Table 3.—Summary of simulations

Reference simulations	Results
Calibration (1940-1989): Considered transport of chloride in the Equus Beds aquifer. Sources considered are: the Arkansas River, deep natural saltwater, and oil field brine. Calibration performed by attempting to match chloride breakthrough curves of measured data at various locations.	Reasonable representation of actual conditions in the primary areas of interest from the Arkansas River and the Burrton Oil Field area to the Wichita well field area. The model appears to overpredict the rate of chloride movement in the upper layer.
Base projection (1990-2049): Projection of conditions existing at the end of the calibration simulation to the year 2049. *Boundary conditions, initial conditions, and stresses*: Same as those existing at the end of the calibration simulation in 1989.	*Water elevations*: Cone of depression centered over the Wichita well field area. *Chloride movement*: Plumes migrating from the Arkansas River and Burrton Oil Field area toward the Wichita well field area. Predicted chloride concentrations are as high as 400 mg/L in the southern part and 300 mg/L extreme northwest part of the well field by 2049.
Simulations of individual sources	**Results**
Arkansas River (1940-2049): Saltwater flowing from the river to the aquifer was considered as the only source of chloride. Chloride concentrations in the river varied from 480 mg/L to 630 mg/L from 1940 to 1989 and were constant at 630 mg/L from 1990 to 2049. *Initial conditions*: No chloride present in aquifer in 1940.	Water from the river accounts for the majority of chloride in the upper layer. Significant vertical movement of chloride from the river to the middle and lower model layers. Chloride plume in all layers expanding toward the Wichita well field area.
Deep natural saltwater (1940-2049). Natural chloride located around a low or trough in the bedrock surface near the course of the Arkansas River was considered as the only source of chloride. *Boundary conditions*: Constant concentration cells in the lower layer represent chloride in the trough below the river. *Initial conditions*: The concentration of chloride ranges from 900 to 4,000 mg/L in the constant concentration cells.	Chloride is moving from the trough to the east toward the Wichita well field primarily in the lower layer, with some movement upward into the middle layer.

Table 3.—Summary of simulations (continued)

Simulations of individual sources (continued)	Results (continued)
Burrton Oil Field brine (1940-2049). Brine from oil field operations that was disposed into surface pits from the 1930's to 1940's considered as the only source of chloride. *Initial conditions*: Chloride placed in upper and middle model layers.	Movement of the brine is primarily to the east toward the Wichita well field and Little Arkansas River. Significant vertical movement of chloride into the lower layer from the middle layer.
Management simulations (1990-2049)	**Results**
Investigate the impacts of Arkansas River flow on the aquifer. (2a) Divert Arkansas River upstream of study area. *Stresses*: No flow in Arkansas River during simulation. (2b) Divert Arkansas River upstream of study area and eliminate underflow entering study area below Arkansas River. *Stresses*: No flow in Arkansas River during simulation. *Boundary conditions*: Constant head cells eliminated in upper and middle model layers below Arkansas River at the northwest boundary of the model.	These simulations demonstrate the importance of the Arkansas River acting as a water supply for the aquifer. *Water elevations*: (2a) Predicted to fall as much as 25 feet near the river with an average drop of about 13 feet within the Wichita well field zone. (2b) Greater impacts than simulation 2a. *Chloride movement*: (2a) Little movement of the chloride plume that originated from the river toward the Wichita well field, because the river has been removed as a water and chloride source. (2b) Results similar to simulation 2a.
Install pumping wells to intercept oil field saltwater. Install pumping wells strategically located to remove chloride from the aquifer. *Stresses*: Twenty wells located in the middle and lower model layers (10 each layer) pumping a total of: 2,000 gpm 1,000 (4a2) 3,200 acre-feet per year (100/gallons per minute/well) (4b2) 1,600 acre-feet per year (50/gallons per minute/well) (4c2) 6,400 acre-feet per year (200/gallons per minute/well) 4000	*Water elevations*: All simulations resulted in a cone of depression centered at the pumping wells. Maximum water elevation drops of around 3, 7, and 15 feet as withdrawal rates increase. *Chloride movement*: Effective in minimizing the impact of the Burrton oil field saltwater on the Wichita well field area. *Brine zone*: Average chloride concentrations decrease as withdrawal rates increase by as much as 30 percent from that predicted by the base projection.

50 gpm

Table 3.—Summary of simulations (continued)

Management simulations (1990-2049) (continued)	**Results (continued)**
Eliminate pumping near Arkansas River in an area from the Little Arkansas River to approximately 33 miles north. Pumping in this area may become undesirable as chloride concentrations increase in the aquifer. *Stresses*: Eliminated pumping within this area in the: (3a) upper model layer (15,300 acre-feet per year) and (3b) upper and middle model layers (18,500 acre-feet per year)	*Water elevations*. Minimal impacts. *Chloride movement*. Minimal impacts. *River zone*. Rate of chloride concentration increase is only slightly less than that of the base projection.
Place hydraulic barrier along Arkansas River by recharging better quality water between the Arkansas River and the Wichita well field to inhibit the movement of poor quality water from the river to the aquifer. *Stresses*: The water was recharged to the upper layer at the following rate, concentration, and location: (5a) 5,600 acre-feet per year, 150 mg/L, 1 mile north of Arkansas River. (5b) 2,800 acre-feet per year, 150 mg/L, 1 mile north of Arkansas River. (5c) 11,200 acre-feet per year, 150 mg/L, 1 mile north of Arkansas River. (5d) 5,600 acre-feet per year, 150 mg/L, 2 miles north of Arkansas River. (7a) 5,600 acre-feet per year, 50 mg/L, 1 mile north of Arkansas River. (7b) 5,600 acre-feet per year, 250 mg/L, 1 mile north of Arkansas River. (5e) Alternatively, withdrawals were reduced in the lower model layer by 5,600 acre-feet per year in the southern portion of the Wichita well field.	*Water elevations*: Minimal impact with a maximum rise of 3 feet at the recharge location. *Chloride movement*: In general, effective in inhibiting the movement of chloride from the river. *River zone*: Average chloride concentrations are decreased from the base projection by as much as 23 percent at the highest recharge rate. The decreases in average concentration are less for lower recharge rates. The predicted concentrations are relatively insensitive to the concentrations of recharge water and the areas of recharge considered. Reducing withdrawals within the Wichita well field was less effective in reducing chloride concentration from that predicted in the base projection.

Table 3.—Summary of simulations (continued)

Management simulations (1990-2049) (continued)	**Results (continued)**
Reduce pumping within the Wichita well field to lessen the water quality impact from chloride sources. *Stresses*: Pumping was reduced within the well field area by the following total amount: (8a1) 5,600 acre-feet per year, lower layer (8a2) 11,200 acre-feet per year, lower layer (8a3) 16,800 acre-feet per year, lower layer (8a4) 22,400 acre-feet per year, lower layer (8b1) 5,600 acre-feet per year, all layers (8b2) 11,200 acre-feet per year, all layers (8b3) 16,800 acre-feet per year, all layers (8b4) 22,400 acre-feet per year, all layers (8c1) 5,600 acre-feet per year, upper layer (8d1) 5,600 acre-feet per year, middle layer	*Water elevations*: Increased for all simulations with the largest increases centered in the Wichita well field area. *Chloride movement*: In general, decreases the impacts from chloride sources. Larger reductions in withdrawals have a greater impact in reducing average chloride concentrations. Average concentrations are relatively insensitive to the model layer in which withdrawals are reduced.

Simulations of Individual Sources

General Methodology

The transport of chloride observed in the calibration and projection simulations (1940-2049) can be further characterized by considering each source individually. This allows the relative movement and distribution of chloride in the aquifer source to be evaluated for each source:

- The Arkansas River.
- Deep natural saltwater.
- Brine from the Burrton Oil Field.

Characterizing transport from each of these sources helps to better understand how the aquifer is being contaminated and provides insights into the effective management of the aquifer.

These simulations involved changing the initial and boundary conditions to reflect only the source being considered. They cover the calibration and projection periods from 1940 through 2049. Because the relative contribution from each source to this distribution cannot be determined, these simulations only consider the chloride contributed to the aquifer since 1940 from the source being considered. They do not consider the initial distribution of chloride in the aquifer in 1940. Therefore, the results are used to compare the relative predicted movement and distributions of chloride from these sources.

Chloride distribution maps for each layer were produced for 1989 and 2049, as well as graphs of chloride concentration, chloride mass, and water level versus time for the three zones previously defined.

