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Methodology

The colloidal borescope is an *in situ* instrument capable of directly observing suspended colloidal size particles (1 to 10 μm) and determining ground water flow direction and velocity in an open borehole or monitor well in real time. In addition, the borescope can be used to investigate colloid mobilization during well sampling and the influence of pumping, tides, and subsurface drains. The fixed-focus colloidal borescope was developed at the Oak Ridge National Laboratory-Grand Junction (ORNL-GJ) in Colorado, and has been used to characterize ground water flow at several DOE facilities including Lawrence Livermore National Laboratory (LLNL), Kansas City, Fernald, Savannah River, Hanford, Portsmouth, and Paducah. The borescope consists of a video camera, compass, optical 140X magnification lens, and illumination source, all encased in a stainless steel, waterproof housing (Figs. 1 and 2). The colloidal borescope is lowered to the desired depth in the well and video images of colloids are tracked by a Video Image Analysis System (VIAS) which uses a PC computer with a video frame-grabber board to digitize up to 256 colloids every 4 seconds (Fig. 3). The VIAS analyses the digitized video images and calculates the number, size, flow direction, and flow rate of the colloids. These data are recorded on the PC hard drive and plotted. Two borescopes have been used at the LLNL facilities: the original fixed-focus borescope instrument with software designed by the ORNL-GJ, and the remote-focus, variable-illumination borescope with particle image processing LabView software designed by LLNL (Fig. 4). Both instruments function similarly, however, the remote-focus borescope provides a 500-mm focal range, variable illumination for better particle tracking, a flux-gate compass, an alpha-numeric image encoder, and LabView processing software that provides several real-time image processing options and digital sampling frequencies. A typical borescope log is shown on Figure 5.

Results

In 1994, we used the colloidal borescope to observe colloid movement in 28 ground water monitor wells at LLNL Site 300 and Main Site. Site locations are shown on Figure 6. LLNL Site 300 is a DOE experimental test facility located in the Altamont Hills of California approximately 60 miles east of San Francisco. The hydrogeology of Site 300 is dominated by consolidated silty sandstone aquifers, as well as a channel fill alluvial aquifer system composed of unconsolidated sand, gravel, and clay. LLNL Main Site is a DOE research facility located in Livermore, California, approximately 40 miles east of San Francisco. The hydrogeology of Main Site consists of semi-consolidated valley-fill alluvial deposits that contain a heterogeneous mixture of buried stream channel and overbank deposits. The application of the colloidal borescope at both sites allowed us

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to compare and contrast our hydrologic models, as well as assess microscale ground water flow with respect to regional flow as indicated by potentiometric surface maps.

The colloidal borescope was used in two areas of the General Services Area (GSA) at Site 300. Flow directions indicated by the borescope are shown in Figures 7 and 8, along with potentiometric surface contours. There is good general agreement between the two methods. Variations are attributable to preferential flow paths or changes in structural dip. Colloids were observed to flow generally perpendicular to potentiometric contours in the more restricted portions of the buried channel, and flow direction was more variable in the wider areas of the channel. In general, these data confirmed our hydrologic model and were used to help site several new monitor wells near a VOC release site and ground water plume. The colloidal borescope was also used to monitor the hydraulic influence of a nearby ground water extraction and treatment system operated as a CERCLA Removal Action. During the period of observation, ground water was being extracted from the shallow alluvial aquifer at 42 gpm. Prior to pumping, colloid flow direction generally followed the regional flow direction for alluvial ground water. During ground water extraction, colloid flow directions in nearby wells clearly showed the influence of the ground water extraction system.

Figure 9 shows flow directions indicated by the colloidal borescope and potentiometric surface contours at LLNL Main Site. Hydrogeologic data obtained during monitor well installation and long term hydraulic tests indicate that the hydraulic system is very complex and consists of many poorly to moderately well connected meandering stream channels and preferential flow paths. The colloidal borescope measurements indicated that the local ground water flow direction was highly variable, as expected given the fluvial depositional environment. As seen during the Site 300 investigation, monitor wells completed near operating extraction/irrigation wells demonstrated either swirling colloid patterns or distinct colloid velocities and flow directions toward the extraction well.

