A Cost-Effective Approach to Multi-Parameter Hydrologic Monitoring to Characterize Groundwater Flow Conditions

Katherine Monks[1] and Mike Godwin[2]

This discusses a cost-effective approach to characterizing horizontal and vertical groundwater movement from a naval installation to an adjacent community within three hydrogeologic zones. To accomplish this, water levels and velocities are continuously measured with pressure transducers and velocity sensors at strategic locations along the naval facility property boundary, and groundwater levels are measured quarterly in 122 on- and off-site wells to characterize groundwater flow within a 64-square mile area. Eight in situ groundwater velocity sensors (developed with the Technology Deployment Initiative Institute for the Department of Energy) and eight pressure transducers are used to collect data to estimate groundwater velocities and gradients in three dimensions. Data collected continuously from the velocity sensors and pressure transducers, coupled with the water level data collected quarterly from a regional monitoring well network, are used to accomplish the following: (1) monitor changes in horizontal and vertical groundwater gradients and velocities, (2) determine the direction and rate of groundwater movement from the naval facility to an adjacent community, and (3) provide particle tracking estimates. This approach provides greater coverage over a longer duration of time than conventional aquifer testing, which is limited to a discrete zone of influence during a "snapshot" in time.

The quarterly groundwater elevation study is conducted at the Naval Air Weapons Station (NAWS) China Lake in the central portion of the Indian Wells Valley (IWV) in southern California, located approximately 150 miles north of Los Angeles. The City of Ridgecrest, California is along the southern boundary of the China Lake Complex. Municipal, agricultural, industrial, and domestic water supplies in the IWV are all produced from groundwater.

A total of 63 monitoring wells (5 of which contain pressure transducers) and 4 velocity sensors are used to collect water level data for the shallow hydrogeologic zone. The shallow hydrogeologic zone is composed of alluvium, playa deposits, and lacustrine deposits, with low-permeability lacustrine clays marking the bottom of the shallow hydrogeologic zone and top of the intermediate hydrogeologic zone. Groundwater within the shallow hydrogeologic zone is unconfined. A groundwater mound is centered around the vicinity of the NAWS Public Works Area, with groundwater elevations decreasing radially away from the groundwater mound. Horizontal groundwater gradients from the center of the mound range from 0.00008 to the south to 0.005 to the east. The groundwater mound is believed to result from a fault-bounded structural high or the presence of low-permeability lacustrine sediments and from external recharge sources, such as infiltrating irrigation water, stormwater runoff, and leaking underground water lines. The occurrence of shallow groundwater is discontinuous to the west and is likely stratigraphically and structurally controlled by the extent of the low-permeability

[1] Certified Groundwater Professional, Tetra Tech EM Inc., Albuquerque, NM, 87110, USA, ph 505-881-3188, fx 505-881-3283, monksk@ttemi.com (primary author).
[2] Registered California Geologist, Washington Group International, Inc., San Francisco, CA, 94111, USA, ph 415-442-7628, fx 415-442-7673, mike.godwin@wgint.com (contributing author).

lacustrine sediments and by subsurface fault zones. The depth to groundwater is generally shallowest in the northeastern portion of the study area, where it is generally between 5 and 10 feet below ground surface (bgs), and increases toward the south and west, where it is about 90 feet bgs to the southeast and about 125 feet bgs in the western portion of the study area. Continuous measurements collected from pressure transducers indicate the occurrence of cyclic perturbations in water levels over a 3- to 4-day period that appear to lag several days behind changes in water levels observed for the deeper groundwater. Generally, changes in the shallow groundwater levels are limited to several hundredths to about two-tenths of a foot over a period of several days. These cyclic groundwater elevation changes result from regional water supply pumping. Horizontal groundwater velocities measured from the four in situ velocity sensors that are installed in the shallow hydrogeologic zone range from less than 0.01 to 0.25 foot/day. Vertical groundwater velocity data for all four locations show strong downward flows between -0.03 and -0.67 foot/day (negative value denotes downward flow), with a vertical velocity highest in areas closest to supply well fields. The groundwater velocity sensor data generally corroborate horizontal and vertical groundwater flow directions determined from groundwater level measurements.