General Conclusion

The increasing pumpage from the aquifer is primarily responsible for the Arkansas River's contribution of chloride and the oil field saltwater plume's movement toward the well field. Withdrawals from the aquifer have also induced significant vertical movement of chloride into the lower part of the Equus Beds aquifer. Chloride from the Arkansas River appears to pose the greatest long-term threat to the quality of water in the well field zone.

Arkansas River

Chloride originating in the Arkansas River was simulated by assigning a chloride concentration to water that flows from the Arkansas River to the aquifer. Chloride concentrations in the river varied from 480 mg/L to 630 mg/L from 1940 to 1989 (table 2) and were constant at 630 mg/L from 1990 through 2049. The aquifer was assumed not to have any chloride present at the start of the simulation in 1940 because only the chloride contributed to the aquifer since 1940 was considered.

The Arkansas River accounts for the majority of chloride in the upper layer (figures 15-20 in appendix A). There would be significant vertical movement of chloride originating in the river to the middle and lower model layers, with a plume of chloride in all layers that expanded toward the well field zone (figures 15 and 16 in appendix A). The plume in the lower layer is predicted to reach the southern boundary of the well field by 2049, though calibration results suggest that the rate of chloride movement in this area may be overpredicted.

The influence of withdrawals from the aquifer during 1940 to 1989 (figure 4), especially by the Wichita well field, would be primarily responsible for the movement of chloride from the Arkansas River into the aquifer. Losses from the Arkansas River increase when gradients inducing flow between the river and aquifer increase. The gradients are increased by withdrawals from the aquifer (figure 18). In 1940, the Arkansas River had a simulated net gain of about 15,000 acre-feet per year within the study area. By 1989, there would be a net loss of about 38,000 acre-feet per year.

The water elevation would fall as much as 30 feet, with an average drop within the well field zone of about 20 feet (figures 14a and 19). The large drawdowns in this zone have induced vertical movement of chloride into the middle and lower layers, since roughly 74 percent of the pumpage in this zone is from the middle and lower layers (from data provided by Myers et al., in review). Water levels are predicted to reach steady-state conditions around 2010 with an average water level drop of about 24 feet in the well field zone.

Chloride mass and concentration graphs for the river zone for each layer characterize chloride transport over time from the Arkansas River toward the well field. The mass of chloride would increase steadily from about 1990 with the bulk

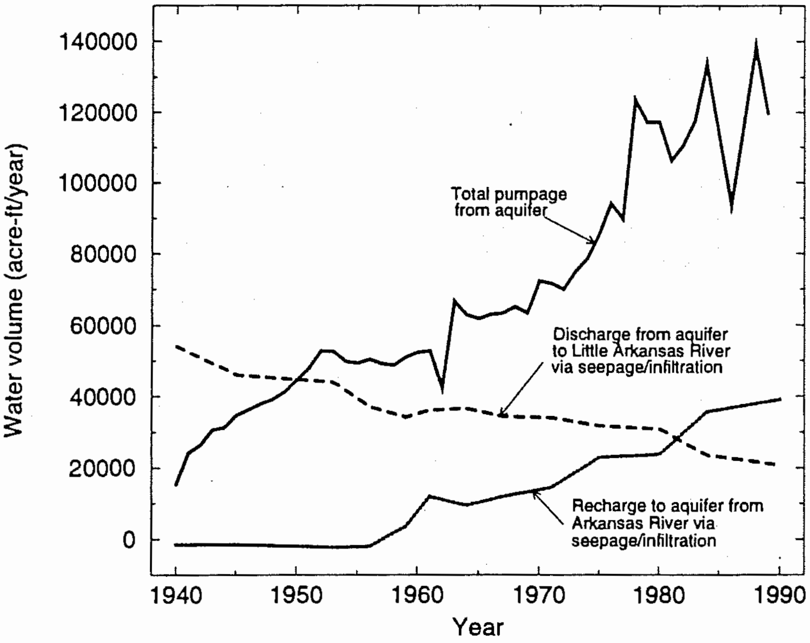

Figure 18.—Total pumpage from aquifer and simulated net stream losses/gains in the Arkansas and Little Arkansas Rivers, 1940-1989.

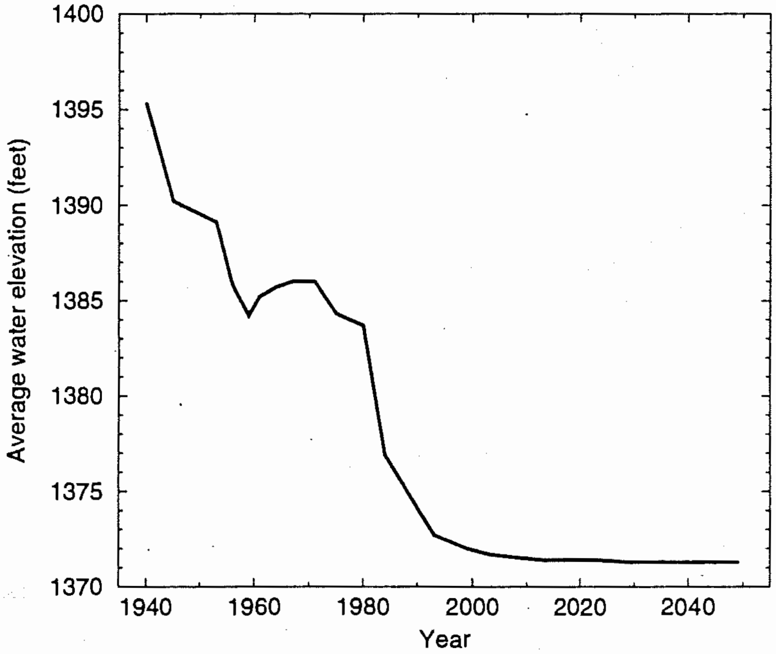

Figure 19.—Predicted average water table elevation in the Wichita well field zone, 1940-1989.

entering the middle and lower model layers (figure 21a in appendix A). After 1990, the mass of chloride in the upper layer would change only slightly when compared to the middle and lower layers because almost as much chloride would leave the zone as enters it. As the chloride plume moves downgradient in the upper layer, it would be displaced downward and diluted by recharge from precipitation. The average chloride concentration in 2049 would be much less in the lower layer than the upper layer (figure 21b in appendix A), although the lower layer would contain more than twice the mass of chloride because the lower layer has much more water in storage than the upper layer.

Deep Natural Saltwater

Natural saltwater located in the deepest part of the aquifer around a bedrock low, or trough, near the course of the Arkansas River is simulated by using constant concentration cells in the lower model layer (figures 10 and 20). The concentration of these cells ranges from 900 mg/L to 4,000 mg/L. This is the only chloride shown as present in the aquifer in 1940 for this simulation.

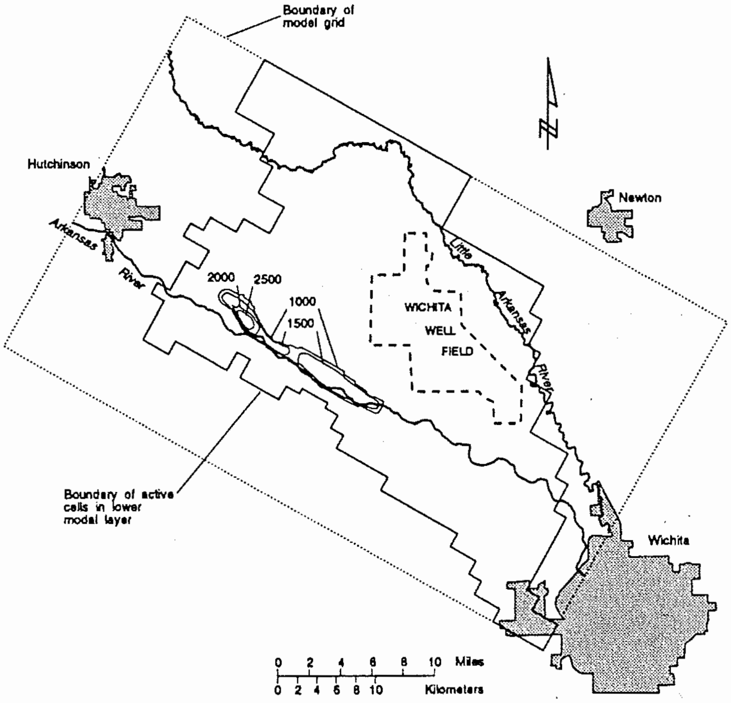

Figure 20.—Distribution of chloride in the lower model layer, representing initial conditions with deep natural saltwater as the only chloride source, 1940.

Chloride would move from the constant concentration cells to the east toward the well field primarily in the lower layer with some movement upward into the middle layer (figures 17 and 18 in appendix A). Movement of chloride into the river zone would be predominantly in the lower layer and would increase steadily from about 1990 on (figure 22 in appendix A).

