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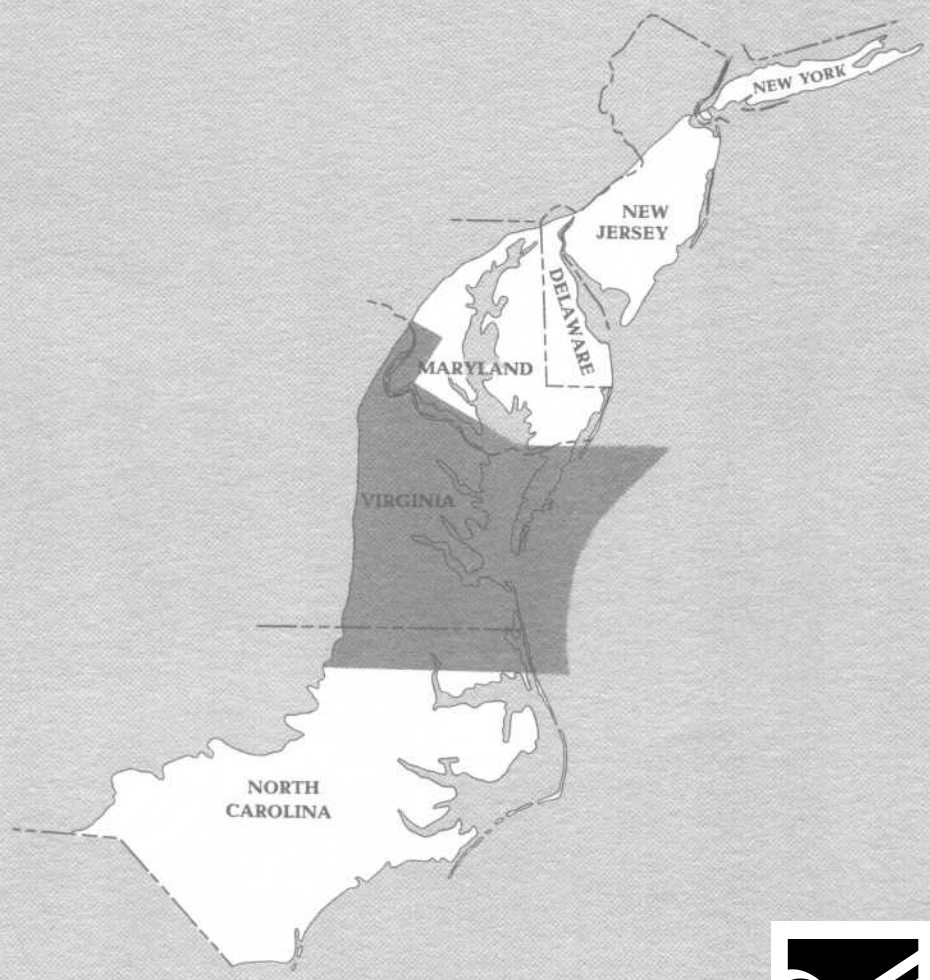
CONCEPTUALIZATION AND ANALYSIS OF GROUND-WATER FLOW SYSTEM IN THE COASTAL PLAIN OF VIRGINIA AND ADJACENT PARTS OF MARYLAND AND NORTH CAROLINA

REGIONAL AQUIFER-SYSTEM ANALYSIS



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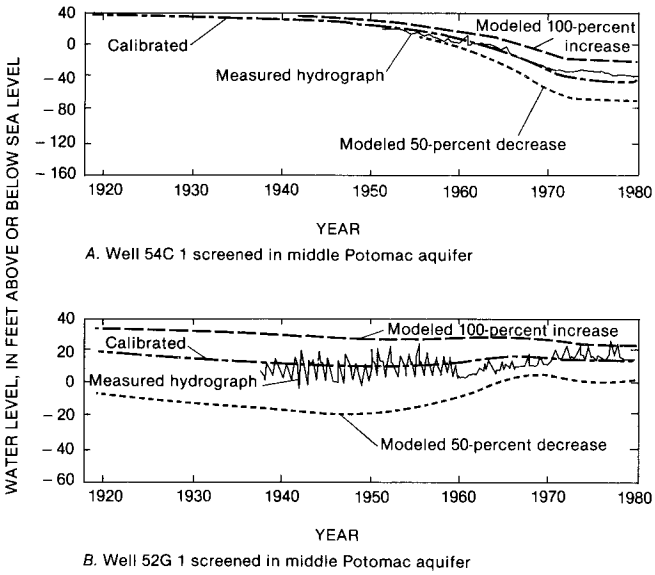

FIGURE 72.—Effects on simulated heads of varying the calibrated value of transmissivity of the middle Potomac aquifer. (Location of wells shown in fig. 62.)

