# Concluding Remarks

In conclusion, we would like to emphasize the following interrelated facts and concepts:

- The most important and most extensively discussed concept in this report is that volumes of water pumped from a ground-water system must come from somewhere and must cause a change in the ground-water system. Possible sources of water for pumpage are (1) more water entering the ground-water system (increased recharge), (2) less water leaving the system (decreased discharge), and (3) removal of water that was stored in the system.
- One of the critical linkages in both unstressed and stressed ground-water systems is between ground water and surface water. Pumping water from aquifers that are hydraulically connected with surface-water bodies can have a significant effect on those bodies by reducing ground-water discharges to surface water and possibly causing outflow from those bodies into the ground-water system. Thus, an evaluation of ground-water management strategies needs to involve consideration of surface-water resources, including closely related biological resources.
- A key feature of some aquifers and ground-water systems is the large volume of ground water in storage, which allows the possibility of using aquifers for temporary storage, that is, managing inflow and outflow of ground water in storage in a manner similar to surface-water reservoirs.
- From the standpoint of water use and water management, all ground water is not equal—the suitability of water, as measured by its quality, is a key consideration in developing water-management strategies. Furthermore, determining water suitability (or unsuitability) requires detailed information on the three-dimensional distribution and concentrations of potential contaminants, both naturally occurring contaminants and those resulting from human activities.
- Continuing large withdrawals of water from an aquifer often result in undesirable consequences. The most common of these consequences have been discussed throughout this report. From a management standpoint, water managers, stakeholders, and the public must decide the specific conditions under which the undesirable consequences can no longer be tolerated.
- The effects of ground-water development may require many years to become evident. Thus, there is an unfortunate tendency to forego the data collection and analysis that is needed to support informed decision making until well after problems materialize.
- Evaluation of possible ground-water management approaches (a) depends on the continuing collection, archiving, and analysis of a broad range of different types of information, and (b) can be assisted by well-designed computer simulation models.

# *ACKNOWLEDGMENTS*

Technical review of this Circular was provided by John Vecchioli, J.W. LaBaugh, W.W. Lapham, S.A. Leake, and T.C. Winter. G.J. Beserra, M.J. Focazio, Cindy Gehman, P.D. Hays, R.E. Krause, P.J. Lacombe, V.L. McGuire, Jack Monti, D.S. Morgan, L.C. Murray, A.S. Navoy, D.L. Nelms, G.B. Ozuna, G.L. Rowe, M.P. Scorca, A.G. Spinello, and D.K. Yobbi provided information for some of the examples. J.V. Flager, M.A. Kidd, and Chet Zenone provided editorial and technical reviews. The final manuscript was prepared by M.J. VanAlstine, J.K. Monson, J.M. Evans, R.J. Olmstead, E.J. Swibas, and C.L. Anderson.

# *REFERENCES*


Alley, W.M., and Emery, P.A., 1986, Groundwater model of the Blue River Basin, Nebraska—Twenty years later: Journal of Hydrology, v. 85, p. 225–249.

Alley, W.M., and Schefter, J.E., 1987, External effects of irrigator's pumping decisions, High Plains aquifer: Water Resources Research, v. 23, no. 7, p. 1123–1130.

American Society of Civil Engineers, 1969, Saltwater intrusion in the United States: Journal of the Hydraulics Division Proceedings of the ASCE, v. 95, no. HY5, p. 1651–1669.

Avery, C.F., 1995, Reversal of declining ground-water levels in the Chicago area: U.S. Geological Survey Fact Sheet 222–95, 2 p.

Bacchus, S.T., 1998, Determining sustainable yield for karst aquifers of the southeastern coastal plain—A need for new approaches, *in* Borchers, J.W., ed., Land subsidence case studies and current research, Proceedings of the Dr. Joseph F. Poland Symposium on Land Subsidence: Association of Engineering Geologists, Special Publication no. 8, p. 503–519.

Beattie, B.R., 1981, Irrigated agriculture and the Great Plains—Problems and management alternatives: Western Journal of Agricultural Economics, v. 6, no. 2, p. 289–299.

Bredehoeft, J.D., Papadopulos, S.S., and Cooper, H.H. Jr., 1982, Groundwater—The water-budget myth, *in* Scientific basis of water-resource management: National Academy Press, p. 51–57.

