

# Improved cavity detection from coupled seismic and hydrologic models

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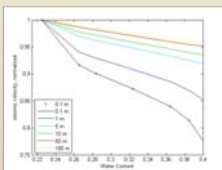
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## Problem Statement

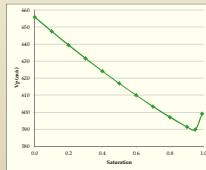
Seismic methods hold much promise for cavity detection, but the results from field measurements have been frustratingly inconsistent between field sites. The reasons for the inconsistencies are not fully understood, though water saturation in the near-surface may be responsible to some extent. The conventional approach has been to focus on reflections and refractions generated from the impedance contrast of the cavity wall itself, where the dimensions and geometry of the cavity should play key roles. Here, we instead focus on the influence of impedance contrasts that are generated by hydrologic processes in the adjacent porous medium.

## Theory

We take advantage of two approaches to account for soil moisture effects on seismic velocities. Velocities in the near-surface unconsolidated medium are best described by Brutsaert (1964) which accounts for the increased elasticity in bulk modulus from unsaturated capillary forces. This effect persists to approximately 10 m depth after which it is balanced by overburden. The Biot-Gassmann relation, adjusted for partial saturation by the Reuss average, is used below 10 m.



Brutsaert

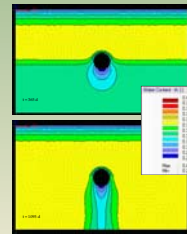


Biot-Gassmann

## Hydrology

Detectable hydrologic anomalies can be created by drainage of groundwater into the cavity or by the creation of a capillary barrier around the cavity. Because both processes ultimately involve unsaturated conditions we use HYDRUS 2D to numerically solve the Richard's equation and simulate flow through the vadose zone.

Four cases were modeled to represent likely scenarios for method success. In the first case (A), a 3 m diameter circular cavity is placed at 5 m depth. In the three remaining cases, a 5 m diameter circular cavity was placed at 15 m depth. For these an unconfined aquifer was placed so that the cavity was far-above (B), near-above (C), or below (D) the water table (depth = below modeled area, 20 m, 10 m, respectively).



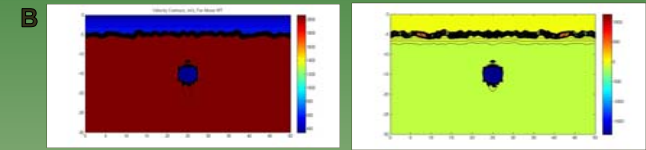
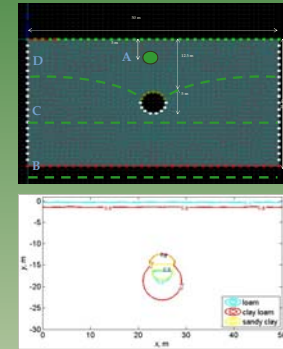
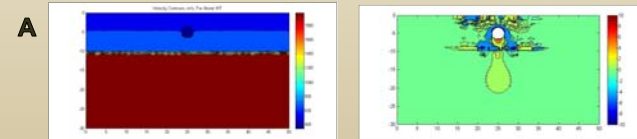
In the vadose zone, the best case medium for this method is a high-capillarity soil to expand the hydrological influence of the anomaly. The 80% saturation line is shown for three representative soil types using the far-above water table case.

A seasonal 3 yr precipitation forcing pattern is applied. Given the downward movement of this moisture, the vadose-zone cavity causes two disturbances: (1) water accumulates above the cavity, crossing the seepage boundary only when saturation is attained; (2) a 'shadow' area of lower saturation develops beneath the cavity. These two phenomena can more than double the anomalous area beyond the cavity itself.

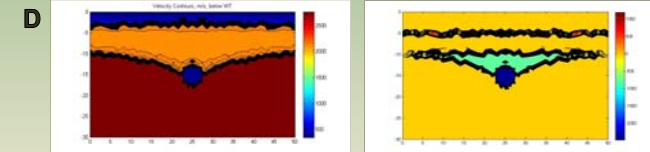
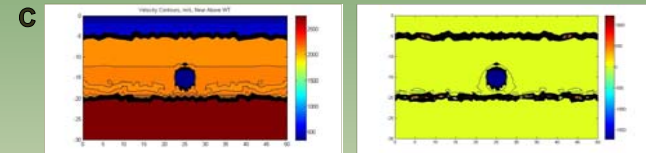
## Seismic Velocity

Results are shown for each of the four scenarios. In each case the left panel displays contours of seismic velocity and the right panel shows the difference in velocity for that hydrological scenario between calculations with and without the cavity present.

For the two vadose zone cases, A and B, the 'shadow-effect' anomalies remain visible beyond the cavity; however, the relative magnitude of change from the background is significantly moderated.



When the cavity is near-above the water table the shadow effect is diminished. However, a cavity that dewateres a section of the aquifer creates the largest anomaly in size and magnitude.



Our hydrology-determined velocity models will be used in finite-difference wave propagation simulations to determine the effects on seismic waves at various depths and saturations. Saturation features in the seismic data can then be utilized to detect cavities rather than relying on traditional yet inconsistent reflection/refraction approach. In ongoing work, we will ground-truth these models with both laboratory and experimental results.

## Conclusions

Saturation anomalies created by infiltrating water passing around a cavity or by draining an already saturated area can more than double the footprint of the original cavity.

Additional work with wave-propagation simulations is in progress to determine whether the increased footprint is sufficient to improve detectability and to resolve previous inconsistencies with seismic methods.

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