Burrton Oil Field Brine

Chloride from the Burrton Oil Field operations is simulated with the initial conditions for oil field brine in the upper and middle model layers, as discussed previously (figure 21). All other chloride sources are excluded from the simulation with no chloride initially present in the lower layer.

Movement of chloride would be primarily to the east toward the Wichita well field and Little Arkansas River (figures 15 and 16 in appendix A). The majority of the chloride initially placed in the upper layer would have moved into the middle layer by 1989. Movement of chloride into the lower layer from

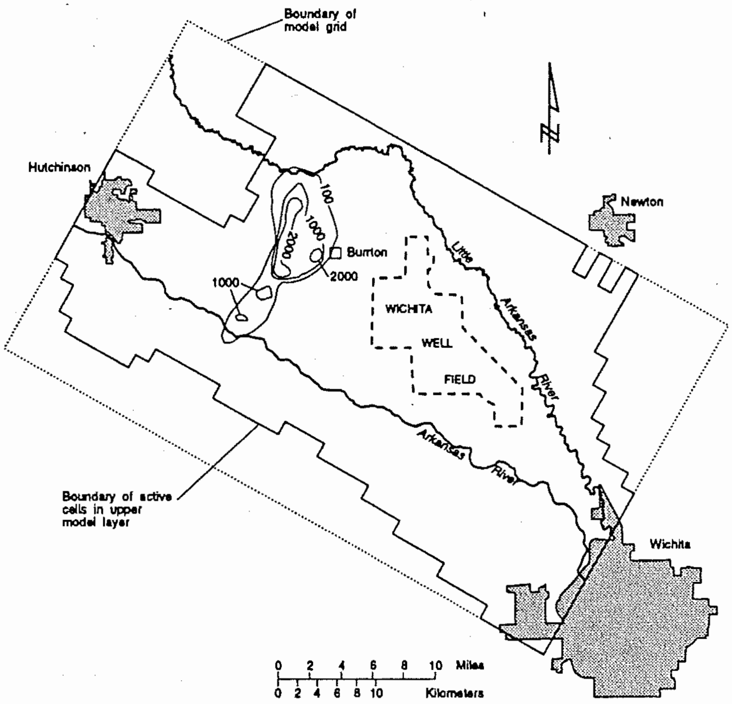

Figure 21a.—Distribution of chloride in the upper model layer, representing initial conditions with oil field brine as the only chloride source, 1940.

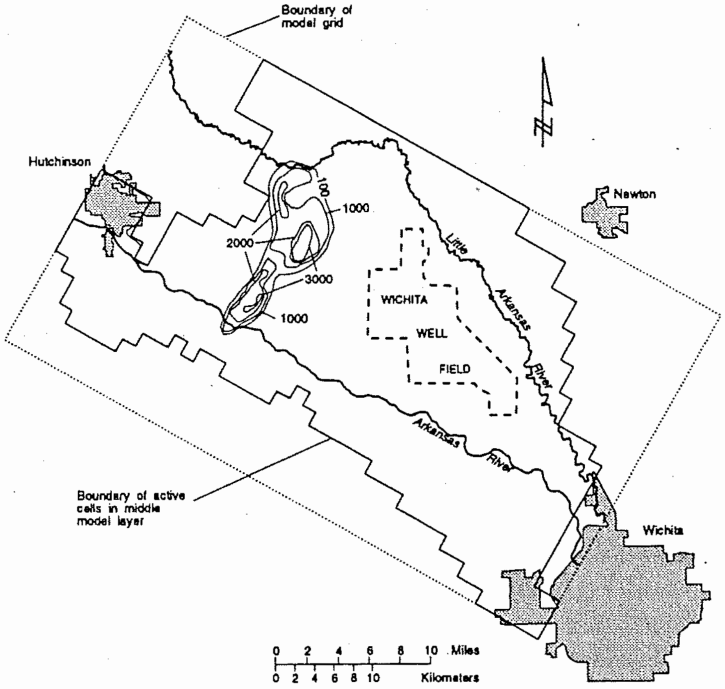

Figure 21b.—Distribution of chloride in the middle model layer, representing initial conditions with oil field brine as the only chloride source, 1940.

above would be significant. This vertical movement is attributed to pumping from the middle and lower layers, primarily within the well field zone.

The withdrawals of water in the well field zone significantly influence the movement of the oil field saltwater. Water levels prior to well development indicate that flow in the northern half of the saltwater plume would be to the northeast toward the Little Arkansas River (figure 4 in appendix A). Movement would be almost due east toward the well field at the present. Thus, eventually much of the Burrton Oil Field saltwater would be collected by the Wichita well field.

The predicted plume in the middle and lower layers would reach beyond the northwest border of the well field zone by 2049. By this time, the plume would have dispersed with peak chloride concentrations decreasing as the initial mass of chloride is mixed with larger volumes of water and is diluted by recharge from precipitation. In addition, chloride would be removed from the aquifer by wells and flow into the Little Arkansas River.

Graphs of the chloride mass and average concentration versus time within the brine zone for each layer characterize transport of the oil field saltwater plume toward the well field (figure 23 in appendix A). The plume would arrive in this zone around 1952 in the upper layer with a peak in mass around 1980. Later arrivals in the middle and lower layers would be followed by steady increases in mass and concentration.

Impacts of Individual Sources on the Wichita Well Field

The relative impacts of specific sources on a defined area, such as the Wichita well field area, can be observed by comparing graphs for each source. Each figure presents a graph for the reference simulation (1940-2049) as well as graphs for each source: the Arkansas River, deep natural saltwater, and oil field brine. The chloride mass graphs do not balance because the simulations of individual sources do not consider the chloride that was in the aquifer in 1940. The difference between the sum of the chloride mass of the three sources and the 1940-2049 reference simulation varies through time. Thus, the sum will be less because of the chloride actually present in the aquifer in 1940 and the redistribution of that chloride with time.

Examination of graphs for the well field zone indicates that the Arkansas River poses the greatest threat through 2049, although the oil field saltwater plume contributes a significant amount of chloride (figure 24 in appendix A). Chloride mass and concentration from the river would steadily increase from about 1990 to 2049, while curves for the oil field saltwater would flatten out somewhat. The oil field saltwater would contribute the largest mass of chloride until about 2010 when the Arkansas River would become the largest contributor.

Inspection of graphs for the reference simulation reveal that by 2049 over half of the chloride would be located in the lower layer, although the average concentration would be at least as low as that in the other layers (figure 25 in appendix A). The lower layer has more water in storage than the other layers and even at a lower concentration can contain more mass.

Graphs for the lower layer for different sources indicate that the Arkansas River and oil field brine would have contributed similar amounts of chloride, while the deep natural saltwater would account for a smaller but increasing amount (figure 26 in appendix A).

Management Simulations

General Methodology

Potential management issues and strategies were investigated, and the results from these simulations were predicted through 2049. These simulations primarily involved modifying the stresses on the aquifer in the flow model to represent new conditions. All changes in stresses were assumed to begin in 2000.

Results were evaluated by using:

- Water level difference maps.
- Chloride concentration maps.
- Water level graphs.
- Chloride mass and concentration graphs.

The water level difference maps depict the difference between water levels predicted by the simulation being investigated and the base projection.

Investigate Impacts of Arkansas River Flow

The Arkansas River loses water during extended periods of baseflow in much of the model area and provides a significant amount of water to the aquifer. Two simulations were run to investigate the impacts of flow in the Arkansas River:

1. **Arkansas River streamflow set to zero**. As water demands upstream increase in the future, flows in the river may decrease. The entire flow of the Arkansas River was assumed to be diverted upstream of the model area and was simulated by reducing riverflow to zero where the river enters the model area.

2. **No-flow boundary and zero streamflow**. For a more extreme scenario, the constant head boundary located where the Arkansas River enters the

> model area (northwestern edge) was changed to a no-flow boundary in addition to a streamflow of zero in the Arkansas River. Although this scenario is unrealistic, simulation results demonstrate the importance of Arkansas River and subsurface flows as water sources to the aquifer.

The impacts of eliminating Arkansas River flow into the area demonstrate the importance of the river acting as a water supply for the aquifer. The projected water levels in 2049 would drop as much as 25 feet near the river, with average drops of about 13 and 9 feet within the river zone and well field zone (figures 27a and 28 in appendix A). The predicted water level differences reveal where water is currently being supplied to the aquifer from the river. The greatest amount of water (and thus chloride) currently being contributed to the aquifer is around the maximum predicted water level differences along the river (figure 27a in appendix A). The primary impacts of removing Arkansas River flow stem from the removal of the water and chloride source. Consequently, the chloride plume that originated from the river would move only slightly toward the Wichita well field (figure 29 in appendix A).