Conclusions

The initial investigations at both LLNL Site 300 and at Main Site were useful in determining ground water flow direction and velocity. Although many of the colloid flow directions measured were consistent with potentiometric surface contours, significant microscale variations were observed with the colloidal borescope. We were able to enhance our understanding of local ground water flow dynamics. These data helped site several monitor wells near a VOC release site and ground water plume, where the colloidal borescope data were used to verify regional flow and to make minor adjustments to the well placement. In many hydrogeologic environments, microscale flow patterns are likely to exist and influence ground water flow and contaminant transport. The colloidal borescope is a very useful instrument to enhance the general site hydrologic model and to characterize preferential flow paths near release areas.

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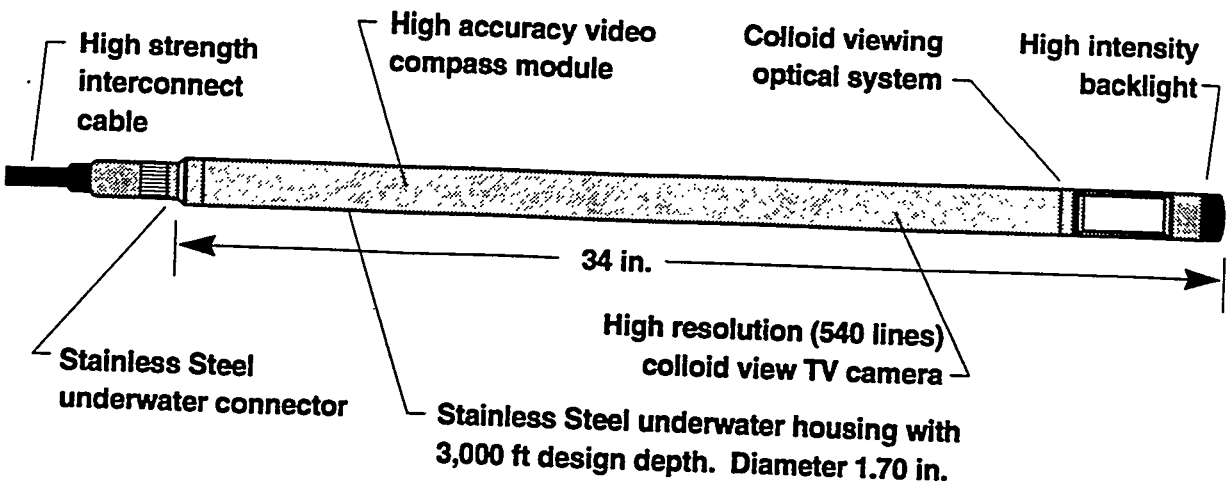

Figure 1. Schematic of the fixed focus Colloidal Borescope.