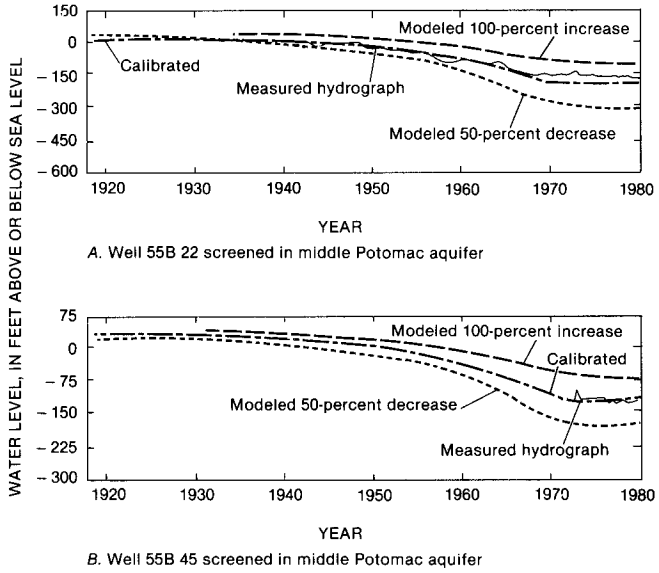

FIGURE 73.—Effects on simulated heads of varying the calibrated value of transmissivity of the middle Potomac aquifer. (Location of wells shown in fig. 62.)

SENSITIVITY ANALYSIS

Sensitivity analysis determines the accuracy of model results in accordance with the degree of uncertainty associated with the simulated value of hydraulic characteristics. In the procedure, the value of an individual calibrated hydraulic characteristic is changed over a specific range, while other values of calibrated characteristics remain unchanged. The magnitude of the change in water levels defines the sensitivity of the model to that hydraulic characteristic and is measured by comparing water-level hydrographs simulated by the calibrated model with those simulated with the changed value of the hydraulic characteristic.

Hydraulic characteristics varied to test model sensitivity were (1) transmissivity of the middle Potomac aquifer, (2) vertical hydraulic conductivity of the middle Potomac confining unit, (3) storage coefficient of the confined aquifers, and (4) specific storage of the confining units. The first two were selected because it was found during calibration that these two hydraulic characteristics had the greatest effect on simulated water levels. The aquifer storage coefficient was tested to evaluate the response of the ground-water flow system to changes in aquifer storage. Storage properties of confining units were tested to determine the significance of neglecting storage in confining units during transient simulations. Table 12 summarizes these sensitivity tests and the results. Lateral flow across model boundaries was not recalculated for any of the sensitivity simulations.

Figures 72 and 73 compare water levels in the middle Potomac aquifer at four observation wells resulting from a 50-percent decrease and a 100-percent increase in the calibrated values of transmissivity. The locations of the wells are shown in figure 62. Water levels within this same aquifer resulting from a 50-percent decrease and a 100-percent increase in the calibrated value of vertical hydraulic conductivity of the overlying confining unit are compared in figures 74 and 75. The sensitivity analysis showed that simulated water levels are much more sensitive to decreases in the selected values of transmissivity and vertical hydraulic conductivity than to increases in the values tested.

Four hydrographs (figs. 76, 77), representing observation wells in the Chickahominy-Piney Point, Brightseat-upper Potomac, and middle Potomac aquifers, compare water levels resulting from an increase of and a decrease of one order of magnitude in the calibrated storage coefficient (1.0×10^{-4}). The locations of these wells are shown in figure 62. The general agreement between hydrographs simulated with the calibrated and the lower value of storage coefficient (1.0×10^{-5}) indicates that the system is near equilibrium at the end of each pumping period and suggests that the calibrated storage coefficient is a reasonable value for simulation. The water levels, which result from an increase in storage coefficient of one order of magnitude, show that the system is sensitive to the higher value (1.0×10^{-3}). The increase in the amount of water released from storage had a significant effect on simulated water levels. The higher value of storage coefficient is not reasonable for confined aquifers in the study area except in a few local areas.