In addition to removing riverflow, the second simulation involving the no-flow boundary would have a greater impact in the well field zone and a much greater impact on water levels in the Hutchinson area (figure 27b in appendix A). Water quality impacts are similar to the first simulation (figure 29 in appendix A).

The scenarios necessary to produce these conditions may be unrealistic, and the simulations do not account for the change in boundary conditions that would actually occur. For example, a lack of flow in the Arkansas River because of conditions upstream would likely change the boundary conditions along the northwestern edge of the model because water levels upstream of the model also depend on flow in the river.

Eliminate Pumping Near Arkansas River

Pumping ground water for agricultural use near the Arkansas River may become undesirable in the future as chloride concentrations increase in the aquifer. Most pumping near the river is from the upper two layers of the model. Pumping was eliminated from these layers within an area extending north of the river for about 3 miles (figure 22). Simulations were made to represent scenarios with no pumping from the upper layer and with no pumping from the upper and middle layers within this area.

The impacts of eliminating this pumping would be minimal with a water level rise of as much as 7 feet and average water level rises of 3 and 4 feet within the river zone predicted by 2049 for the two simulations (figures 30 and 31a in appendix A). The rate of chloride concentration increase in the river zone would be only slightly less than that of the base projection with a predicted decrease in average concentration of about 20 mg/L by 2049 (figure 31b in appendix A).

Install Pumping Wells to Intercept Oil Field Saltwater

Installing pumping wells in strategic locations to remove chloride from the aquifer may effectively minimize the impact of Burrton Oil Field saltwater on the Wichita well field. A relatively large mass of chloride may be removed from the

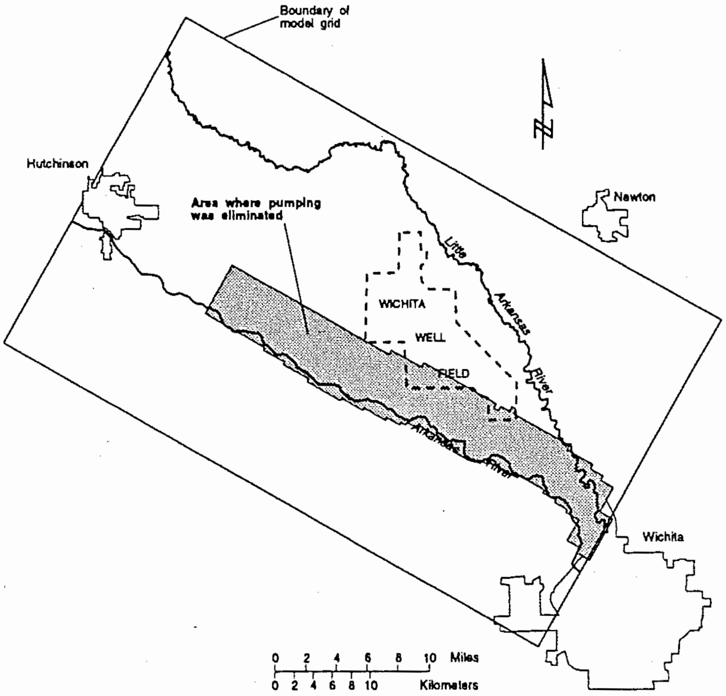

Figure 22.—Area where pumping was eliminated near the Arkansas River.

aquifer by locating withdrawal wells in the highest concentration area of the plume. A total of 20 wells located just east of Burrton were assumed to be divided between the middle and lower model layers (figure 23). Pumping rates for each well of 50, 100, and 200 gallons per minute (gpm) were considered. The water produced might be blended with the Wichita well field supply water.

All three simulations with varying withdrawal rates result in a cone of depression centered at the pumping wells and have an extent which increases as withdrawals are increased. Maximum water level drops of around 3, 7, and 15 feet are predicted in 2049 for the three withdrawal rates relative to the base projection. Drawdown impacts would reach the well field zone (figure 32 in appendix A).

The results of these simulations for water quality were evaluated using graphs of average chloride concentration. The average chloride concentrations within the brine zone decrease in the middle and lower layers as withdrawal rates would increase (figure 33 in appendix A). At the highest withdrawal rate of 200 gpm per well (a total of 6,450 acre-feet

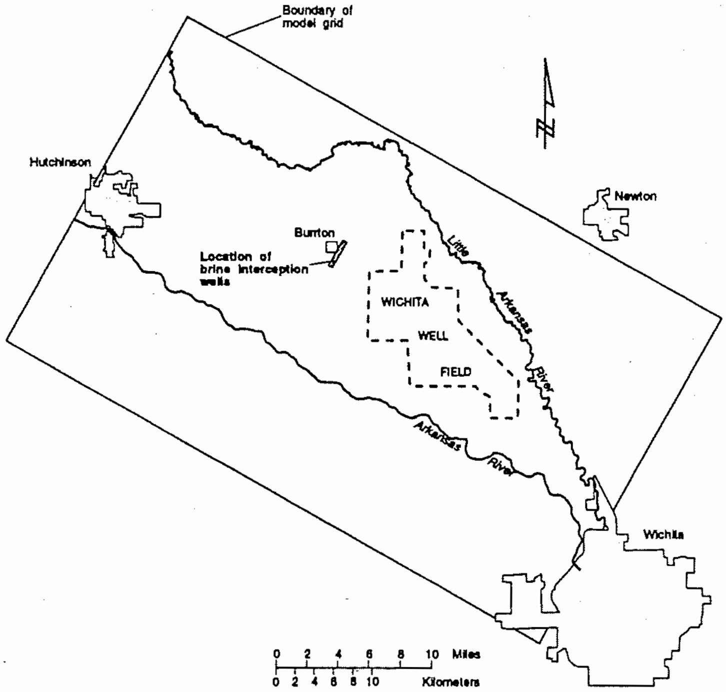

Figure 23.—Location of oil field brine interception wells.

per year for all wells), average chloride concentrations are predicted to fall approximately 30 percent from the base projection in 2049.

The predicted average concentration of the produced water from the interception wells would decrease over time for the middle and lower layers (figures 34a-b in appendix A) with a maximum concentration for the two layers averaged of about 1,150 mg/L when pumping starts in 2000. This water could be blended with and supplement Wichita well field water, which would result in initial chloride concentrations of around 170, 120, and 90 mg/L for the three withdrawal rates considered and around 30 mg/L without blending (figure 34c in appendix A). The calculated concentrations converge to similar values over time. This assumes that the total water provided (from the well field and interception wells) would equal the current production from the well field of approximately 35,000 acre-feet per year.

Place Hydraulic Barrier Along Arkansas River

The recharge of better quality water to the aquifer between the Arkansas River and the Wichita well field might mitigate the movement of chloride to the aquifer from the river, though the source of this recharge water has not been identified. This water was assumed to be recharged evenly to the upper layer along a narrow band approximately 1 mile north of the Arkansas River (figure 24). Total recharge rates of 2,528; 5,650; and 11,300 acre-feet per year as well as chloride concentrations of 50, 150, and 250 mg/L, were applied along this band. The location of a similar recharge band 2 miles north of the river was also considered (figure 24). In addition, a simulation showed the effects of reducing pumpage from the lower model layer within the southern part of the Wichita well field area.