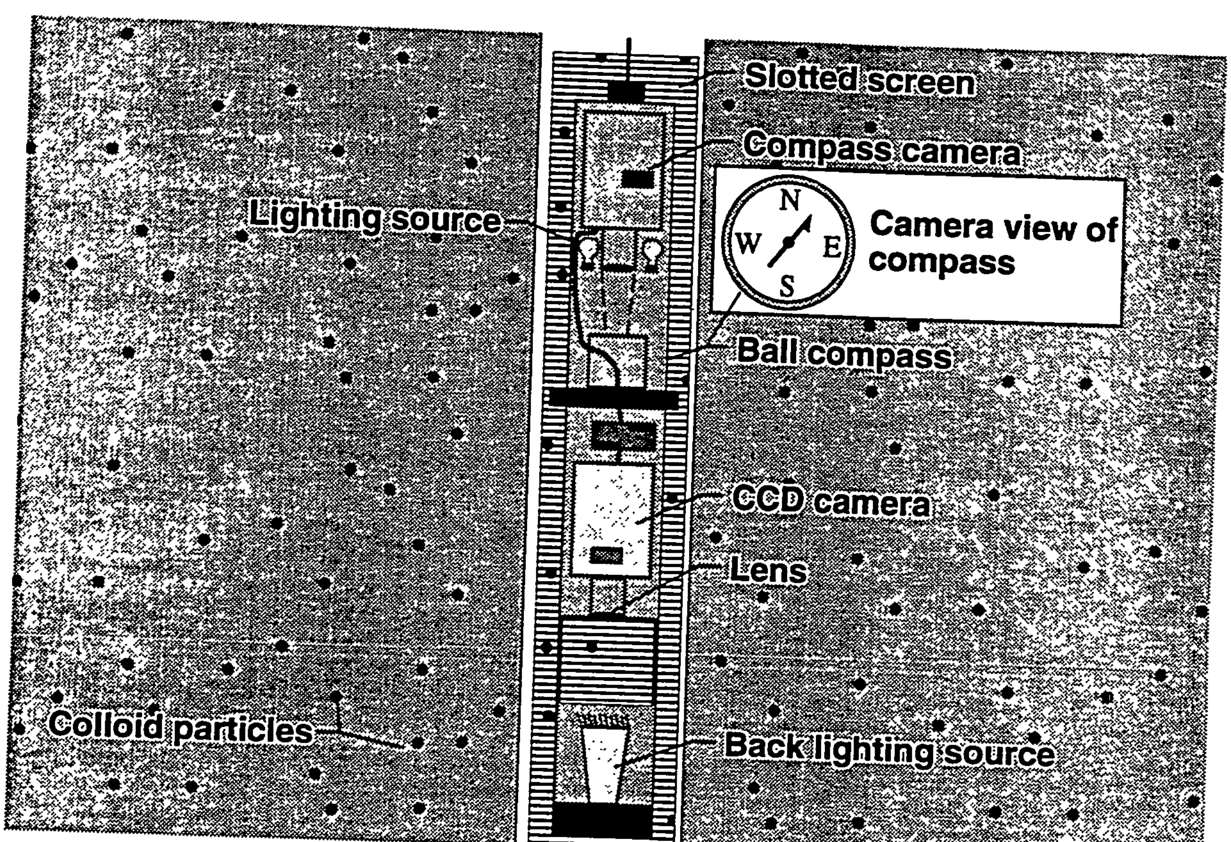

Figure 2. Detailed diagram of the Colloidal Borescope.