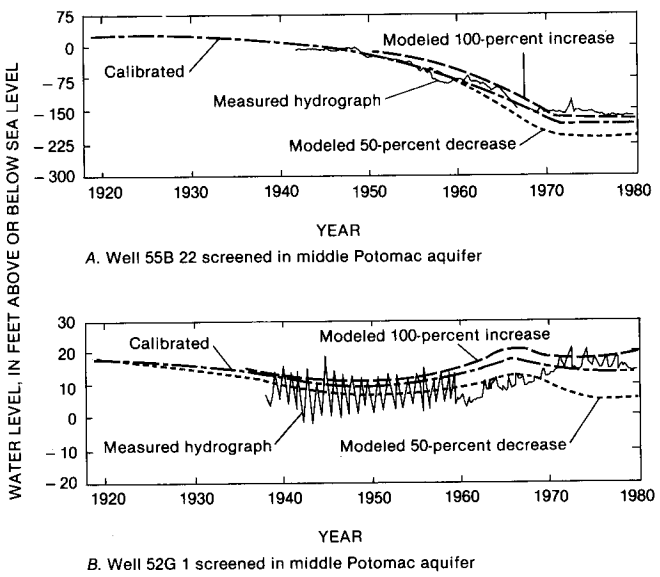

FIGURE 74.—Effects on simulated heads of varying the calibrated value of vertical hydraulic conductivity of the middle Potomac confining unit. (Location of wells shown in fig. 62.)

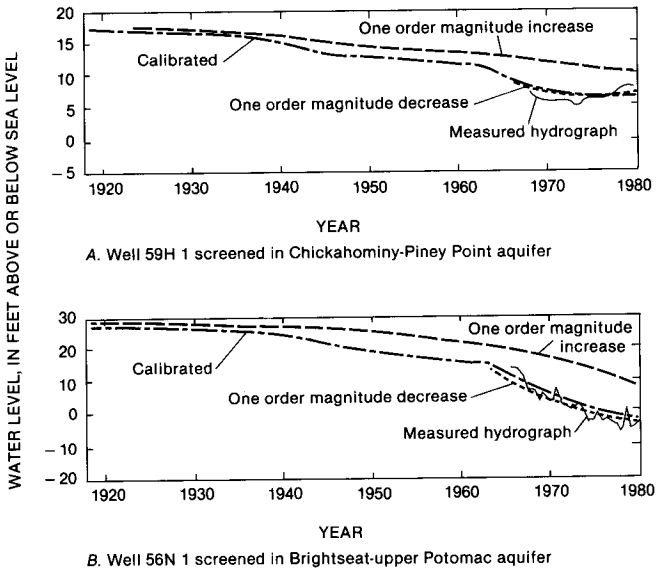

FIGURE 76.—Effects on simulated heads of varying the calibrated value of storage coefficient. (Location of wells shown in fig. 62.)

The calibrated model was developed on the assumption that the effects of storage released from the confining units are negligible over a pumping period. The sensitivity of the model to confining unit storage was tested simulating two values of storage coefficient for each confining unit. One value of storage coefficient was calculated by multiplying the average thickness of each confining unit by a specific storage of 1.0×10^{-6} ft^{-1} (Lohman, 1979). This method assumes that all water released from storage results only from the compressibility of water. The other set of values tested was computed by multiplying the average confining unit thickness by a specific storage of 1.0×10^{-4} ft^{-1}. Storage coefficients tested are shown for each aquifer in table 13.

