When water meets an underground hole

Conventionally, the question of whether water seeps into caverns, tunnels, and other underground holes is answered by a simple yes or no: yes, if the soil surrounding the hole is saturated with water; no, if it isn't.

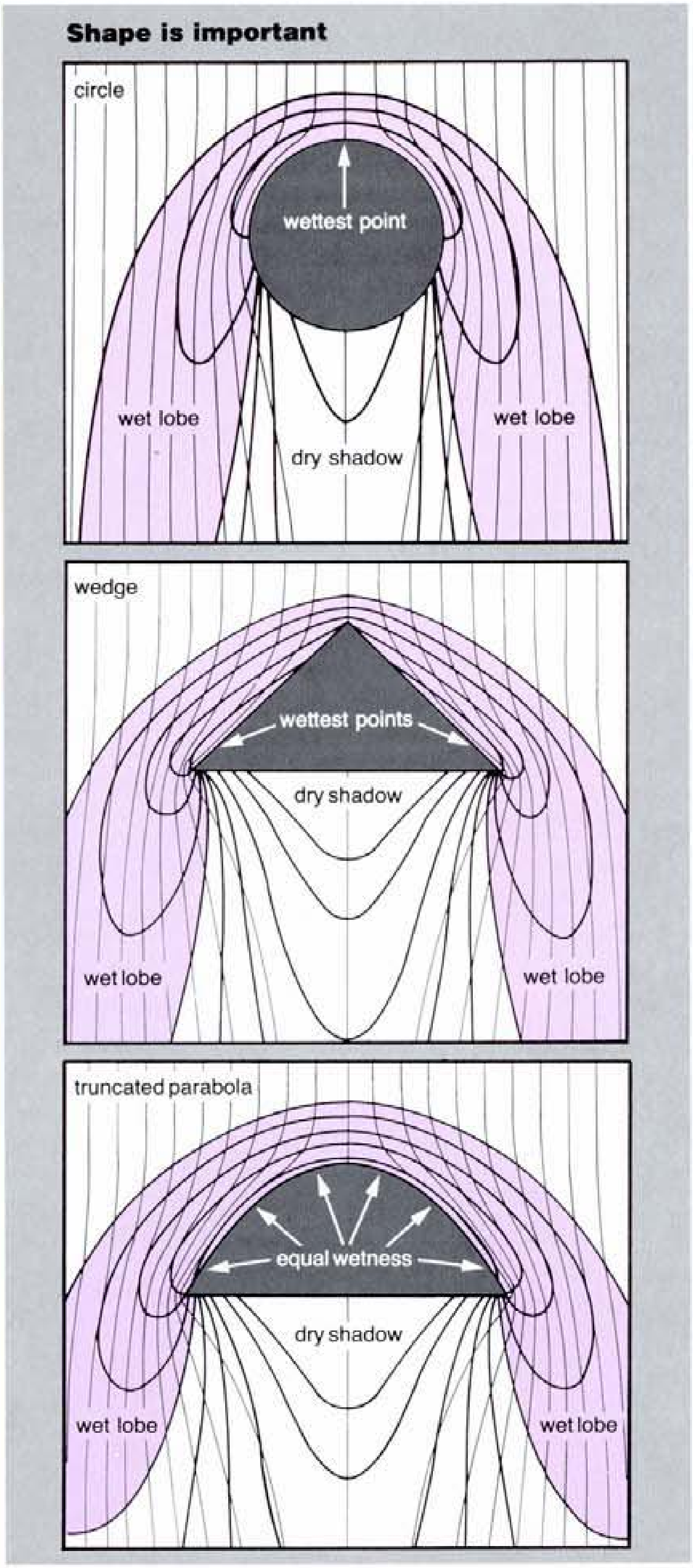
Unsaturated soil is found at great depths in the world's well-watered regions or close to the surface in arid and semi-arid regions like Australia. Hydrologists have commonly believed that, in these soils, because the pressure of the soil air exceeds that of water seeping downwards, the higher pressure keeps that water out when it meets the hole.

Recently, Dr John Philip and Dr John Knight, of CSIRO's Centre for Environmental Mechanics, and Dr Trevor Waechter of the University of Melbourne have shown that this is not always true: water in unsaturated soil can indeed enter holes.

Their discovery is important because it sheds light on the role of macropores in hydrologic processes and on the patterns of water distribution near and under buried stones and rocks — helpful for scientists studying the ecology of various soil fauna and flora. Information about the way water enters macropores — the small tunnels created by, among other things, earthworms and decayed tree roots — is valuable for agriculturalists and hydrologists who need to need to know exactly what is happening to water in soil. And the research also gives insight into water entry and the formation of stalactites in caves.

Knowledge about water entry into caves, or any other underground hole, has great practical interest for engineers designing tunnels and cavities in unsaturated zones. For example, an ideal design of a repository for storing nuclear wastes would allow little or no water to seep in (or out).

In fact, Dr Philip has given presentations on the research to staff of the United States Department of Energy's Yucca Mountain Project, whose headquarters are at Las Vegas. The Australian work is highly relevant to the proposal for safe storage of high-level nuclear wastes some hundreds of metres below the Nevada desert. Dr Philip hopes that negotiations between the Centre for Environmental Mechanics and the Department of Energy will lead to a contract on hole research specifically oriented to Yucca Mountain.



In unsaturated soils, the way in which water flows around and into a hole depends to a large extent on the hole's shape. The light lines represent water flow. The heavy lines are contours of constant wetness.

In Nature, downward seepage represents precipitation less run-off, evaporation, and transpiration. In the soil's upper layers, the velocity of this downward seepage increases in response to precipitation and diminishes (or may even reverse direction) during dry periods. But at great depths, few fluctuations occur and the downward seepage velocity tends to be constant in time. Although by most standards the speed is fairly slow — in arid and semi-arid regions it lies in the range $0{\cdot}032$ to $3{\cdot}2 \times 10^{-9}$ metres per second (1 to 100 mm per annum) — it has a large influence on the rate at which water enters the hole, as do the hole's size and shape.

But the key to why water enters is that an underground hole serves as an obstacle to the water's downward movement and therefore increases water pressure at parts of the hole surface. Dr Philip and his colleagues have calculated that for a great enough seepage velocity, or a large enough cavity, the water pressure increases to the point where a seepage surface forms and water enters the hole.

Although the conventional soil-physical picture, based on theories of capillary movement, indicates that the larger the hole the less prone it is to contain water, they have shown that the opposite is true: the larger the hole, the more vulnerable it is to water entry. Shape too, is very significant.

According to the scientists, for cylindrical and spherical cavities, the crucial point of water entry is the topmost point of the cavity roof, whereas in 'sharper' shapes, such as a wedge, water enters near the cavity floor. They have calculated that flat-roofed cavities are inefficient and readily admit water, while the performance of vee-shaped roofs is even worse.

When it comes to designing underground cavities and tunnels, they have calculated that a parabolic roof is the most efficient. In this case the water exerts uniform pressure on the roof and so it leaks either nowhere or everywhere. This means that, other things being equal, parabolic shapes provide the largest possible seepage-free storage volume or floor area under given conditions.

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An analog for infiltration and unsaturated seepage. J.R. Philip. *Eos*, 1987, **11**, 153–4.

Unsaturated seepage and subterranean holes: conspectus, and the exclusion problem for circular cylindrical cavities. J.R. Philip, J.H. Knight, and R.T. Waechter. *Water Resources Research*, 1989, **25**, 16–29.