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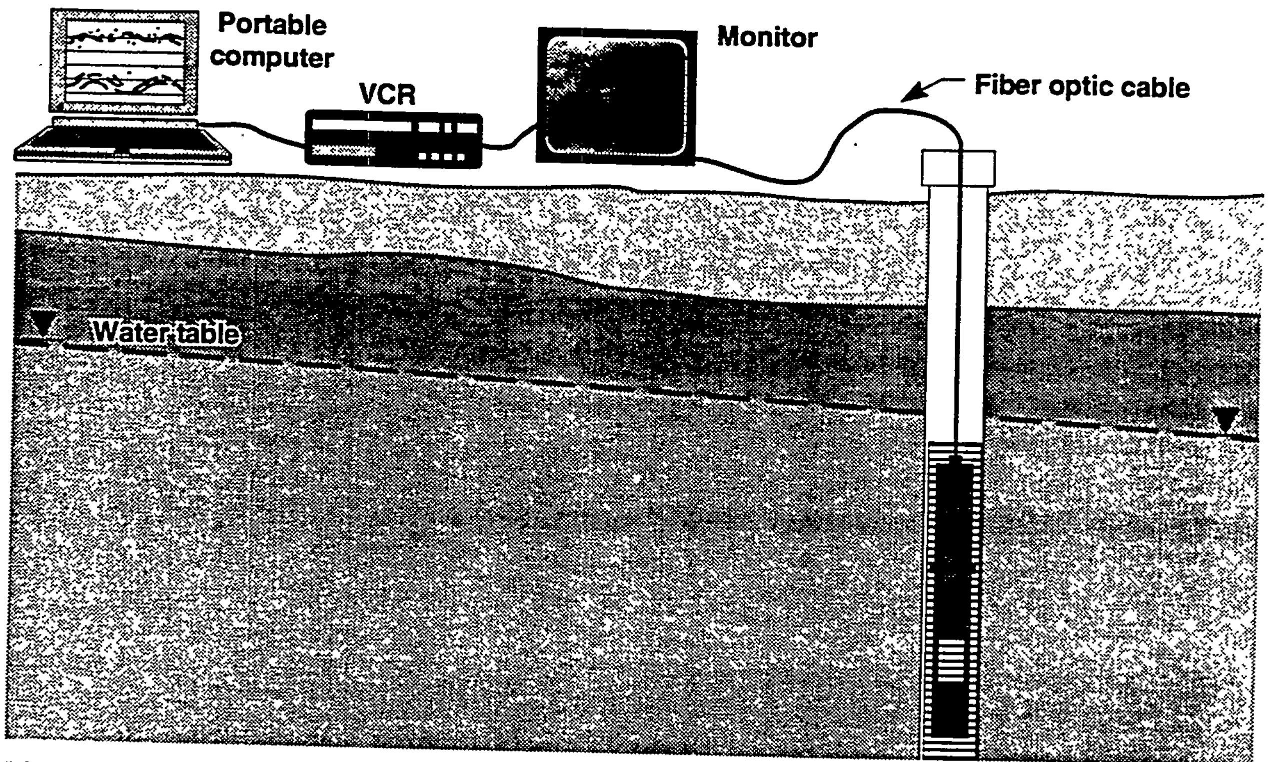

Figure 3. Field setup of the Colloidal Borescope and Video Image Analysis System (VIAS).

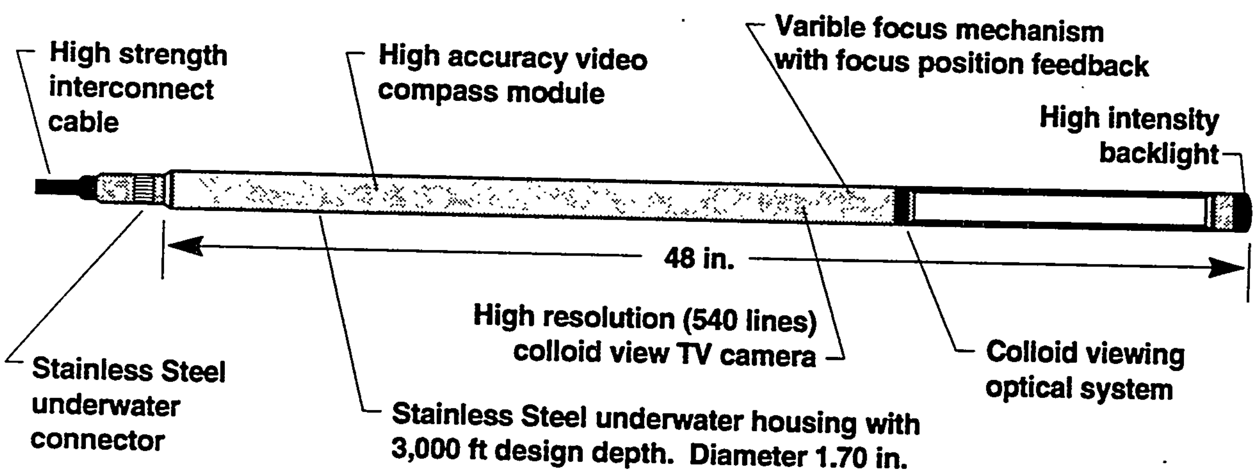

Figure 4. Schematic of the Remote-Focus Colloidal Borescope.

