PIEDMONT GEOHYDROLOGY: IMPLICATIONS FOR FLOW AND TRANSPORT

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INTRODUCTION

Little attention has been paid to groundwater and contaminant flow in complicated geohydrologic settings such as the Piedmont Province. Usually, analogy is made, either explicitly or implicitly, to hydrologic conditions in the Coastal Plain. Such analogies are inappropriate. The flow domain in the Piedmont consists of the following materials: a thin layer of soil, a variably thick zone of chemically weathered bedrock (saprolite), a transition zone of less-well weathered rock that gradates into a relatively unweathered fractured bedrock. This paper will examine some theoretical flow conditions of the saturated saprolite/bedrock system to illustrate how water flows through this system.

BACKGROUND

The Piedmont consists of ancient igneous and metamorphic rocks of the Appalachian Mountain system. These rocks are hard and dense; primary porosity is virtually absent in unweathered rock. Groundwater moves through the rocks entirely in fractures and the flow is dependent upon the density, size, and orientation of these fractures. It is often assumed that the fractures will preferentially align with the direction of foliation.

Near the surface, the bedrock has been weathered to saprolite. Although it may be quite thick, the saturated thickness above the relatively competent bedrock is usually fairly shallow, and in some areas for part of the year the saprolite may be entirely unsaturated.

Fully weathered saprolite has a porosity of 40-50%, and the saturated hydraulic conductivity is generally assumed to be greater parallel to foliation, which is often near vertical. For example, Stewart (1962) found that vertical hydraulic conductivities exceeded horizontal conductivities by 25 to 100 times. Several other studies (Schoeneberger and Amoozegar, 1990; Vepraskas et al., 1991; White and Fleck, 1990) have not found significant correlation between foliation and saturated hydraulic conductivity. These latter studies used direct observation: permeameter results from cores taken at precise orientations while the earlier study inferred the anisotropy based upon the observed watertable response to hydraulic loading. It is possible that the latter study was influenced by more partially weathered material that maintained the original anisotropy of the rock.

THEORETICAL MODEL

Flow in this system depends upon more than hydraulic conductivity. Darcy's law must be incorporated with continuity to provide the governing equation for flow in a domain. For a unique solution, appropriate boundary conditions must be imposed on the edge of the flow domain. For this discussion, we will assume a domain that is a vertical slice (x,z) that extends from an upland ridge to a valley stream. The upland and valley boundaries are assumed to be no flow. The upper boundary of the domain is the watertable. This can be represented as a boundary of known head. The bottom of the flow domain is assumed to be no flow. For simplicity, steady-state conditions, with no sources or sinks, are assumed.

If the entire domain is isotropic and homogeneous (hydraulic conductivity the same in all directions and at all locations), then flow will occur from the upland portion of the cross-section to the lower portion, exiting near the stream. The relative amount of vertical flow into the bedrock portion of the domain depends upon the lateral versus vertical scale of the cross-section. If the lateral scale is quite long compared to the depth, the flow will be essentially horizontal for much of the domain. The relative importance of saprolite versus bedrock for this case depends upon the thickness of the saturated saprolite. This result, of course, is not very enlightening because it is unreasonable to assume isotropy and homogeneity for a saprolite - bedrock system.

If we change the system to incorporate anisotropy ($K_v > K_h$), we find the flow paths moving deeper into the flow domain. This would imply that most of the flow would occur in the bedrock, as the saprolite is a fairly thin layer overlying the bedrock. The shape of the potential surface in a steady-state problem can be misleading with respect to flow; the shape is independent of hydraulic conductivity. The amount of flow through the domain will be strongly influenced by the minor axis (horizontal) conductivity. Therefore, while vertical anisotropy will imply a deeper involvement with the bedrock, the total amount of flow will be smaller in this system because of the relatively small K_h.

A more realistic picture of flow in the saprolite - bedrock system is obtained by assuming heterogeneous, isotropic conditions. We can expect that the hydraulic conductivity in the saprolite to be greater than in the bedrock. This results in a flow system where the flow is essentially horizontal in the saprolite and essentially vertical in the bedrock. This result is something like the shallow lateral flow condition, of the first case, in the saprolite over a deeper flow condition in the bedrock. The relative amounts of flow in the two systems depend upon the hydraulic conductivities of the two systems. Because conductivity will be greater in the saprolite, more flow will occur in that region.

CONCLUSION

An even more realistic picture is obtained if we assume the problem is heterogeneous and anisotropic. The studies cited earlier indicate that the saprolite can be assumed to be isotropic, while the bedrock is highly anisotropic with $K_v >> K_h$. The behavior of this flow problem will be similar to the two-layer isotropic problem, except much more flow will occur in the saprolite than in the bedrock. The flow in the saprolite will dominate because the hydraulic conductivity in the saprolite will be many times greater than the minor axis conductivity in the bedrock.

Modeling a hypothetical cross-section of a saprolite - bedrock system can help us understand where flow will occur. For a realistic saprolite - bedrock condition, flow will be predominantly in the saprolite. These results have important implications for contaminant transport as well as for developing monitor well site plans.

LITERATURE CITED

Stewart, J. W., 1962. Water-yielding potential of weathered crystalline rocks at the Georgia Nuclear Laboratory. U.S.G.S. Professional Paper 450-B, p. B106-B107.

Schoeneberger, Philip and Aziz Amoozegar, 1990. Directional saturated hydraulic conductivity and macropore morphology of a soil-saprolite sequence. *Geoderma* 46: 31-49.

Vepraskas, M. J., A. G. Jongmans, M. T. Hoover, and J. Bouma, 1991. Hydraulic conductivity of a saprolite as determined by channels and porous groundmass. *Soil Sci. Soc. Am. J.* 55: 932-938.

White, Richard and William Fleck, 1990. Effects of foliation on the hydrologic properties of Piedmont saprolite. Technical Completion Report G1588-05, South Carolina Water Resources Research Institute, Clemson University, Clemson, SC, 89 pp.