For all simulations with varying recharge rates, there would be a minimal impact on water levels with a maximum rise of 3 feet and an average rise within the river zone of about 2 feet at a recharge rate of 11,300 acre-feet per year (figures 35 and 36 in appendix A). The simulations with varying recharge rates assume a recharge water concentration of 150 mg/L chloride. At a recharge rate of 11,300 acre-feet per year, the average concentration would decrease from the base projection of about 23 and 13 percent within the river zone

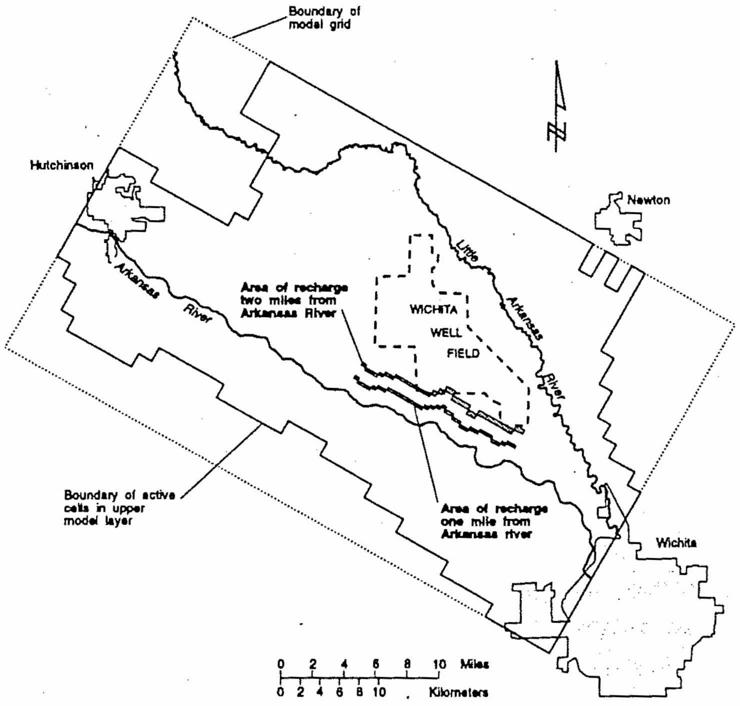

Figure 24.—Hydraulic barrier recharge locations.

and well field zone. The decreases in average concentration would be less for lower recharge rates (figure 37 in appendix A). The largest impact is on the upper layer with decreases in average concentration from the base projection within the river zone of 41, 33, and 15 percent for the three respective layers at a recharge rate of 11,300 acre-feet per year (figure 38 in appendix A). The impacts are similar in the well field zone.

The predicted concentrations are relatively insensitive to the concentrations of recharge water and the areas of the recharge considered in these simulations (figure 39 in appendix A).

An alternative to the hydraulic barrier approach would be to supplement water produced from the well field with recharge water directly, thereby allowing well field production to be decreased. Blending a higher chloride recharge water with a much larger volume of produced water would minimize water quality impacts on the water supply. In this simulation, pumpage equivalent to 5,650 acre-feet per year was removed from the lower layer in the southern part of the well field (figure 25).

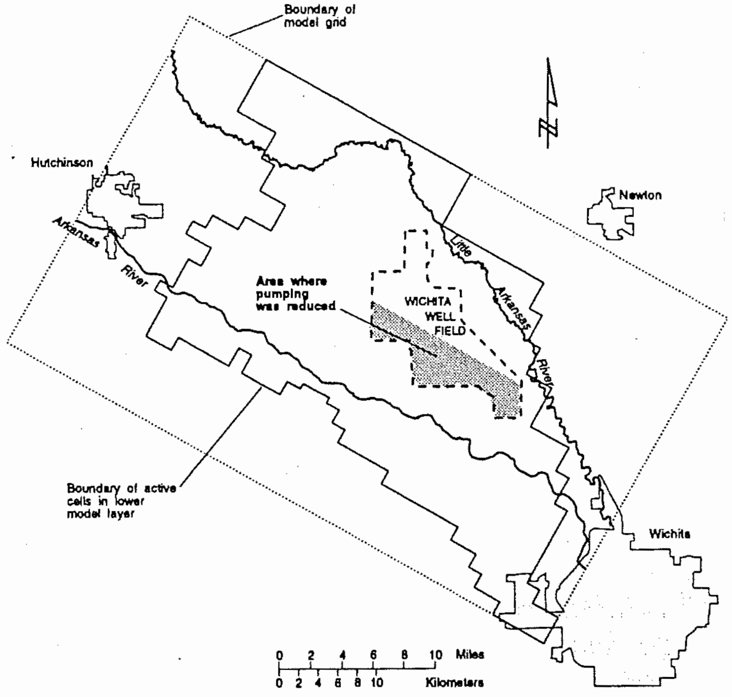

Figure 25.—Area of reduced pumping within Wichita well field zone.

This alternative is slightly less effective than the hydraulic barrier approach in reducing chloride concentrations from that predicted in the base projection (figure 40 in appendix A). Resulting average chloride concentrations were smaller only in the lower layer of the river zone and well field zone when compared with the hydraulic barrier scenario (figure 41 in appendix A).

Reduce Pumping Within the Wichita Well Field

Decreased withdrawals from within the Wichita well field area may lessen the water quality impact from chloride sources. Reduced production from the well field area might be possible if an alternative source of water could supplement the water produced from the aquifer. Withdrawals were reduced by 5,600; 11,200; 16,800; and 22,400 acre-feet per year in the lower model layer. These same reductions were also applied evenly to all three layers. In addition, a comparison between layers was made for a reduction in withdrawals of 5,600 acre-feet per year.

All simulations of reduced withdrawals result in increased water levels; the largest increases center in the Wichita well field area (figure 42 in appendix A). A maximum water level rise of approximately 19 feet and an average rise of around 12 feet is predicted within the Wichita well field area for a reduction in pumpage of 22,400 acre-feet per year (figure 43 in appendix A).

The predicted average concentrations in the brine and river zones appear to be relatively insensitive to the layer in which withdrawals are reduced, though reductions in the deeper layers seem to have slightly more impact on concentration (figure 44 in appendix A). As expected, larger reductions in withdrawals would have a greater impact in reducing average concentrations.

Comparison of Management Simulations

The management simulations affect the Equus Beds aquifer and rivers to different degrees. These impacts are compared for stream losses and gains, water levels, and the distribution of salinity in the aquifer.

Impacts on Arkansas River

The Arkansas River generally loses water throughout the study area during extended periods of baseflow. This water loss from the river to the Equus Beds aquifer is directly related to the stresses in the aquifer. Losses from the river have increased as pumpage from this aquifer has increased (figure 18). The contribution of salinity from the river is, therefore, a function of river losses resulting from aquifer withdrawals. The predicted net loss of water from the Arkansas River in the study area was compared for each of the predictive simulations (figure 26).

Most simulations performed involve decreasing the net withdrawal of water from the aquifer. This decrease creates a corresponding decrease in river losses (figure 26). The simulations of interception wells (simulations 4a2, 4b2, and 4c2) involve increased withdrawals from the aquifer and result in increased losses from the Arkansas River. In general, as the net stress (pumpage less recharge) on the aquifer is decreased, the net loss from the river also decreases. Also, as the simulated stress (artificial recharge or decreased withdrawals) is located nearer to the Arkansas River, the impact on river losses increases. For example, the recharge of

11,200 acre-feet per year to the upper layer at two different locations (simulations 5a and 5d) indicates a greater impact on river losses for the location nearest the river (simulation 5a). The simulations that eliminate pumping near the river (simulations 3a and 3b) show a much greater effect on river losses than simulations that decrease the net withdrawals from the aquifer by similar amounts (simulations 8a3 and 8b3).

Impacts on Little Arkansas River

The Little Arkansas River generally gains throughout the study area. This gain of water from the aquifer is directly related to the stresses in the aquifer. As withdrawals from the Equus Beds have increased over time, gains from the aquifer have decreased (figure 18). The predicted net gain of water to the river from the aquifer in the study area was compared for each of the predictive simulations (figure 27).

In general, as the net stress (pumpage less recharge) on the aquifer is decreased, the net gain in the Little Arkansas River increases. In addition, as the location of the simulated stress (artificial recharge or decreased withdrawals) nears the Little Arkansas River, the impact on river gains grows. For example, decreasing withdrawals by 11,200 acre-feet per year in the lower layer within the Wichita well field area (simulation 8a2) would result in roughly twice the gains in the Little Arkansas River when compared to the simulation of recharge of 11,300 acre-feet per year to the upper layer much farther from the Little Arkansas River and near the Arkansas River (simulation 5c).

Movement of Natural Salinity

The sources of natural salinity include the Arkansas River and the deep natural saltwater. The impacts of management simulations on water quality for these sources can be evaluated using average chloride concentrations within the river zone (figure 28).

The importance of the Arkansas River as a salinity source was demonstrated by simulating the diversion of the river upstream of the study area (figure 28; simulation 2a). Predicted average chloride concentrations within the river zone would not increase significantly, confirming that river

LEGEND OF SIMULATIONS

(1) **Base Projection.** Projection of the conditions existing at the end of the calibration simulation to the year 2049.

Impacts of Arkansas River flow:

(2a) Diversion of Arkansas River upstream of study area.
(2b) Simulation 2a and elimination of underflow entering study area below the Arkansas River.

Eliminate pumping near Arkansas River by:

(3a) 15,300 acre-feet per year in upper model layer.
(3b) 18,500 acre-feet per year in upper and middle model layers.

Install interception wells with total withdrawal rate of:

(4a2) 3,200 acre-feet per year.
(4b2) 1,600 acre-feet per year.
(4c2) 6,400 acre-feet per year.

