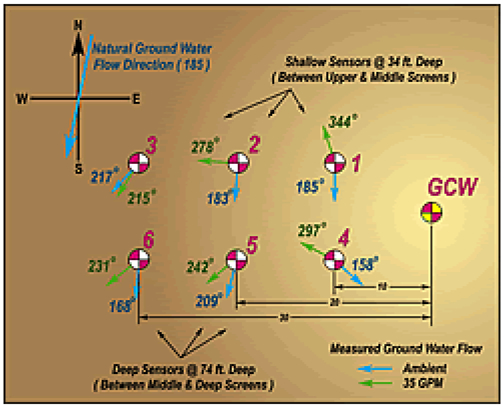
mGCW Technology for Remediation of Groundwater Containing Chlorinated Hydrocarbons and Heavy Metals:

What follows here is a synopsis of a Fall, 1999 paper as prepared by URS for Soil & Groundwater Magazine: Special Issue on Innovative Technologies.

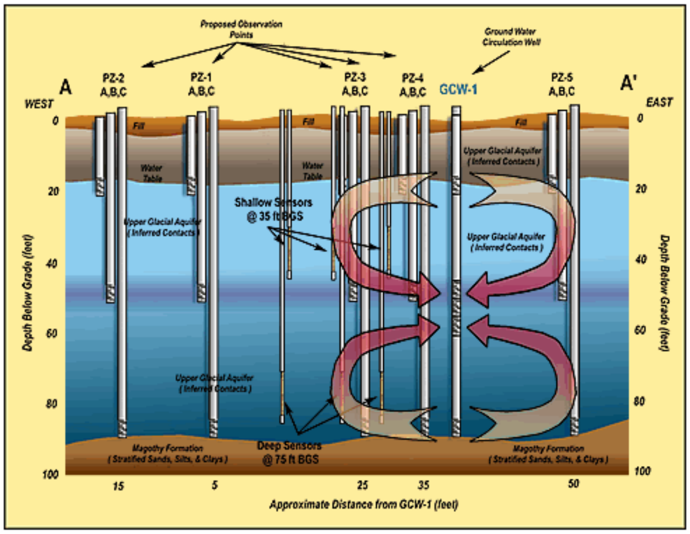
In addition to establishment of differences in potentiometric head via function of the mGCW, it is important to document the direction of vertical and horizontal groundwater movement. It is equally important to measure the in situ velocity of groundwater movement in order to validate numerical calculations of groundwater circulation time.

Perhaps the most timely, accurate, and cost-efficient means of generating these data in the field employs the use of in situ groundwater velocity sensors (ISGV). As described by Ballard (1996) and Pacific Northwest National Laboratory (1996), these in situ probes use a thermal perturbation technique to directly measure the three-dimensional groundwater flow direction and velocity inunconsolidated, saturated, porous media. The probe consists of a cylindrical heater about 30-inches long by 2-inches in diameter with an array of 30 calibrated temperature sensors located on their surface. The probes are buried in the ground and surrounded by the natural formation. Once positioned, a heater is activated and the sediment and groundwater surrounding the probe are warmed 20 to 30C above ambient groundwater temperature. In the absence of groundwater flow past the sensors, the temperature distribution on the probe's surface is independent of azimuth and symmetric about the vertical midpoint of the probe. When there is flow past the probe, the temperature distribution is perturbed as the heat emanating from the probe is advected by the moving fluid. Sensors monitor continuously and record to a central data acquisition system. PC-based software converts the measured probe surface temperature distribution into flow velocity i.e., three-dimensional magnitude and direction.



Strategic placement of the flow sensors is necessary to ensure that the sensors yield desired information on the velocity and direction of groundwater flow at two points radial of the mGCW system. Results of the numerical modeling were considered in the positioning of six ISGV probes to yield three sets of shallow and deep sensors (see Figure 2). One pair of sensors was placed at a distance of 10, 20, and 30 feet from the mGCW. Each pair contained one probe placed at a depth of 35 feet bgs and one probe placed at a depth of 75 feet bgs. These depths correspond with the middle of the upper circulation cell (standard flow) and the lower circulation cell (reverse flow), and their radial locations were selected such that changes in horizontal and vertical flow velocities could be measured within the range of accuracy of these sensors.

mGCW technology creates in situ vertical groundwater circulation cells by drawing groundwater through one screen section of a double-screened well and discharging it through the second screen section (Bernhardt et al., 1999; Lakhwala et al., 1998). This circulation pattern commonly occurs from the top of the formation to the bottom (herein termed standard flow).



