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Inferring unsaturated hydraulic properties from measurements made in angled boreholes

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Angled boreholes provide access to the subsurface for monitoring while minimizing disturbance of overlying sediments. However, boreholes in the vadose zone alter the flow of water near the borehole. The altered flow patterns can cause significant changes in the water content and pressure head within the sample volume of instruments placed on or in a cased borehole. Specifically, the pressure head and water content will be overestimated if instruments are placed at the top of the borehole and underestimated if instruments are placed at the bottom of the borehole. We first examine the dependence of these over- and under-estimates on the borehole diameter and dip angle, applied flux, and soil hydraulic properties. We then identify optimal locations for measurements in angled boreholes and provide approximate corrections for existing instrumented boreholes. Finally, we demonstrate that measurements made at multiple locations around an angled borehole can be used to infer the water flux and/or the soil hydraulic properties. This final analysis makes use of the Shuffled Complex Evolution Metropolis model to infer these parameter values and to determine the uncertainty of the predictions. The results of these analyses show that the errors caused by flow diversion around angled boreholes can often be corrected and that the presence of the boreholes may allow for unique hydrologic monitoring opportunities if analyzed correctly.