Carpenter, M.C., in press, South-central Arizona, *in* Galloway, D., Jones, D., and Ingebritsen, S., eds., Land subsidence in the United States: U.S. Geological Survey Circular 1182.

Carter, Virginia, 1996, Wetland hydrology, water quality, and associated functions, *in* National water summary—Wetland resources: U.S. Geological Survey Water-Supply Paper 2425, 431 p.

Cederstrom, D.J., 1945, Geology and ground-water resources of the Coastal Plain in southeastern Virginia: Virginia Geological Survey Bulletin 63, 384 p.

Cohen, P., Franke, O.L., and Foxworthy, B.L., 1968, An atlas of Long Island's water resources: New York Water Resources Commission Bulletin 62, 117 p.

Downing, R.A. (compiler), 1998, Groundwater our hidden asset: Earthwise Series, British Geological Survey, Keyworth, Nottingham, UK, 59 p.

Emery, P.A., 1965, Effect of ground-water pumping on streamflow and ground-water levels, Blue River Basin, Nebraska: U.S. Geological Survey Open-File Report, 11 p.

Franke, O.L., and McClymonds, N.E., 1972, Summary of the hydrologic situation on Long Island, New York, as a guide to water-management alternatives: U.S. Geological Survey Professional Paper 627–F, 59 p.

Galloway, D., Jones, D., and Ingebritsen, S., eds., in press, Land subsidence in the United States: U.S. Geological Survey Circular 1182.

Galloway, D., and Riley, F.S., in press, San Joaquin Valley, California, *in* Galloway, D., Jones, D., and Ingebritsen, S., eds., Land subsidence in the United States: U.S. Geological Survey Circular 1182.

Gelt, J., Henderson, J, Seasholes, K., Tellman, B., Woodard, G., and others, 1999, Water in the Tucson area: Seeking sustainability: Water Resources Research Center, University of Arizona, Issue Paper #20, 155 p.

Gutentag, E.D., Heimes, F.J., Krothe, N.C., Luckey, R.R., and Weeks, J.B., 1984, Geohydrology of the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Professional Paper 1400–B, 63 p.

Heath, R.C., 1983, Basic ground-water hydrology: U.S. Geological Survey Water-Supply Paper 2220, 84 p.

Hubbell, J.M., Bishop, C.W., Johnson, G.S., and Lucas, J.G., 1997, Numerical ground-water flow modeling of the Snake River Plain aquifer using the superposition technique: Ground Water, v. 35, no. 1, p. 59–66.

Hunt, R.J., Walker, J.F., and Krabbenhoft, D.P., 1999, Characterizing hydrology and the importance of ground-water discharge in natural and constructed wetlands: Wetlands, v. 19, no. 2, p. 458–472.

Johnson, M.S., and Pederson, D.T., 1983, Groundwater levels in Nebraska, 1982: Lincoln, University of Nebraska, Conservation and Survey Division, Nebraska Water Survey Paper 56, 65 p.

Johnston, R.H., 1989, The hydrologic responses to development in regional sedimentary aquifers: Ground Water, v. 27, no. 3, p. 316–322.

Konikow, L.F., and Bredehoeft, J.D., 1992, Groundwater models cannot be validated: Advances in Water Resources, v. 15, p. 75–83.

Konikow, L.F., and Reilly, T.E., 1999, Groundwater modeling, *in* Delleur, J.W., ed., The handbook of groundwater engineering: Boca Raton, Fla., CRC Press, p. 20–1—20–40.

Lohman, S.W., 1972, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 70 p.

Luckey, R.R., Gutentag, E.D., Heimes, F.J., and Weeks, J.B., 1986, Digital simulation of the ground-water flow in the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Professional Paper 1400–D, 57 p.

McGrail, L., Berk, K., Brandes, D., Munch, D., Neubauer, C., Osburn, W., Rao, D., Thomson, J., and Toth, D., 1998, St. Johns River Water Management District, *in* Fernald, E.A., and Purdum, E.D., eds., Water resources atlas of Florida: Tallahassee, Florida State University, Institute of Science and Public Affairs, p. 214–237.