Place hydraulic barrier along Arkansas River: water recharged to the upper model layer at the following rate, concentration, and location north of Arkansas River:

(5a) 5,600 acre-feet per year, 150 mg/L, 1 mile.
(5b) 2,800 acre-feet per year, 150 mg/L, 1 mile.
(5c) 11,200 acre-feet per year, 150 mg/L, 1 mile.
(5d) 5,600 acre-feet per year, 150 mg/L, 2 miles.
(7a) 5,600 acre-feet per year, 50 mg/L, 1 mile.
(7b) 5,600 acre-feet per year, 250 mg/L, 1 mile.
(5e) Alternatively, withdrawals were reduced in the lower model layer by 5,600 acre-feet per year in the southern portion of the Wichita well field.

Reduce pumping within the Wichita well field by:

(8a1) 5,600 acre-feet per year in lower layer.
(8a2) 11,200 acre-feet per year in lower layer.
(8a3) 16,800 acre-feet per year in lower layer.
(8a4) 22,400 acre-feet per year in lower layer.
(8b1) 5,600 acre-feet per year in all layers.
(8b2) 11,200 acre-feet per year in all layers.
(8b3) 16,800 acre-feet per year in all layers
(8b4) 22,400 acre-feet per year in all layers.
(8c1) 5,600 acre-feet per year in upper layer.
(8d1) 5,600 acre-feet per year in middle layer.

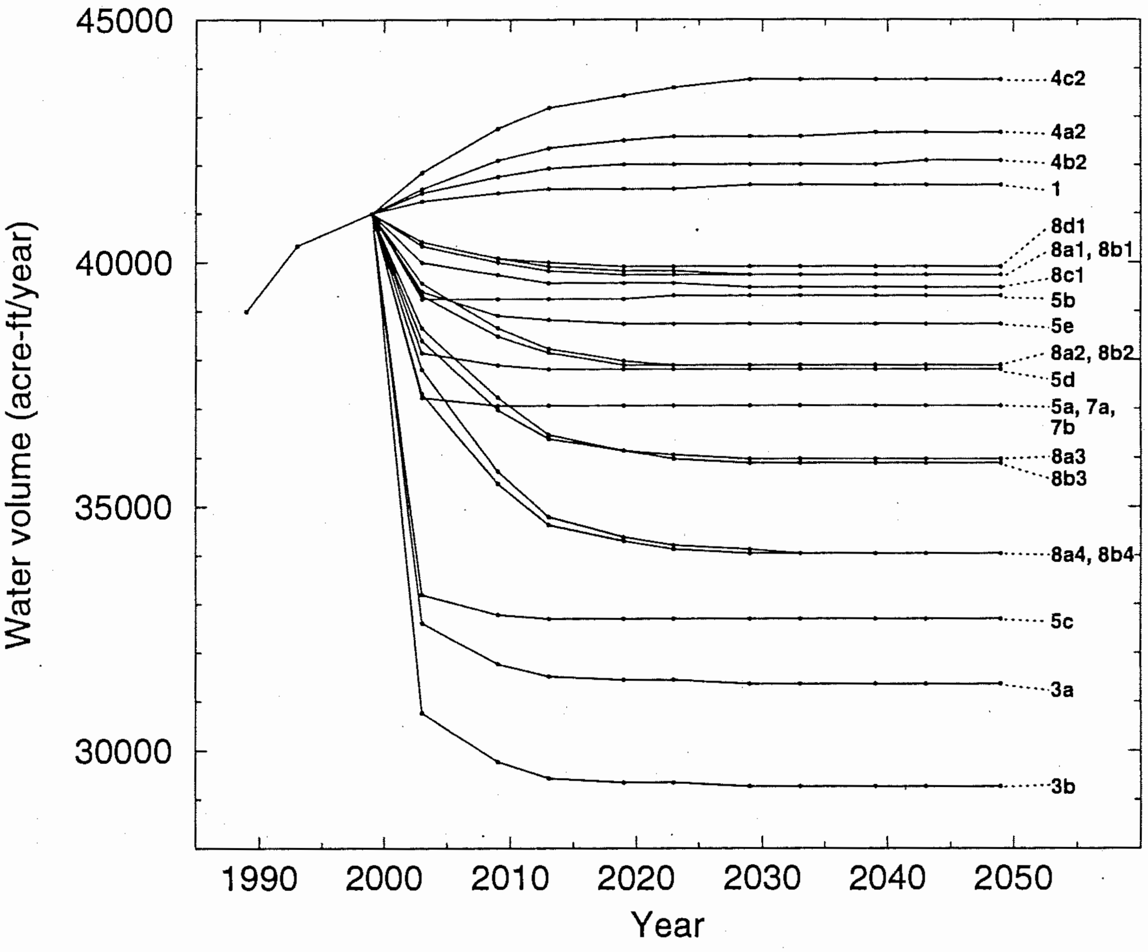

Figure 26.—Predicted net loss of water from the Arkansas River to the aquifer for predictive simulations, 1989-2049.

LEGEND OF SIMULATIONS

(1) **Base Projection.** Projection of the conditions existing at the end of the calibration simulation to the year 2049.

Impacts of Arkansas River flow:

(2a) Diversion of Arkansas River upstream of study area.
(2b) Simulation 2a and elimination of underflow entering study area below the Arkansas River.

Eliminate pumping near Arkansas River by:

(3a) 15,300 acre-feet per year in upper model layer.
(3b) 18,500 acre-feet per year in upper and middle model layers.

Install interception wells with total withdrawal rate of:

(4a2) 3,200 acre-feet per year.
(4b2) 1,600 acre-feet per year.
(4c2) 6,400 acre-feet per year.

Place hydraulic barrier along Arkansas River: water recharged to the upper model layer at the following rate, concentration, and location north of Arkansas River:

(5a) 5,600 acre-feet per year, 150 mg/L, 1 mile.
(5b) 2,800 acre-feet per year, 150 mg/L, 1 mile.
(5c) 11,200 acre-feet per year, 150 mg/L, 1 mile.
(5d) 5,600 acre-feet per year, 150 mg/L, 2 miles.
(7a) 5,600 acre-feet per year, 50 mg/L, 1 mile.
(7b) 5,600 acre-feet per year, 250 mg/L, 1 mile.
(5e) Alternatively, withdrawals were reduced in the lower model layer by 5,600 acre-feet per year in the southern portion of the Wichita well field.

Reduce pumping within the Wichita well field by:

(8a1) 5,600 acre-feet per year in lower layer.
(8a2) 11,200 acre-feet per year in lower layer.
(8a3) 16,800 acre-feet per year in lower layer.
(8a4) 22,400 acre-feet per year in lower layer.
(8b1) 5,600 acre-feet per year in all layers.
(8b2) 11,200 acre-feet per year in all layers.
(8b3) 16,800 acre-feet per year in all layers
(8b4) 22,400 acre-feet per year in all layers.
(8c1) 5,600 acre-feet per year in upper layer.
(8d1) 5,600 acre-feet per year in middle layer.