A specific storage of 1.0×10^{-6} ft^{-1} and the calibrated value, which neglects water released from confining unit storage, resulted in approximately the same water levels (figs. 78, 79). These simulations indicate that the effect of

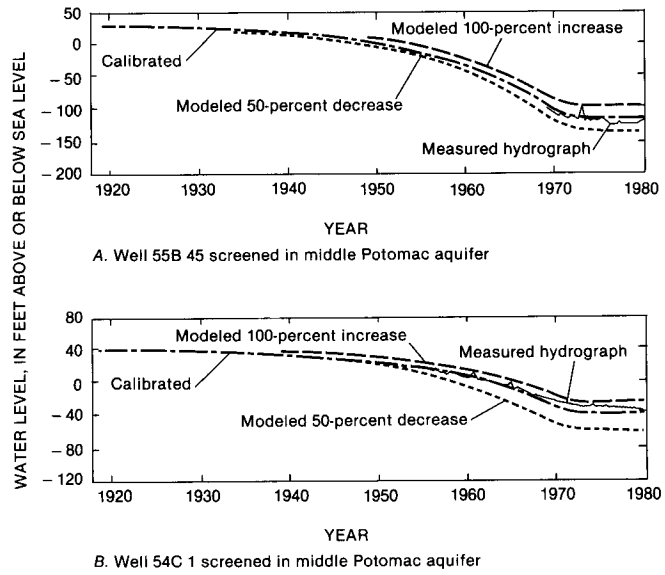

FIGURE 75.—Effects on simulated heads of varying the calibrated value of vertical hydraulic conductivity of the middle Potomac confining unit. (Location of wells shown in fig. 62.)

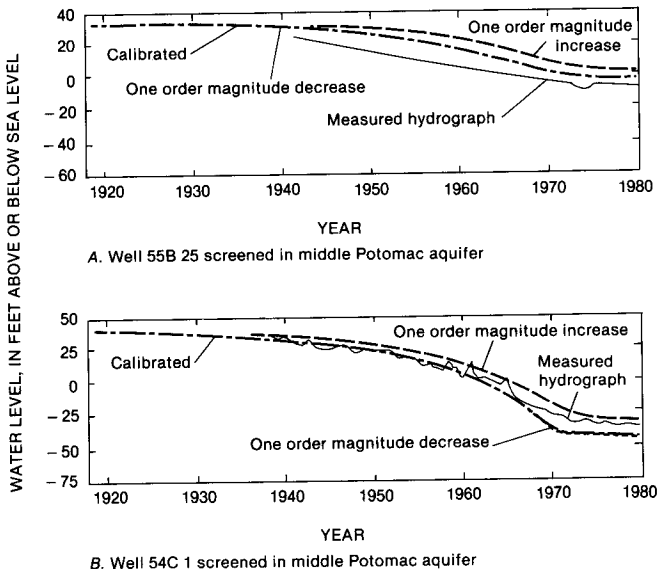

FIGURE 77.—Effects on simulated heads of varying the calibrated value of storage coefficient. (Location of wells shown in fig. 62.)

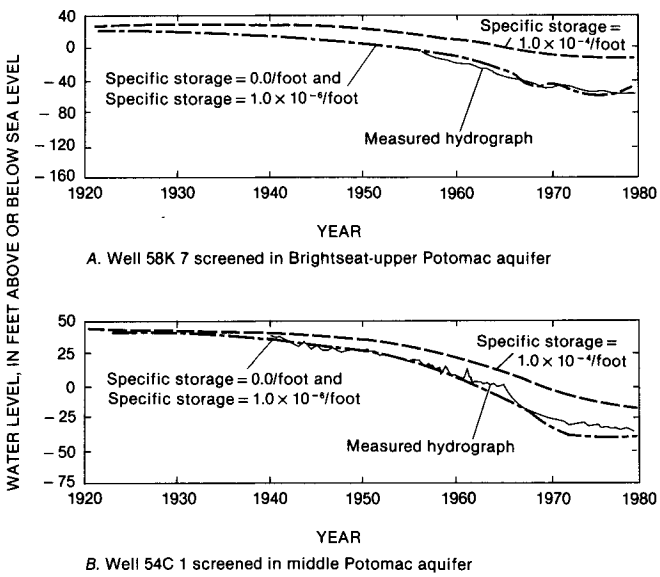

FIGURE 78.—Effects on simulated heads of transient leakage. (Location of wells shown in fig. 62.)

