EVALUATION OF SPECIFIC-STORAGE VALUES

Calibrated models of aquifer-system compaction developed by Helm (1975, 1976, 1977, 1978) and by Williamson and others (1989) indicate that a narrow range of both aquitard inelastic skeletal specific storage values and aquitard elastic skeletal specific storage values have been used to successfully simulate aquifer-system compaction despite differences in depth, thickness, lithology, and stratigraphy among the San Joaquin Valley sites that were modeled (table 4). The aquitard inelastic skeletal specific storage values derived by Helm (1978) for seven sites in the San Joaquin Valley ranged from about 1.4×10^{-4} to 6.7×10^{-4} ft^{-1}, and have a mean of about 3.2×10^{-4} ft^{-1} and a standard deviation of about 1.8×10^{-4} ft^{-1}. The aquitard elastic skeletal specific storage values that Helm (1978) derived ranged from about 2.0×10^{-6} to 7.5×10^{-6} ft^{-1}, and have a mean of about 4.5×10^{-6} ft^{-1} and a standard deviation of about 2.1×10^{-6} ft^{-1}. Aquitard elastic and inelastic skeletal specific storage values used by Williamson and others (1989) fall within the ranges of values derived by Helm.

The narrow range of aquitard inelastic and elastic skeletal specific storage values derived by Helm (1978) at these seven sites also has been found elsewhere in the United States, including areas of California other than the San Joaquin Valley. For seven sites in the Santa Clara Valley, California, model-derived values of aquitard inelastic skeletal specific storage ranged from 1.4×10^{-4} to 4.0×10^{-4} ft^{-1} (Helm, 1978) and have a mean of 2.8×10^{-4} ft^{-1} and a standard deviation of 8.9×10^{-5} ft^{-1}. The model-derived values of aquitard elastic skeletal specific storage for the seven Santa Clara Valley sites ranged from 2.2×10^{-6} to 1.6×10^{-5} ft^{-1} (Helm, 1978) and have a mean of 6.7×10^{-6} ft^{-1} and a standard deviation of 5.2×10^{-6} ft^{-1}.

At an extensometer site in Antelope Valley in the Mojave Desert of southern California, the model-derived value of aquitard inelastic skeletal specific storage for aquitards that were actively compacting inelastically was 3.5×10^{-4} ft^{-1} (Sneed and Galloway, 2000), which is strikingly close to the mean value of 3.2×10^{-4} ft^{-1} for the 7 sites in San Joaquin Valley. At this same Antelope Valley site, the model-derived value of aquifer-system elastic skeletal specific storage was 1.7×10^{-6} ft^{-1} (Sneed and Galloway, 2000). This value is slightly smaller than those reported for the San Joaquin and Santa Clara Valleys, perhaps because the elastic skeletal specific storage value for the Antelope Valley site represents an average value for the aquifer system, rather than an elastic skeletal specific storage value that explicitly represents the aquitard component of the aquifer system.

Hanson (1989) reported model-derived estimates for selected extensometer sites in the Tucson basin and in the Avra Valley using the Helm model approach. For the six Arizona sites, the model-derived values of aquitard inelastic skeletal specific storage ranged from 7.3×10^{-6} to 2.7×10^{-4} ft^{-1} (Hanson, 1989) and have a mean of 9.4×10^{-5} ft^{-1} and a standard deviation of 1.1×10^{-4} ft^{-1}. Smaller values in this range may indicate that the aquifer systems were still in transition to predominantly inelastic compaction when the study was done; hence long-term inelastic skeletal specific-storage values may initially increase because of increased compaction through time (Hanson, 1989). The model-derived values of aquitard elastic skeletal specific storage for the six Arizona sites ranged from 1.0×10^{-6} to 2.0×10^{-5} ft^{-1} (Hanson, 1989) and have a mean of 7.1×10^{-6} ft^{-1} and a standard deviation of 6.6×10^{-6} ft^{-1}. Epstein (1987) reported on model-derived estimates for an extensometer site near Eloy, Ariz. The model-derived value of aquitard inelastic skeletal specific storage for the upper five layers was 1.5×10^{-4} ft^{-1}; layers 6 and 7 used 1.8×10^{-4} and 2.7×10^{-4} ft^{-1}, respectively. The model-derived value of the aquitard elastic skeletal specific storage for layers 1 through 5 and 7 was 3.0×10^{-6} ft^{-1}; layer 6 used 2.4×10^{-6} ft^{-1} (Epstein, 1987).