McGuire, V.L., and Sharpe, J.B., 1997, Water-level changes in the High Plains aquifer—Predevelopment to 1995: U.S. Geological Survey Water-Resources Investigations Report 97–4081, 2 pl.

Morgan, D.S., and Jones, J.L., 1999, Numerical model analysis of the effects of ground-water withdrawals on discharge to streams and springs in small basins typical of the Puget Sound Lowland, Washington: U.S. Geological Survey Water-Supply Paper 2492, 73 p.

Morris, E.E., and Bush, W.V., 1986, Extent and source of saltwater intrusion into the alluvial aquifer near Brinkley, Arkansas, 1984: U.S. Geological Survey Water-Resources Investigations Report 85–4322, 123 p.

Nace, R.L., 1960, Water management, agriculture, and ground-water supplies: U.S. Geological Survey Circular 415, 12 p.

Plummer, L.N., Busenberg, E., McConnell, J.B., Drenkard, S., Schlosser, P., and Michel, R.L., 1998, Flow of river water into a karstic limestone aquifer. 1. Tracing the young fraction in groundwater mixtures in the Upper Floridan aquifer near Valdosta, Georgia: Applied Geochemistry, v. 13, no. 8, p. 995–1015.

Reilly, T.E., and Pollock, D.W., 1993, Factors affecting areas contributing recharge to wells in shallow aquifers: U.S. Geological Survey Water-Supply Paper 2412, 21 p.

Schaefer, F.L., and Walker, R.L., 1981, Saltwater intrusion into the Old Bridge aquifer in the Keyport-Union Beach area of Monmouth County, New Jersey: U.S. Geological Survey Water-Supply Paper 2184, 21 p.

Solley, W.B., 1995, United States Geological Survey National Water-Use Information Program: U.S. Geological Survey Fact Sheet FS–057–95, 4 p.

Solley, W.B., Pierce, R.R., and Perlman, H.A., 1998, Estimated use of water in the United States in 1995: U.S. Geological Survey Circular 1200, 71 p.

Sophocleous, M., ed., 1998, Perspectives on sustainable development of water resources in Kansas: Kansas Geological Survey Bulletin 239, 239 p.

Spinello, A.G., and Simmons, D.L., 1992, Base flow of 10 south-shore streams, Long Island, New York, 1976–85, and the effects of urbanization on base flow and flow duration: U.S. Geological Survey Water-Resources Investigations Report 90–4205, 34 p.

Sun, R.J., ed., 1986, Regional Aquifer-System Analysis Program of the U.S. Geological Survey—Summary of projects, 1978–84: U.S. Geological Survey Circular 1002, 264 p.

Swanson, A.A., 1998, Land subsidence in the San Joaquin Valley, updated to 1995, *in* Borchers, J.W., ed., Land subsidence case studies and current research: Proceedings of the Dr. Joseph F. Poland Symposium on Land Subsidence, Sacramento, Calif., October 4–5, 1995, Association of Engineering Geologists, Special Publication no. 8, p. 75–79.

Theis, C.V., 1940, The source of water derived from wells: Civil Engineering, v. 10, no. 5, p. 277–280.

U.S. Geological Survey, 1984, National water summary 1983—Hydrologic events and issues: U.S. Geological Survey Water-Supply Paper 2250, 243 p.

U.S. Geological Survey, 1998, Strategic directions for the U.S. Geological Survey Ground-Water Resources Program: A report to Congress, November 30, 1998, 14 p.

U.S. Water Resources Council, 1980, Essentials of ground-water hydrology pertinent to water-resources planning: U.S. Water Resources Council Hydrology Committee Bulletin 16 (revised), 38 p.

Visocky, A.P., 1997, Water-level trends and pumpage in the deep bedrock aquifers in the Chicago region, 1991–1995: Illinois State Water Survey, Champaign, Circular 182.

Walton, W.C., 1964, Future water-level declines in deep sandstone wells in Chicago region: Ground Water, v. 2, no. 1, p. 13–20.

Winter, T.C., Harvey, J.W., Franke, O.L., and Alley, W.M., 1998, Ground water and surface water—A single resource: U.S. Geological Survey Circular 1139, 79 p.