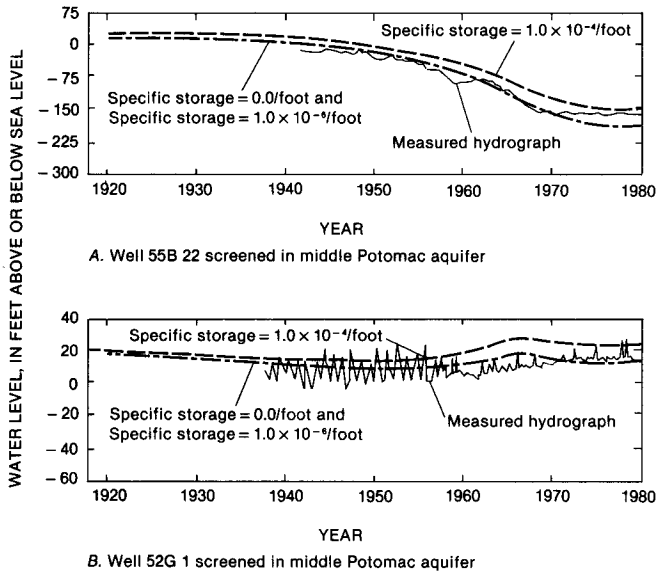

FIGURE 79.—Effects on simulated heads of transient leakage. (Location of wells shown in fig. 62.)

confining unit storage probably is not significant if the water released from confining unit storage is due to the compressibility of water only. Hydrographs generated from confining units having a specific storage of 1.0×10^{-4} ft^{-1} show significantly higher water levels (figs. 78, 79; table 12). The calibrated model does not include confining unit storage because quantitative data defining the storage properties of confining units are not available, and actual storage coefficients probably are closer to the values computed assuming a specific storage of 1.0×10^{-6} ft^{-1}.

LIMITATION AND APPLICATION OF THE FLOW MODEL

The calibrated model is suitable for analyzing the regional flow of ground water in the confined flow system and for evaluating the long-term effects of large-scale withdrawal from the confined aquifers. The model can project the regional impact of proposed large-scale withdrawal scenarios. The large grid scale limits the model's ability to provide detailed analysis of local flow effects. In this study, the accuracy of the model is governed by estimates of hydraulic characteristics, grid spacing (12.25-mi^2 blocks), and time intervals of the 10 pumping periods (3 to 30 yr). Further refinement of the model grid and the values of hydraulic characteristics of aquifers and confining units is needed to analyze local ground-water flow and the short-term effects of ground-water withdrawal and recharge.

The method used to simulate ground-water flow in the water-table aquifer provides an upper boundary condition for the model. The simulation allows water levels to fluctuate in the water-table aquifer; however, it is not intended to provide a detailed analysis of flow in the water-table aquifer or of flow between the water-table aquifer and streams. Additional data defining streambed leakance, stream base flow, and withdrawal from the water-table aquifer are needed to simulate the water-table aquifer more accurately and to quantify flow between the water-table aquifer and streams locally.

More detailed definition of the time-dependent stresses acting on the ground-water flow system and the transient effects of confining unit storage is needed to simulate short-term effects of droughts, seasonal variations in precipitation, and withdrawal. Data needed are storage coefficients of individual confining units and ground-water withdrawal and recharge rates for time intervals smaller than the average annual value.

SUMMARY AND CONCLUSIONS

The unconsolidated sand, silt, and clay of the Coastal Plain aquifer system are an important source of industrial, municipal, domestic, and agricultural water supplies in the Coastal Plain of Virginia. This fresh-ground-water flow system is bounded below and on the west by bedrock, and on the east by salty water. These unconsolidated sediments form a multiaquifer system consisting of a water-table aquifer and an underlying sequence of confined aquifers and intervening confining units that unconformably rest on basement. Near major river channels, aquifers and confining units have been partially or completely eroded and replaced by material more permeable than the confining unit but less permeable than the aquifer.

Use of ground water from confined aquifers began in the Virginia Coastal Plain in the late 1800's and had increased to about 100 Mgal/d in 1980. The continued withdrawal of large quantities of water has resulted in a steady decline of water levels. The decline has changed the direction of ground-water flow toward major pumping centers. These centers are located near the cities of Franklin, Williamsburg, Suffolk, and Alexandria and the towns of West Point and Smithfield. Total withdrawal from these centers is estimated to have been 65 Mgal/d in 1980. The largest center is near Franklin, where withdrawals exceeded 40 Mgal/d in 1980.