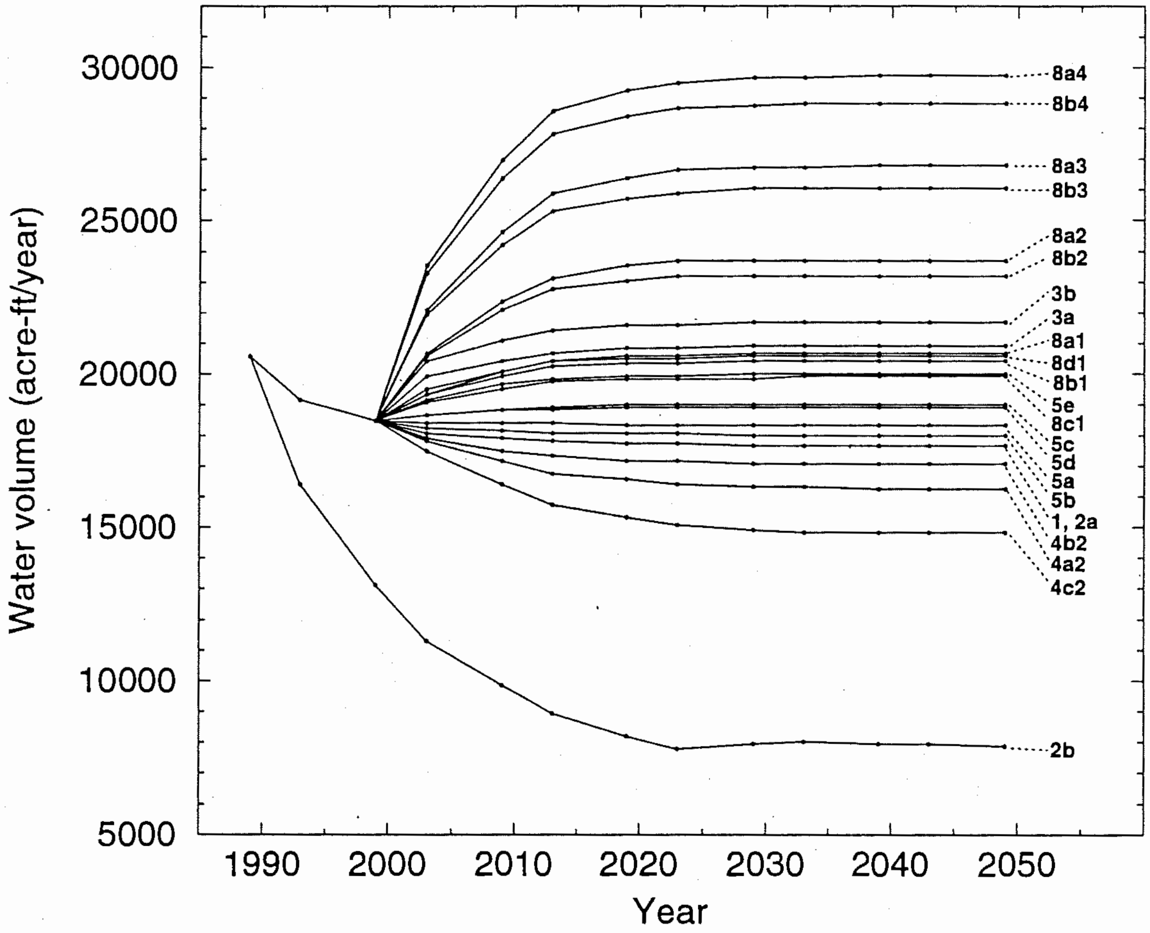

Figure 27.—Predicted net gain of water to the Little Arkansas River from the aquifer for predictive simulations, 1989-2049.

contributions to the aquifer are primarily responsible for the chloride plume migrating through the river zone toward the Wichita well field. Chloride from the deep natural saltwater appears to be less of an immediate threat to the Wichita well field.

Using a hydraulic barrier between the Arkansas River and the Wichita well field area appears to be an effective approach to minimize the impact of chloride from natural sources (figure 28; simulations 5a, 5b, 5c, 5d, 7a, and 7b). This water barrier is more effective as recharge rates are increased. Application of the recharge water reduces losses from the Arkansas River (figure 26) and dilutes the resulting chloride plume.

Reductions in pumpage within the Wichita well field area (all of simulation 8) favorably inhibit the migration of chloride from the Arkansas River but are less effective than the hydraulic barrier approach in terms of the amount of water required. For example, recharging 11,200 acre-feet per year as a hydraulic barrier (simulation 5c) would be much more effective in reducing chloride concentrations than reducing pumpage by 11,200 acre-feet per year (simulation 8a2) within the river zone (figure 28).

Movement of Oil Field Saltwater Plume

The saltwater plume from the Burrton Oil Field operations is moving primarily to the east toward the Wichita well field and the Little Arkansas River. Impacts of management simulations on water quality for this source can be evaluated using average chloride concentrations within the brine zone (figure 29).

An effective approach in minimizing the impact of the oil field saltwater plume on the well field zone appears to be the use of interception wells. These wells would be located to withdraw water from the highest concentration areas of the saltwater plume. The reduction of average concentrations in the brine zone increases as withdrawal rates increase (figure 29; simulations 4a2, 4b2, and 4c2).

Reducing pumping in the well field zone (all of simulation 8) would deter the migration of the saltwater plume, but this approach would be less effective than the interception well approach. For example, withdrawing 1,600 acre-feet per year (simulation 4b2) through strategically located interception wells may be almost as effective in reducing chloride concentrations as reducing pumpage by 16,800 acre-feet per year (simulation 8b3) within the brine zone (figure 29).

Impacts on Wichita Well Field Water Quality

Natural chloride sources and the saltwater from Burrton Oil Field operations affect the water quality in the Wichita well field area. The impacts of management simulations on water quality in the Wichita well field can be evaluated using average chloride concentrations within the Wichita well field area (figure 30).

Both the hydraulic barrier (all of simulations 5 and 7) and pumping reduction (all of simulation 8) scenarios show similar impacts (figure 30). The hydraulic barrier scenarios restrict chloride movement from the Arkansas River, while reductions in pumpage would reduce chloride migration from both the Arkansas River and the Burrton Oil Field saltwater.

LEGEND OF SIMULATIONS

(1) **Base Projection.** Projection of the conditions existing at the end of the calibration simulation to the year 2049.

Impacts of Arkansas River flow:

(2a) Diversion of Arkansas River upstream of study area.
(2b) Simulation 2a and elimination of underflow entering study area below the Arkansas River.

Eliminate pumping near Arkansas River by:

(3a) 15,300 acre-feet per year in upper model layer.
(3b) 18,500 acre-feet per year in upper and middle model layers.

Install interception wells with total withdrawal rate of:

(4a2) 3,200 acre-feet per year.
(4b2) 1,600 acre-feet per year.
(4c2) 6,400 acre-feet per year.

Place hydraulic barrier along Arkansas River: water recharged to the upper model layer at the following rate, concentration, and location north of Arkansas River:

(5a) 5,600 acre-feet per year, 150 mg/L, 1 mile.
(5b) 2,800 acre-feet per year, 150 mg/L, 1 mile.
(5c) 11,200 acre-feet per year, 150 mg/L, 1 mile.
(5d) 5,600 acre-feet per year, 150 mg/L, 2 miles.
(7a) 5,600 acre-feet per year, 50 mg/L, 1 mile.
(7b) 5,600 acre-feet per year, 250 mg/L, 1 mile.
(5e) Alternatively, withdrawals were reduced in the lower model layer by 5,600 acre-feet per year in the southern portion of the Wichita well field.

Reduce pumping within the Wichita well field by:

(8a1) 5,600 acre-feet per year in lower layer.
(8a2) 11,200 acre-feet per year in lower layer.
(8a3) 16,800 acre-feet per year in lower layer.
(8a4) 22,400 acre-feet per year in lower layer.
(8b1) 5,600 acre-feet per year in all layers.
(8b2) 11,200 acre-feet per year in all layers.
(8b3) 16,800 acre-feet per year in all layers
(8b4) 22,400 acre-feet per year in all layers.
(8c1) 5,600 acre-feet per year in upper layer.
(8d1) 5,600 acre-feet per year in middle layer.