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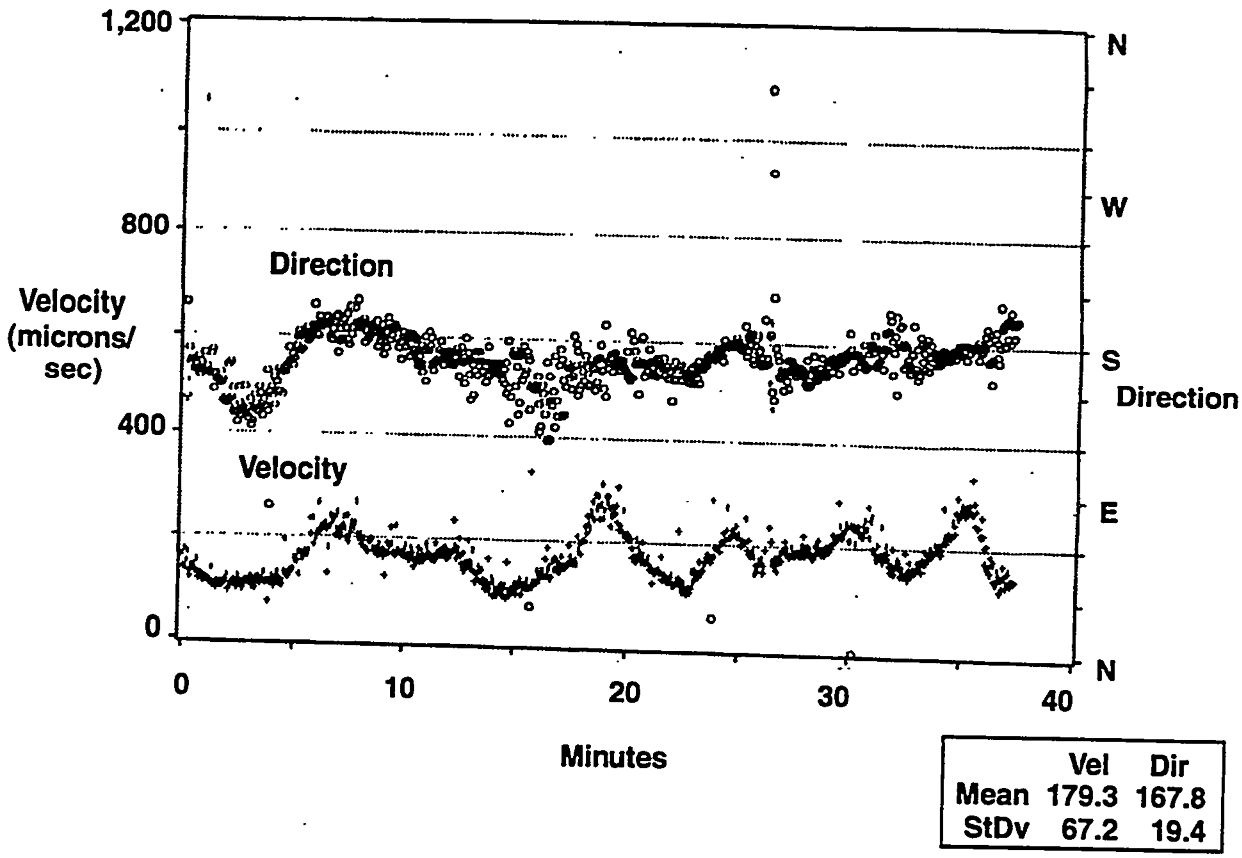

Figure 5. Colloidal Borescope log of LLNL Site 300 Monitor Well W-26R-05.