A digital flow model was developed to simulate the response of the ground-water flow system to ground-water development. Withdrawal data for each confined aquifer were compiled for the period of simulation, 1891–1980. The middle Potomac aquifer is the most important source of ground water in the Virginia Coastal Plain and supplied an average of about 56 Mgal/d during the period 1978–80. The transmissivity distribution was defined for each aquifer; in general, transmissivity increases from the Fall Line eastward but decreases farther eastward near the freshwater-saltwater interface. The lower and middle Potomac aquifers are the most transmissive aquifers; estimated transmissivity ranges from 410 to 18,145 ft^2/d for the middle Potomac aquifer and from 250 to 12,440 ft^2/d for the lower Potomac aquifer. Vertical leakances simulated the effects of confining units on vertical flow between aquifers.

Maps showing simulated prepumping potentiometric surfaces indicate regional movement of water from the Fall Line toward coastal areas and local movement of ground water from interfluves toward major river valleys. Maps showing simulated flow across confining units indicate that most recharge occurred in narrow bands approximately parallel to the Fall Line and under interfluves and that discharge was toward major river valleys and coastal water. Simulated prepumping rates of recharge into the confined flow system varied up to 3.2 in/yr, and rates of discharge varied up to 2.8 in/yr. The highest rates of simulated recharge are concentrated along the Fall Line.

The simulated potentiometric-surface maps of the major aquifers for 1980 show the lower water levels and the cones of depression that are developing around major pumping centers. The largest simulated decline, about 210 ft, is near Franklin. Water budgets indicate that over the period of simulation (1891–1980) (1) pumpage from the model area increased by about 105 Mgal/d, (2) lateral boundary outflow increased by about 5 Mgal/d, (3) ground-water flow to streams and coastal waters decreased by about 107.5 Mgal/d, (4) lateral boundary inflow increased by about 0.7 Mgal/d, and (5) water released from aquifer storage increased by about 1.6 Mgal/d. Changes in the direction of vertical leakage toward major pumping centers resulted from ground-water withdrawal. The major source of recharge replacing the water pumped from confined aquifers was vertical leakage.

Simulated rates of flow into the confined aquifer system in 1980 varied up to 3.8 in/yr, and rates of flow out of the confined flow system varied up to 2.2 in/yr. Simulations show a net increase of about 110 Mgal/d into the confined from the unconfined flow system over the period of simulation. This change in leakage affected the local discharge of ground water to streams and the regional discharge of ground water to coastal water. The withdrawal of ground water from the confined aquifers increased the area of recharge into the confined flow system by about 33 percent and resulted in the movement of brackish water from Chesapeake Bay into the confined flow system.

Sensitivity analysis shows that simulated water levels are more sensitive to decreases in aquifer transmissivity and confining unit vertical hydraulic conductivity than to increases for the values tested. Lowering the storage coefficient has a negligible effect on simulated water levels; however, increasing the storage coefficient has a significant effect. Sensitivity simulations also indicate that the effect of confining unit storage is not significant if the water released from storage in the confining unit is from the compressibility of water only.

The calibrated model is suitable for analyzing the regional flow of ground water through the confined aquifers. The large grid scale limits the capability of the model to provide a detailed local analysis of the ground-water flow system. The adequacy of the model is governed by estimates of hydraulic characteristics, grid spacing, and time intervals of the 10 pumping periods. The method developed for simulating flow in the water-table aquifer provides an adequate upper-boundary condition for this study. Additional data on streambed leakance, stream base flow, and withdrawal from the water-table aquifer are needed to simulate water levels in the water-table aquifer more accurately and to quantify flow between the water-table aquifer and streams locally. More detailed data are needed to define the time-dependent stresses and the transient effect due to the release of water from storage in the confining units that is neglected in the model developed for this study.

REFERENCES CITED

Bal, G.P., 1977, Computer simulation model for ground-water flow in the Eastern Shore of Virginia: Virginia State Water Control Board Planning Bulletin 309, 73 p.