Caves and caverns: seepage in natural caves

Description: Modelling suggests that a capillary barrier will form in unsaturated rock adjacent to a cavern and that this will act as barrier to water inflow into the cavern (Philip et al., 1989; Philip, 1990), although inflow may not be totally precluded (Williams et al., 1990). The effectiveness of the capillary barrier will depend on the dimensions and shape of the cavern, the percolation flux, heterogeneity in rock properties, the ambient flow field, and relative humidity (Williams et al., 1990). There is also some experimental support for the formation of a capillary barrier (Wang et al., 1999).

The US DOE have sought analogues for the volume and nature (drips v diffuse flow) of water seepage into natural and man-made caverns in the unsaturated zone. Evidence for the volume of seepage from natural caverns is considered here. There is a separate critical review of the evidence from man-made caverns.

Simmons (2002) reported two examples of natural caverns in which seepage into the caverns has been measured and compared to surface precipitation and infiltration.

The Altamira Cave, Spain is located in an area of high rainfall, ~1,140 mm yr^{-1}. Infiltration into the bedrock overlying the cave has been estimated as 480 mm yr^{-1}. The cave itself is overlain by only 7 m of fractured interbedded limestone and mudstone. Seepage into the cavern, which is dominated by "14 significant drips", has been estimated to be less than 1% of the infiltrating water above the footprint of the cave (Villar et al., 1985; Simmons, 2002). Seepage is believed to be dominated by fracture flow so that the low seepage has been attributed to near-cavern capillary barrier diversion effects rather than due to the presence of flow barriers such as impermeable mudstones.

The Kartchner Caverns, Arizona, have formed within a fault-bounded block of steeply-dipping Mississipian limestone. The sub-horizontal caverns are above the water table and cut across the bedding in the limestone. Seepage is dominated by fracture flow and along interfaces with impermeable beds (Graf, 1999). At least sixty small displacement faults cut the caverns (Jagnow, 1999). Average annual precipitation is 448 mm yr^{-1}. Despite the highly fractured rock mass, seepage into the cavern has been estimated to be in the range 4.3 to <12.4 mm yr^{-1}, less than 3% of the annual precipitation (Buechar, 1999). Unfortunately, the net infiltration rate into the host rock was not measured so it is unclear as to how much of the reduction in flow is due to flow diversion in proximity to the cavern and/or due to limited infiltration into the limestone at the ground surface.

Relevance: These analogues are relevant to underground facilities constructed within the unsaturated zone e.g. the proposed Yucca Mountain repository. They are also directly relevant to shallow storage concepts such as those being considered in France.

Position(s) in the matrix tables: Near-field, groundwater flow.

Limitations: Percolation rates and inflow rates in the unsaturated zone depend on many factors ranging from present and future climate, infiltration rate, host rock properties especially percolation flux and the shape and size of the caverns. In practice this means that while these analogues are useful, analogues in conditions more closely matching the conditions at a specific site will be of maximum relevance. Intersection of perched water cannot be excluded during construction.

Both caves are at shallower depths and in more fractured rock than proposed for the Yucca Mountain repository and may be expected to show a more direct and rapid response to precipitation and infiltration. The Altamira Cave demonstrates that seepage is only a small fraction of infiltration which provides support for the presence of a capillary barrier. However, no attempt was made to demonstrate that this seepage reduction was not due to other factors such as the presence of a flow barrier in the overlying strata. In the case of the Kartchner Caverns, while showing seepage much less than precipitation, the absence of any data on infiltration means that the reduced seepage cannot unambiguously be attributed to a capillary barrier as suggested by Simmons (2002). A more extensive database of examples would be useful.

Quantitative information: Water inflow into caverns in the unsaturated zone may be only a small percentage of the local groundwater infiltration rate, but localised inflow cannot be precluded.

Uncertainties: There must be considerable uncertainty over the groundwater inflow at a specific location since inflow is in part controlled by local heterogeneity in unsaturated rock flow properties.

Time-scale: These analogues studies are looking at present-day processes.

PA/safety case applications: Utilised in the TSPA developed for Yucca Mountain.

Communication applications: Not known, but probably used by the U.S. DOE.

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Added value comments: These analogues have already been used by the US DOE in the development of their conceptual model for seepage at Yucca Mountain.

Potential follow-up work: Further data acquisition at a larger number of these types of analogue sites could be used to provide additional quantitative data and build confidence in the general applicability of the results.

Keywords: Seepage, Caverns, Unsaturated Zone, Altamira Cave, Kartchner Caverns

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