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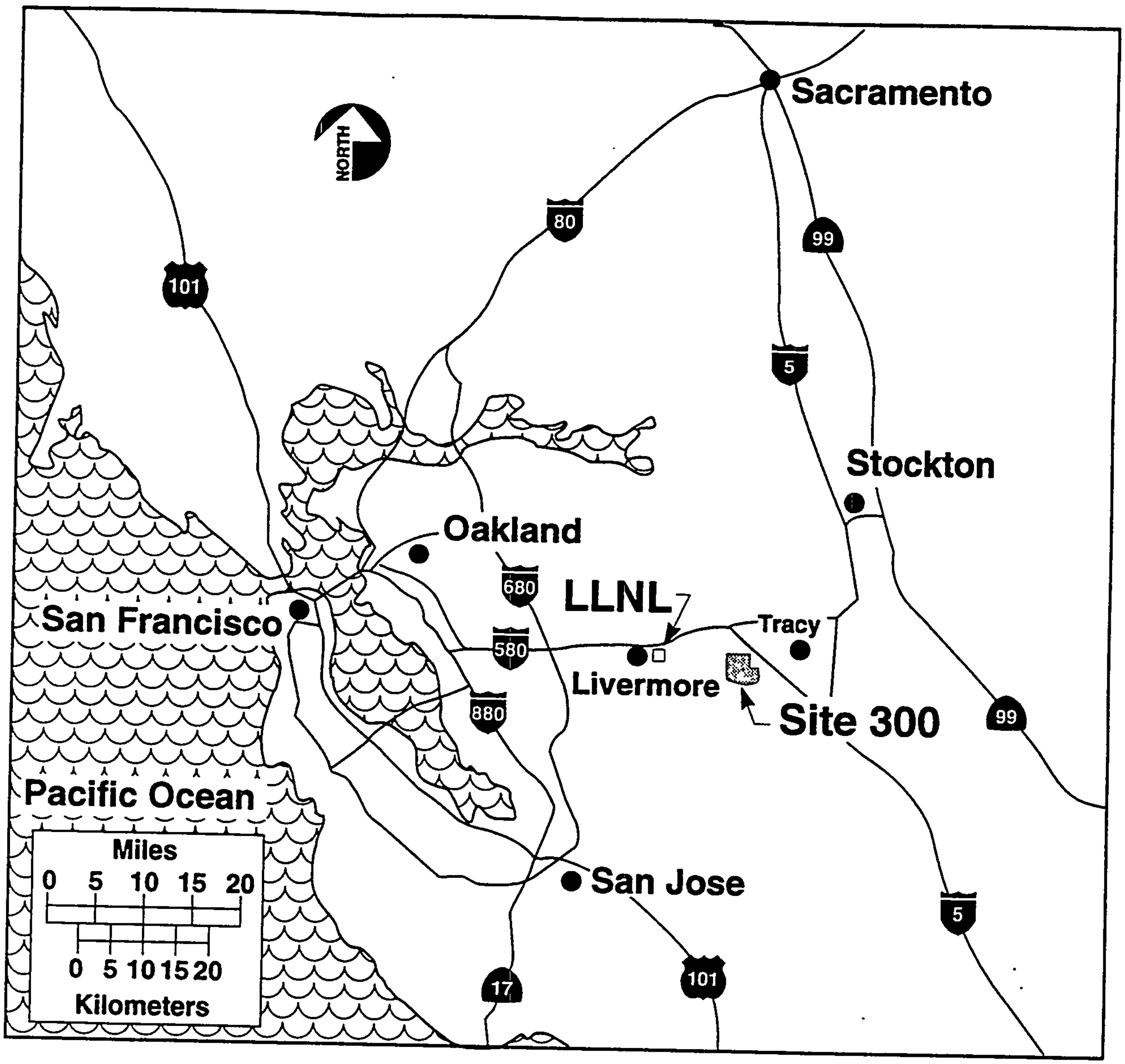

Figure 6. Location of Lawrence Livermore National Laboratory Main Site (Livermore) and Site 300.