Under standard flow conditions, groundwater is directed upward inside the mGCW. The circulation cell flow path thus encompasses groundwater flowing from the upper part of the treatment zone into the lower part of the mGCW. In a reverse circulation mode, the flow of groundwater within the mGCW is downward via the aid of an in-well groundwater pump (i.e., water flows from the bottom of the aquifer formation in a torroidal upward pattern). In the reversecirculation mode, water in the lower portion of the aquifer moves away from the well while water in the upper portion of the aquifer moves toward the treatment well . The general flow dynamics and the dimensions of the capture zone, circulation cell, and release zone for a mGCW system have been presented elsewhere (Borchert et al., 1997; Herrling et al., 1991). Proper design of an effective mGCW system requires that these values be determined for each specific site. This can be done either by numerical simulations of the groundwater hydraulics or by field-testing. Field-tests of the mGCW technology are conducted to confirm the modeled zone of capture and the radius of influence at the desired groundwater flow rates. These data are subsequently used in refining the full-scale design.

Field Validation of mGCW Hydraulics

Data from the IGVS showed that the mGCW changed groundwater flow directions from background conditions at all locations, and at all flow rates tested (20, 25, and 35 gpm). The natural horizontal groundwater flow direction ranged from 158° to 217°. When the mGCW was operated at Q=35 gpm, the flow directions ranged from 215° to 344° (Figure 3). All sensors measured groundwater flowing away from the mGCW. This helped confirm that the stacked circulation cells were established around the well (i.e., water entering the middle screen and exiting the upper and lower screen sections). When the horizontal velocity and azimuth data were projected onto a vertical plane, the data show that the mGCW also induced vertical groundwater flow with observed increases in vertical velocity of up to 3.7 ft/day (ISGV sensor 2) (Figure 4). In the upper circulation cell, vertical velocities increased in a vertically downward direction indicating flow of groundwater to the middle influent screen. However, data from the deep ISGV were variable. By comparison, data from the PT showed sufficient drawdown at all intermediate piezometers to induce flow of groundwater into the mGCW intermediate screens (data not shown). Similarly, sufficient groundwater mounding was measured at most shallow and deep piezometers, indicating flow from the deep and shallow mGCW screens back into the aquifer. These observations emphasize the value of combining ISGV measurements with PT data when evaluating the hydraulics of mGCW and related systems under field conditions.

In summary, the PT data, horizontal and vertical velocity data, and the flow direction data all indicated that a standard circulation cell was established around the mGCW with a ROI of at least 48 feet at a Q of 25 gpm. Data validating the modeled hydraulics of the reverse-flow lower circulation cell were less conclusive, but all field observations were qualitatively consistent with the expected flow fields established around a stacked-cell mGCW.

Site-Specific mGCW Design

Based on these results, a preferred mGCW configuration was proposed to generate an “in situ treatment curtain” to contain and treat the dpCOI as they migrated toward the southern site boundary (i.e., in situ source management). Figure 5 illustrates the cross-sectional extent of the dpCOI plumes and the proposed mGCW well locations. To contain the dpCOI on site, the proposed layout for full-scale implementation of the NTCRA consists of three mGCW systems installed along the downgradient property boundary. Two of the systems (mGCW-1 and -2) would be constructed as stack-cell configurations in order to address the presence of cadmium in the lower portion of the Upper Glacial aquifer. The third system (mGCW-3) would be designed as a single cell unit to address shallow dpCOI toward the eastern end of the site. Each mGCW would operate at an internal flow of 70 gpm (35 gpm per cell for mGCW-1 and -2). This yields an effective cross gradient W of at least 69 feet. The well spacing of 117 ft was therefore chosen conservatively to provide an overlap of 20% from the modeled well spacing of 140 feet.

Conclusions

Hydraulic data from full-scale pilot tests using multiple pressure transducers and strategically positioned in situ groundwater velocity sensors supported the use of mGCW technology for in situ source management and containment of dpCOI at the Liberty Site where groundwater is impacted by both organic and inorganic constituents. Full-scale application of the technology represents an estimated cost savings of > $3 million dollars as compared to conventional ground water pump-and-treat approaches.