tions, a single managed well near a fixed well resulted in numerous wells being shut off. For the Fox Cities simulations, a few wells control the withdrawals in the Heart-of-the-Valley communities due to preferential withdrawals for Western Town wells. Because the water-level constraints were somewhat arbitrary, it would be possible to obtain increased yield by further relaxing the constraints at the individual wells.

For two of the fixed wells in the model (Fort Howard and Hortonville), the projected 2030 withdrawal rate exceeds the capacity of the existing well (see Appendix). For the simulations presented in this report, the projected 2030 rate was used. To meet these rates, the capacities of the existing wells would have to be increased accordingly.

CONCLUSIONS

The results presented in this report verify that optimization is a valuable tool for allocating ground-water resources. This statement is valid given the underlying assumptions of the analysis: (1) managed wells are not allowed to inject water into the aquifer; (2) the maximum withdrawal rate of a particular well is fixed based on the well's actual capacity; (3) the distribution systems of communities sharing water are interconnected; (4) the calibrated ground-water flow model is a realistic representation of the flow system; and (5) all solutions are steady state, thus represent sustainable withdrawals in perpetuity if all conditions of the model remain the same.

Three general conclusions are specific to the results of the individual management alternatives presented. First, ground water can supply nearly all of the projected 2030 demand for Central Brown County municipalities if all of the wells are managed (including the city of Green Bay), 8 new wells are installed, and the water levels are allowed to decline as much as 100 feet below the bottom of the confining unit. Second, if the municipalities in Central Brown County convert to surface water, there is a substantial increase in ground water available to the Fox Cities. Third, optimization alternative results indicate steady-state water levels due to projected 2030 withdrawal rates will rebound to levels within 100 ft of the bottom of the confining unit, resulting in increased well capacity.

Two conclusions pertain to the general use of optimization modeling for ground-water management. First, in some cases either a single managed well or a few closely spaced wells can control the results of an entire simulation. Second, comparisons with other factors remaining constant indicate that managing withdrawals will result in increased withdrawals and a more uniform water-level distribution.

REFERENCES CITED

Batten, W.G., and Bradbury, K.R., 1996, Regional groundwater flow system between the Wolf and Fox Rivers near Green Bay, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 75, 28 p.

Bredehoft, J.D., and Young, R.A., 1970, The temporal allocation of ground water-a simulation approach: Water Resources Research, v. 6, no. 1, p. 321.

Conlon, T.D., 1998, Hydrogeology and simulation of ground-water flow in the sandstone aquifer, Northeastern Wisconsin: U.S. Geological Survey Water-Resources Investigations Report 97–4096, 60 p.

Consoer Townsend & Associates Inc., 1992, Engineering report on the Central Brown County water supply and quality study: project number 12-3520.

Danskin, W.R., and Freckleton, J.R., 1992, Ground-water modeling and optimization techniques applied to high-ground-water problems in San Bernardino, California, *in* Subitzky, S., ed., Selected Papers in the Hydrologic Sciences, 1988–92, Water-Supply Paper 2340, U.S. Geological Survey, p. 165–177.

Drescher, W.J., 1953, Ground-water conditions in artesian aquifers in Brown County, Wisconsin: U.S. Geological Survey Water-Supply Paper 1190, 49 p.

Feinstein, D.A., and Anderson, M.P., 1987, Recharge to and potential for contamination of an aquifer system in Northeastern Wisconsin: University of Wisconsin Water Resources Center Technical Report WIS WRC 87–01, 112 p.

Gorelick, S.M., 1983, A Review of distributed parameter groundwater management modeling methods: Water Resources Research, v. 19, no. 2, p. 305.

Gue, R.L., and Thomas, M.E., 1968, Mathematical methods in operations research: London, Macmillan Company, 385 p.

Heidari, M., 1982, Application of linear system's theory and linear programming to ground water management in Kansas: Water Resources Bulletin, v. 18, no. 6, p. 1003–1012.

International Groundwater Modeling Center, 1996, Modman, Management module for MODFLOW using LINDO optimization Program: Colorado School of Mines IGWMC-FOS 76 Version 3.2, [variously paginated].

Knowles, D.B., 1964, Ground-water conditions in the Green Bay area, Wisconsin, 1950–60: U.S. Geological Survey Water-Supply Paper 1669–J, 37 p.

Knowles, D.B., Dreher, F.C., and Whetstone, G.W., 1964, Water resources of the Green Bay area, Wisconsin:

U.S. Geological Survey Water-Supply Paper 1499–G, 67 p.

Krohelski, J.T., 1986, Hydrology and ground-water use and quality, Brown County, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular Number 57, 42 p.

LeRoux, E.F., 1957, Geology and ground-water resources of Outagamie County, Wisconsin: U.S. Geological Survey Water-Supply Paper 1421, 57 p.

McDonald, M.G., and Harbaugh, A.W., 1988, A modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Techniques of Water-Resources Investigations book 6, chapter A1, [variously paginated].

Olcott, P.G., 1966, Geology and water resources of Winnebago County, Wisconsin: U.S. Geological Survey Water-Supply Paper 1814, 61 p.

Reichard, E.G., 1987, Hydrologic influences on the potential benefits of basinwide groundwater management: Water Resources Research, v. 23, no. 1, p. 77–91.

Schrage, L., 1991, User's manual for linear, integer and quadratic programming with LINDO, Release 5.0: San Francisco, CA, The Scientific Press, 132 p.