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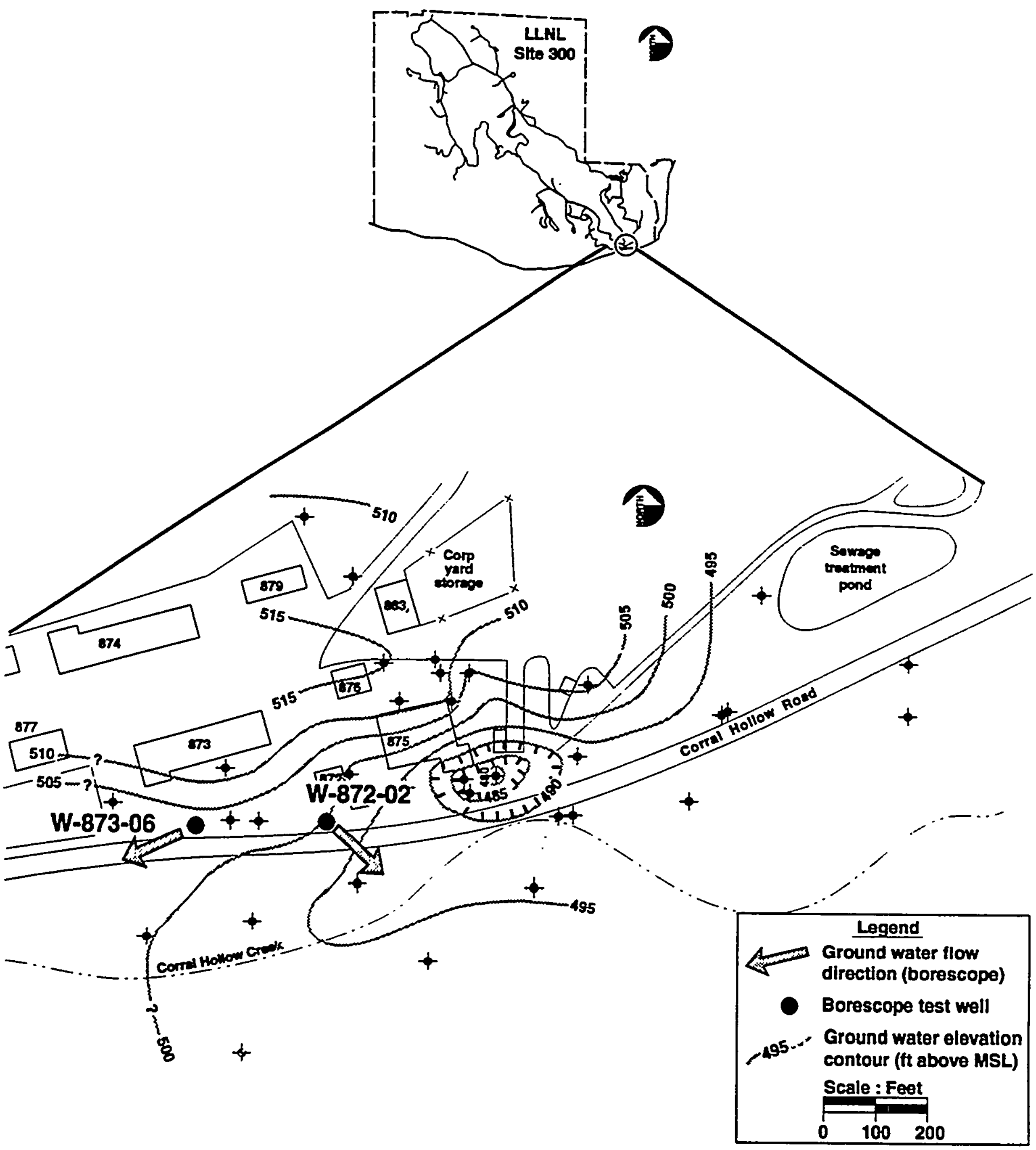

Figure 7. Ground water flow direction in the Central GSA, LLNL Site 300.

