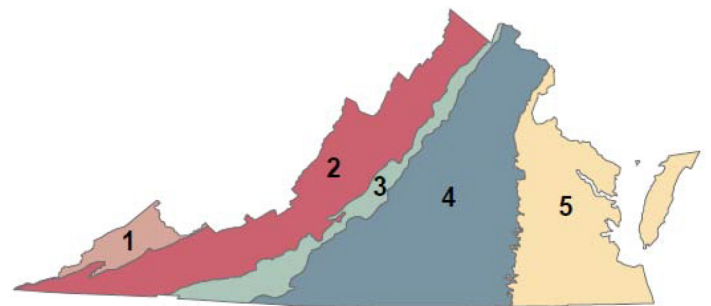
Patterns of pumping of high-yield wells over extended periods of time can result in large, as well as rapid, drawdowns of the water table. Where such rapid and large drawdowns occur in unconsolidated materials, collapse can be catastrophic and subsidence can be extensive over the area subject to the drawdown (Foose, 1967 and 1968). Sinkhole formation can also occur above solutionally enlarged fractures, which have formed caves or "mudseams". Water-table drawdowns can cause soil voids to migrate along solution features eventually leading to sinkhole formation at a distance from the well.

Subsidence is associated also with soil piping. Water leaking from culverts or other drainage structures can create a void beneath the drainage structure by compaction or internal scour of the soil. This reduction in support can result in displacement of the leaking structure and an increase in leakage or breakage. The void may increase in size to the extent that the soil has insufficient strength to support itself with subsequent failure leading to the formation of a steep sided collapse feature. The recognition of water mark stains on fracture surfaces and joints of drainage structures are indicators of this type of collapse feature.

Disposal of storm water in sinkholes or shallow dry wells can induce subsidence. Adjacent to the drainage input additional collapse features may form. Subsidence results from a combination of factors, which may include hydraulic compaction, soil piping, and increases in the range of fluctuation of the water table.

Rock and soil above a void created by underground mining may collapse to form a depression similar to a sinkhole. Voids, created by the solution mining of salt and the conventional underground mining of gypsum, limestone, and coal, have collapsed to form sinkhole-like depressions in Virginia.

Sinkhole flooding can develop from a number of natural conditions, but two man-made conditions are the most common causes in Virginia: the plugging of natural sinkhole drains by sediment and the overwhelming of natural sinkhole drains by increases in runoff due to artificial surfaces. Inadequate erosion control during construction can result in the plugging of natural sinkhole drains by sediment-laden runoff. The accompanying restriction of subsurface drainage causes an increase in ponding or flooding. Increased runoff from roads, parking lots, and structures is the most significant cause of sinkhole flooding. Much of the precipitation that would have percolated through a vegetated soil cover is introduced rapidly into surface and subsurface (input through sinkholes) drainage networks. Increases in runoff have been reported to range from 48 percent for areas of suburban housing to 153 percent or more for industrial or commercial areas (Aley and Thomson, 1981). Such increases in runoff can exceed the drainage capacity of natural sinkhole drain and result in ponding or flooding. In severe cases, excessive runoff can overwhelm the capacity of the natural subsurface drainage systems of sinkholes,



*Figure 2. True sinkholes are common in karst terrains, but other collapse features can occur throughout Virginia: 1) In the Appalachian Plateau province, collapse features are commonly related to mining activity. 2) In the Valley and Ridge province, the dissolution of limestone and dolomite commonly forms karst sinkholes. 3) Sinkhole-like features are very rare in the Blue Ridge province, and typically are related to soil piping. 4) In the Piedmont province, sinkholes may form due to the dissolution of sparse carbonate rock, or soil piping may cause collapse features. 5) Within the Coastal Plain province, the dissolution of concentrated shelly material in sand may lead to the formation of collapse features.*



causing water to back-up and flood sinkholes up-system (Crawford, 1981). An example of an overwhelmed natural subsurface drainage conduit occurred in Virginia in November, 1985. A stream of water estimated with a peak flow of 50,000 gallons per minute was observed flowing from a normally dry sinkhole during this major storm event (D. W. Slifer, 1988, personal communication).

The pollution of groundwater resources is an everpresent problem in karst areas. Sinkholes have long been used as dumps for waste materials. The dumping of solid wastes, such as dead livestock, garbage, and refuse into sinkholes is a major hazard to groundwater resources. It is also prohibited by existing State law (Code of Virginia, Title 10, chapter 12.2, section 10-150.14). Liquid wastes dumped into sinkholes can enter the groundwater system undiluted through the underground drainage routes or conduits. An excellent principle to follow is to never put anything in a sinkhole that you would not want in your drinking water.

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