There are a total of 34 monitoring wells that are screened in the intermediate hydrogeologic zone, including 2 municipal and 3 private supply production wells. The intermediate hydrogeologic zone is composed of lacustrine sediments, primarily low-permeability silts and clays that are between tens of feet to approximately 1,000 feet thick. The top of the intermediate hydrogeologic zone generally occurs between 60 and 150 feet bgs. Water-bearing zones that are screened within the intermediate hydrogeologic zone occur within sand stringers that interfinger with the low-permeability lacustrine sediments and are found at about 190 to 250 feet bgs. Where overlain by low-permeability lacustrine sediments, these water-bearing zones are generally semiconfined to confined in nature and can produce significant quantities of groundwater. Along the boundary between NAWS China Lake and Ridgecrest, there is a downward vertical gradient between the shallow and intermediate hydrogeologic zones. The horizontal groundwater flow direction for the intermediate hydrogeologic zone is generally to the southwest, but is dependent on the orientation of the monitoring well relative to the well fields. Horizontal hydraulic gradients range from 0.002 to 0.005. Groundwater levels measured in wells screened in the intermediate hydrogeologic zone are shallowest in the northeastern portion of the study area, where depths range from 29 to 44 feet bgs. To the south, the depths to groundwater in the intermediate hydrogeologic zone range from 156 to 203 feet bgs and are influenced by pumping at the municipal Intermediate Well Field. The pressure transducer data indicate that the cyclic perturbations in water levels observed in the shallow wells also appear in the intermediate wells. Short-term water level fluctuations in the intermediate hydrogeologic zone range from 0.02 to 0.2 foot, with the greatest fluctuations noted in the westernmost well pair (closest to the well field). Horizontal groundwater velocities measured by the five in situ velocity sensors installed in the intermediate hydrogeologic zone range from 0.01 to 0.05 foot/day. As noted for vertical groundwater velocities in the shallow hydrogeologic zone, vertical groundwater velocity data for all five locations in the intermediate hydrogeologic zone also show strong downward flows between -0.01 and -0.35 foot/day. The groundwater velocity sensor data generally corroborate horizontal and vertical groundwater flow directions determined from groundwater elevation surveys.

A total of 25 monitoring wells, including 11 production wells, are screened in the deep hydrogeologic zone. The majority of active off-site production wells are located in the Intermediate Well Field west of Ridgecrest, 3 to 4 miles west of the NAWS China Lake Main Gate, and in the Ridgecrest Well Field located 2 to 3 miles south of the Main Gate. No velocity sensors are installed within the deep hydrogeologic zone. The top of the deep hydrogeologic zone is designated as the first occurrence of a saturated sedimentary sequence that is predominantly sand for at least 50 feet and the bottom is defined by the contact with the underlying bedrock, up to 6,000 feet deep. The deep hydrogeologic zone is primarily composed of coarse sand and gravel with some interbedded clay. Where the lacustrine clays of the intermediate hydrogeologic zone are present, groundwater within the deep hydrogeologic zone is semiconfined to confined, and it becomes unconfined where these clays pinch out. In general, unconfined areas include areas in the western- and southern-most portions of Ridgecrest, including the Intermediate Well Field area. The wells in these areas are generally screened over multiple intervals between 200 and 1,000 feet bgs. Groundwater levels measured in wells screened in the deep hydrogeologic zone are shallowest in the northeast corner of the study area, where depths to water range from 31 to 35 feet bgs, and are deepest in the vicinity of the Intermediate Well Field, where they range from 197 to 306 feet bgs. Flow within the deep hydrogeologic zone is strongly affected by pumping from water supply wells over the majority of the study area, with the exception of the eastern and northeastern portions of the study area where the lacustrine clays are thickest.

This multi-parameter approach to groundwater flow monitoring has the following advantages: (1) quarterly groundwater level monitoring enables evaluation of groundwater flow conditions, seasonal variations, and the regional effects of pumping in a 64-square-mile area within three variably interconnected hydrogeologic zones; (2) continuous measurements from pressure transducers enable determination of short-term cyclic perturbations and long-term trends in groundwater level fluctuations; and (3) groundwater velocity sensors allow in situ horizontal and vertical flow fluctuations to be measured continuously. The end result is a complete picture of the relative short-term and long-term fluctuations in groundwater levels, gradients, and velocities. However, the level of effort and associated costs for performing these activities on an annual basis are less than those for setting up and performing a week-long constant rate discharge test and recovery for one location at one given point in time.

Biography

Katherine Monks is a senior hydrogeologist with Tetra Tech EM Inc. She has over 15 years of experience in hydrogeology, groundwater modeling, and hydrogeochemistry and holds an M.S. in Geology/Hydrogeology from Wright State University.

Mike Godwin is a California-registered geologist with Washington Group International, Inc. He has 12 years of regulatory and environmental experience and holds a B.S. in Geology from California State University, Northridge.