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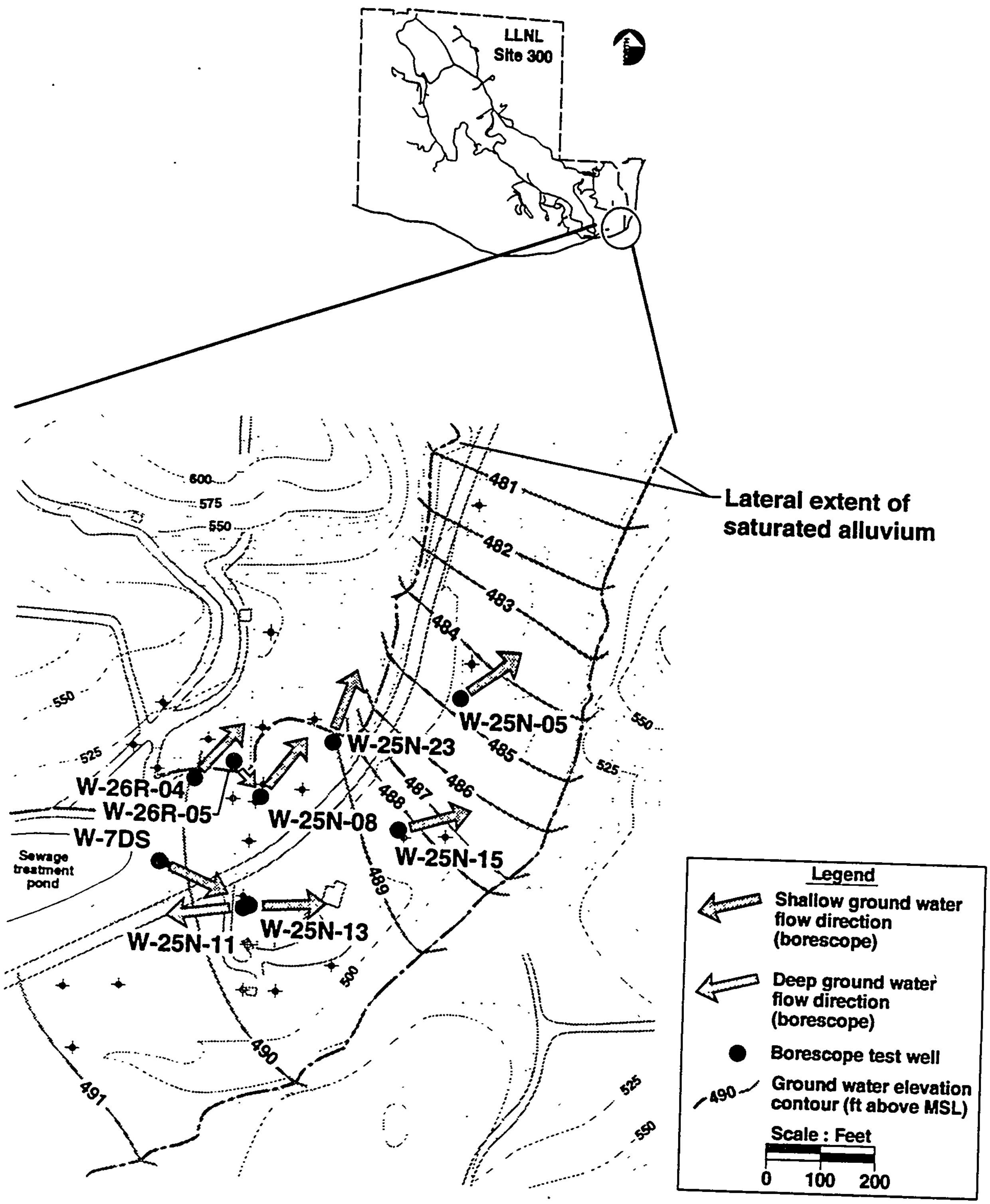

Figure 8. Ground water flow direction in the Eastern GSA, LLNL Site 300.