Category I: Hydrology, Climatology & Hydraulics

Investigation of Groundwater Flow in Foothill and Mountain Regions using Heat Flow Measurements

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EXECUTIVE SUMMARY

Continuing expansion of the human population in foothill and montane areas of California has been accompanied by increased use of groundwater resources in these areas, both for water supply and waste disposal. In many foothill and montane areas, a large proportion of domestic water wells have been contaminated (SWRCB, 2005). Groundwater flow patterns in most montane areas are not well known, due to expense and challenges inherent to hydraulic approaches alone in characterizing groundwater flow in hardrock areas. Consequently, estimation of groundwater recharge rates and sustainable yields as well as development of groundwater management strategies for both quantity and quality are sufficiently difficult that they seldom are performed in these areas. We propose a thermal approach to better define groundwater flow patterns in fractured-rock aquifers that typify foothill and mountainous regions, ultimately for the purpose of providing a scientific basis for groundwater management.

The thermal approach employs precise measurements of subsurface temperature profiles in existing wells and boreholes. Recent improvements in probe technology have enabled easily performed temperature profile measurements. These measurements are made at a small fraction of the cost of standard hydraulic methods of well/aquifer yield testing, and with much less associated expense than standard geophysical methods (e.g. ground-penetrating radar, seismic) often used to characterize sedimentary aquifers. The approach is particularly suited to montane and other high-relief areas, since subsurface temperatures are particularly sensitive to the magnitude and pattern of groundwater flow in these areas. Advances in processing speed of inexpensive desktop computers and the availability of powerful data processing software have recently enabled routine analysis of coupled heat and groundwater flow; with measured heat flow acting as a robust constraint on groundwater flow.

We have performed temperature profile measurements in dozens of wells and boreholes in the Tahoe Basin region. Analysis and modeling of the data has been initiated. Preliminary results indicate that temperature profile data can constrain groundwater models to produce much more reliable estimates of vertical groundwater flow rates, and recharge rates. Measured temperature profiles often indicate the presence of vertical intra-borehole flow; including very small flow rates (much smaller than can be measured

with borehole flowmeters). Further modeling and data analysis should enable us to identify factors determining the sensitivity of the temperature profile to intra-borehole flow.

Preliminary modeling results suggest a particularly powerful application of thermal analysis in high relief areas: the shape of the temperature profile near the borehole bottom is sensitive to small (and large) rates of groundwater flow present at depths far below the bottom of the borehole. For example, temperature profiles in wells in basin-fill that terminate near the bedrock surface are sensitive to groundwater flow deep within the bedrock. This sensitivity is particularly pertinent in hardrock areas of thin or absent sedimentary cover, since the magnitude and depth of flow into bedrock is generally very difficult and/or expensive to determine using hydraulic or other geophysical approaches. Additional modeling and analysis will be used to define conditions under which inferences can be made on the magnitude of deep groundwater flow, using temperature profile data.

Finally, the use of temperature profiles in helping to define the amount of groundwater recharge into montane basin-fill aquifers from adjacent mountain fronts and from the mountain block will be explored. This analysis is being initiated as part of an ongoing project (terminating May 2006) with the South Tahoe PUD. We hope to expand on and generalize from our experience with this project, in particular delineating the influence of heterogeneous surface temperature boundary conditions on the subsurface transport of heat, and accurately accounting for this influence when inferring groundwater flow patterns from heat flow measurements.