Inelastic skeletal specific storage measured from laboratory consolidation tests on samples tend to result in smaller values compared with those derived from calibrated models of aquifer-system compaction. At site 14S/13E-11D, the model-derived estimate of inelastic skeletal specific storage was 4.3×10^{-4} ft^{-1} (Helm, 1978). For the same location, laboratory consolidation tests on eight samples yielded inelastic skeletal specific storage values ranging from 2.0×10^{-5} to 1.6×10^{-4} ft^{-1} (Johnson and others, 1968) (table 3). The larger value was measured in a sample from the Corcoran Clay, which would be expected to be highly compressible, yet this value is smaller than Helm's (1978) derived value by a factor of about 2.7. At site 16S/15E-34N, the model-derived estimate of inelastic skeletal specific storage was 2.4×10^{-4} ft^{-1} (Helm, 1978). For the same location, laboratory consolidation tests on 16 samples yielded inelastic skeletal specific storage values ranging from 1.4×10^{-5} to 1.7×10^{-4} ft^{-1}

(Johnson and others, 1968) (table 3); the largest value in this range is smaller than Helm's (1978) by a factor of about 1.4. In this example, the largest values were not measured in samples from the Corcoran Clay, but in sediments collected above the Corcoran Clay (Johnson and others, 1968) (table 3). At site 23S/25E-16N, the model-derived estimate of inelastic skeletal specific storage was 2.3×10^{-4} ft^{-1} (Helm, 1978). For the same location, laboratory consolidation tests of four samples yielded inelastic skeletal specific storage values ranging from 4.0×10^{-5} to 1.7×10^{-4} ft^{-1} (Johnson and others, 1968) (table 3). At this site, the larger value was measured in a sample from the Corcoran Clay (Johnson and others, 1968) (table 3), which would be expected to be highly compressible, yet this value is smaller than Helm's (1978) model-derived value by a factor of about 1.3. This discrepancy may result from the scale difference: laboratory consolidation tests measure a small sample of an aquifer system, whereas calibrated models focus on larger thicknesses of aquifer systems. Furthermore, laboratory consolidation tests are done with the premise that the sample is undisturbed, which is nearly impossible, and do not mimic natural stresses on, or stress history of, the sample.

SUMMARY

This report summarizes the hydraulic and mechanical properties affecting ground-water flow and aquifer-system compaction in the San Joaquin Valley, California. Because most storage values presented are components of the total aquifer-system storage and include inelastic and elastic skeletal storage values for aquifers and aquitards, the relations of components of aquifer-system storage to total aquifer-system storage were reviewed. Vertical hydraulic conductivity values generally are for discrete thicknesses of sediments—usually aquitards. The property values were obtained from publications that report the values as results of aquifer tests, stress-strain analyses of borehole extensometer observations, laboratory consolidation tests, and model simulations. These values will be used by the USBR during the calibration process of the WESTSIM model, which will simulate ground-water flow and land subsidence in the western San Joaquin Valley.

REFERENCES

Bull, W.B., 1975, Land subsidence due to ground-water withdrawal in the Los Banos-Kettleman City area, California, Part 2. Subsidence and compaction of deposits: U.S. Geological Survey Professional Paper 437-F, 90 p.

Bull, W.B., and Poland, J.F., 1975, Land subsidence due to ground-water withdrawal in the Los Banos–Kettleman City area, California, Part 3. Interrelations of water-level change, change in aquifer-system thickness, and subsidence: U.S. Geological Survey Professional Paper 437-G, 62 p.

Davis, G.H., Green, J.H., Olmsted, F.H., and Brown, D.W., 1959, Ground-water conditions and storage capacity in the San Joaquin Valley, California: U.S. Geological Survey Water-Supply Paper 1469, 287 p., 29 pls.

Epstein, V.J., 1987, Hydrologic and geologic factors affecting land subsidence near Eloy, Arizona: U.S. Geological Survey Water-Resources Investigations Report 87-4143, 28 p.

Hanson, R.T., 1989, Aquifer-system compaction, Tucson Basin and Avra Valley, Arizona: U.S. Geological Survey Water-Resources Investigations Report 88-4172, 69 p.

Helm, D.C., 1975, One-dimensional simulation of aquifer system compaction near Pixley, California—1. Constant parameters: Water Resources Research, v. 11, no. 3, p. 465–478.

———1976, One-dimensional simulation of aquifer system compaction near Pixley, California—2. Stress-dependent parameters: Water Resources Research, v. 12, no. 3, p. 375–391.

———1977, Estimating parameters of compacting fine-grained interbeds within a confined aquifer system by a one-dimensional simulation of field observations, *in* Land subsidence symposium: Proceedings of the second International Symposium on Land Subsidence, held at Anaheim, California, 13–17 December 1976: International Association of Hydrological Sciences, IAHS-AISH Publication series, no. 121, p. 145–156.

———1978, Field verification of a one-dimensional mathematical model for transient compaction and expansion of a confined aquifer system, *in* Verification of mathematical and physical models in hydraulic engineering: Proceedings, 26th annual Hydraulics Division specialty conference, University of Maryland, College Park, Maryland, August 9-11, 1978: New York, American Society of Civil Engineers, p. 189–196.

Ireland, R.L., 1986, Land subsidence in the San Joaquin Valley, California, as of 1983: U.S. Geological Survey Water-Resources Investigations Report 85-4196, 50 p.

Ireland, R.L., Poland, J.F., and Riley, F.S., 1984, Land subsidence in the San Joaquin Valley, California, as of 1980: U.S. Geological Survey Professional Paper 437-I, 93 p., 1 pl. in pocket.

Johnson, A.I., 1984, Laboratory tests for properties of sediments in subsiding areas, pt. 1, chap. 4 *of* Poland, J.F., ed., Guidebook to studies of land subsidence due to ground-water withdrawal: Paris, UNESCO, Studies and Reports in Hydrology 40, p 55–88.

Johnson, A.I., Moston, R.P., and Morris D.A., 1968, Physical and hydrologic properties of water-bearing deposits in subsiding areas in central California: U.S. Geological Survey Professional Paper 497-A, 71 p., 14 pls.

Jorgensen, D.G., 1980, Relationships between basic soils-engineering equations and basic ground-water flow equations: U.S. Geological Survey Water-Supply Paper 2064, 40 p.

Lofgren, B.E., 1976, Hydrogeologic effects of subsidence, San Joaquin Valley, California: International Symposium on Land Subsidence, 2nd, Anaheim, Calif., December 13–17, program and abstracts, no. 12, unnumbered pages.

———1979, Changes in aquifer-system properties with ground-water depletion, *in* Saxena, S.K., ed., Evaluation and prediction of subsidence: New York, American Society of Civil Engineers, p. 26–46.

Lofgren, B.E., and Klausing, R.L., 1969, Land subsidence due to ground-water withdrawal, Tulare–Wasco area, California: U.S. Geological Survey Professional Paper 437-B, 23 p.

Lohman, S.W., 1972, Definitions of selected ground water terms—Revisions and conceptual refinements: U.S. Geological Survey Water-Supply Paper 1988, 21 p.

McClelland, E.J., 1962, Aquifer-test compilation for the San Joaquin Valley, California: U.S. Geological Survey Open-File Report [62-80], 40 p. (rev. 1966).

Page, R.W., 1986, Geology of the fresh ground-water basin of the Central Valley, California, with texture maps and sections: U.S. Geological Survey Professional Paper 1401-C, 54 p., 5 pls. in pocket.

Poland, J.F., 1961, The coefficient of storage in a region of major subsidence caused by compaction of an aquifer system, *in* Geological Survey Research 1961: U.S. Geological Survey Professional Paper 424-B, p. B52–B54.

Poland, J.F., Lofgren, B.E., and Riley, F.S., 1972, Glossary of selected terms useful in studies of the mechanics of aquifer systems and land subsidence due to fluid withdrawal: U.S. Geological Water-Supply Paper 2025, 9 p.

Poland, J.F., Lofgren, B.E., Ireland, R.L., and Pugh, R.G., 1975, Land subsidence in the San Joaquin Valley, California, as of 1972: U.S. Geological Survey Professional Paper 437-H, 78 p.

Prudic, D.E., and Williamson, A.K., 1986, Evaluation of a technique for simulating a compacting aquifer system in the Central Valley of California, U.S.A., *in* Johnson, A.I., Carbognin, Laura, and Ubertini, Lucio, eds., Land subsidence: Proceedings of the Third International Symposium on Land Subsidence held in Venice, Italy, 19-25 March 1984: Wallingford, Oxfordshire, IAHS Press, Institute of Hydrology, IAHS publication 151, p. 53–63.

Riley, F.S., 1969, Analysis of borehole extensometer data from central California, *in* Tison, L.J., ed., Land subsidence: [Brussels], IASH–Unesco, International Association of Scientific Hydrology Publication 89, v. 2, p. 423–431.

———1998, Mechanics of aquifer systems—The scientific legacy of Joseph F. Poland, *in* Borchers, J.W., ed., Land subsidence case studies and current research: Proceedings of the Dr. Joseph F. Poland Symposium on Land Subsidence: Belmont, Calif., Star Publishing Co., Association of Engineering Geologists Special Publication 8, p. 13–27.

Riley, F.S., and McClelland, E.J., 1971, Application of the modified theory of leaky aquifers to a compressible multiple-aquifer system: Mechanics of aquifer systems: Analysis of pumping tests near Pixley, California: U.S. Geological Survey Open-File Report, 96 p.

Sneed, Michelle, and Gallaway, D.L., 2000, Aquifer-system compaction and land subsidence: Measurements, analyses, and simulations—the Holly Site, Edwards Air Force Base, Antelope Valley, California: U.S. Geological Survey Water-Resources Investigations Report 00-4015, 65 p.

Terzaghi, Karl, 1925, Principles of soil mechanics: IV; settlement and consolidation of clay: Erdbaummechanic, v. 95, no. 3, p. 874–878.

———1943, Theoretical soil mechanics: New York, Wiley, 510 p.

U.S. Bureau of Reclamation, 1974, Earth manual: A guide to the use of soils as foundations and as construction materials for hydraulic structures (2nd ed.): U.S. Department of the Interior, Bureau of Reclamation, Water Resources Technical Publication series, 751 p. [Reprinted 1980].

Williamson, A.K., Prudic, D.E., and L.A. Swain, 1989, Ground-water flow in the Central Valley, California: U.S. Geological Survey Professional Paper 1401-D, 127 p.