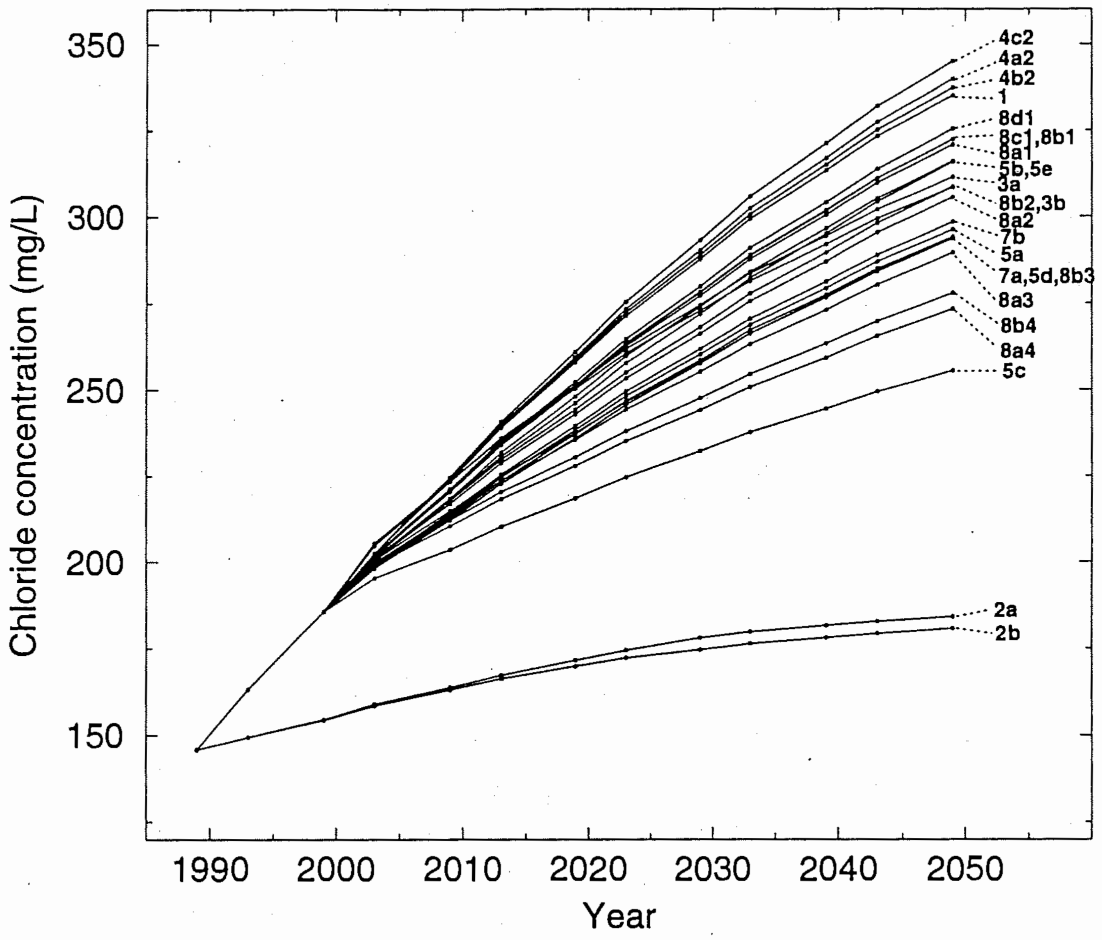

Figure 28.—Predicted average chloride concentration in the river zone for predictive simulations, 1989-2049.

LEGEND OF SIMULATIONS

(1) **Base Projection.** Projection of the conditions existing at the end of the calibration simulation to the year 2049.

Impacts of Arkansas River flow:

(2a) Diversion of Arkansas River upstream of study area.
(2b) Simulation 2a and elimination of underflow entering study area below the Arkansas River.

Eliminate pumping near Arkansas River by:

(3a) 15,300 acre-feet per year in upper model layer.
(3b) 18,500 acre-feet per year in upper and middle model layers.

Install interception wells with total withdrawal rate of:

(4a2) 3,200 acre-feet per year.
(4b2) 1,600 acre-feet per year.
(4c2) 6,400 acre-feet per year.

Place hydraulic barrier along Arkansas River: water recharged to the upper model layer at the following rate, concentration, and location north of Arkansas River:

(5a) 5,600 acre-feet per year, 150 mg/L, 1 mile.
(5b) 2,800 acre-feet per year, 150 mg/L, 1 mile.
(5c) 11,200 acre-feet per year, 150 mg/L, 1 mile.
(5d) 5,600 acre-feet per year, 150 mg/L, 2 miles.
(7a) 5,600 acre-feet per year, 50 mg/L, 1 mile.
(7b) 5,600 acre-feet per year, 250 mg/L, 1 mile.
(5e) Alternatively, withdrawals were reduced in the lower model layer by 5,600 acre-feet per year in the southern portion of the Wichita well field.

Reduce pumping within the Wichita well field by:

(8a1) 5,600 acre-feet per year in lower layer.
(8a2) 11,200 acre-feet per year in lower layer.
(8a3) 16,800 acre-feet per year in lower layer.
(8a4) 22,400 acre-feet per year in lower layer.
(8b1) 5,600 acre-feet per year in all layers.
(8b2) 11,200 acre-feet per year in all layers.
(8b3) 16,800 acre-feet per year in all layers
(8b4) 22,400 acre-feet per year in all layers.
(8c1) 5,600 acre-feet per year in upper layer.
(8d1) 5,600 acre-feet per year in middle layer.

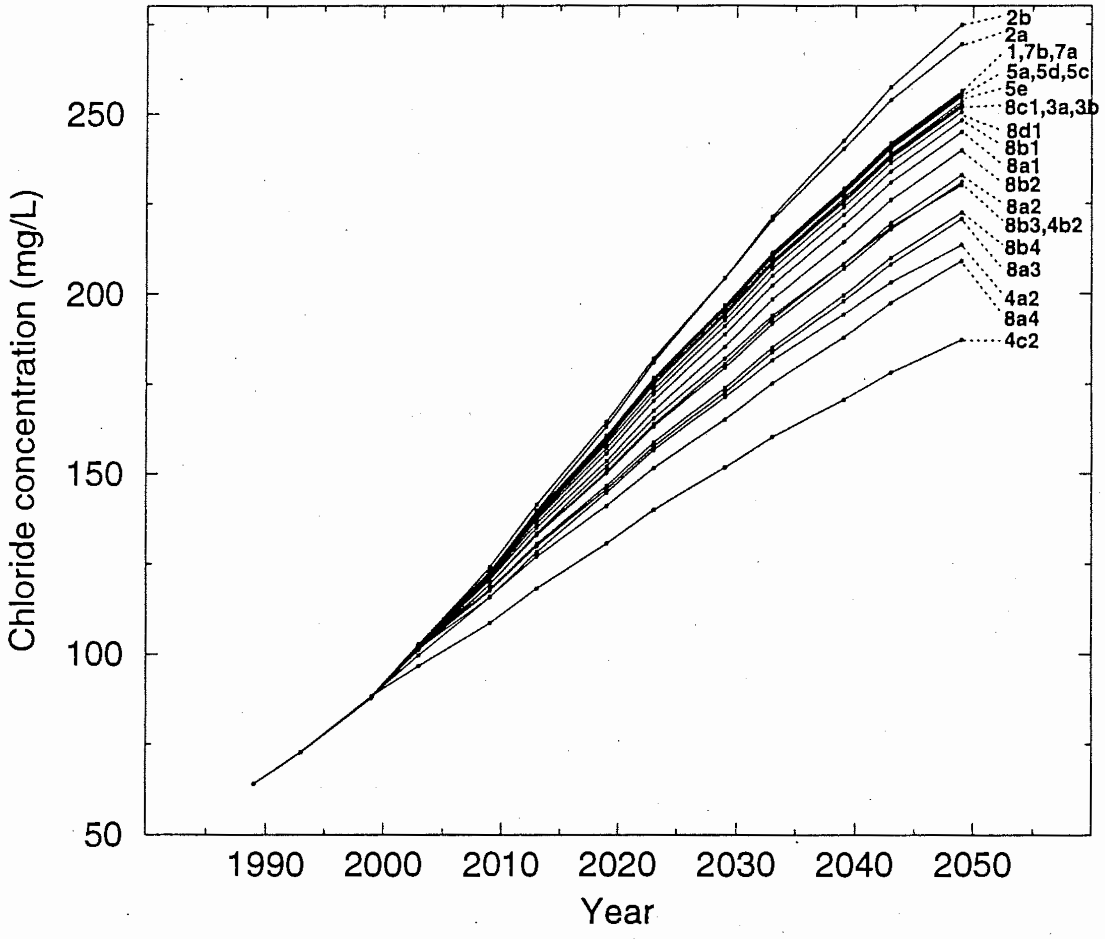

Figure 29.—Predicted average chloride concentration in the brine zone for predictive simulations, 1989-2049.

LEGEND OF SIMULATIONS

(1)	**Base Projection.** Projection of the conditions existing at the end of the calibration simulation to the year 2049.

Impacts of Arkansas River flow:

(2a)	Diversion of Arkansas River upstream of study area.
(2b)	Simulation 2a and elimination of underflow entering study area below the Arkansas River.

Eliminate pumping near Arkansas River by:

(3a)	15,300 acre-feet per year in upper model layer.
(3b)	18,500 acre-feet per year in upper and middle model layers.

Install interception wells with total withdrawal rate of:

(4a2)	3,200 acre-feet per year.
(4b2)	1,600 acre-feet per year.
(4c2)	6,400 acre-feet per year.

Place hydraulic barrier along Arkansas River: water recharged to the upper model layer at the following rate, concentration, and location north of Arkansas River:

(5a)	5,600 acre-feet per year, 150 mg/L, 1 mile.
(5b)	2,800 acre-feet per year, 150 mg/L, 1 mile.
(5c)	11,200 acre-feet per year, 150 mg/L, 1 mile.
(5d)	5,600 acre-feet per year, 150 mg/L, 2 miles.
(7a)	5,600 acre-feet per year, 50 mg/L, 1 mile.
(7b)	5,600 acre-feet per year, 250 mg/L, 1 mile.
(5e)	Alternatively, withdrawals were reduced in the lower model layer by 5,600 acre-feet per year in the southern portion of the Wichita well field.

Reduce pumping within the Wichita well field by:

(8a1)	5,600 acre-feet per year in lower layer.
(8a2)	11,200 acre-feet per year in lower layer.
(8a3)	16,800 acre-feet per year in lower layer.
(8a4)	22,400 acre-feet per year in lower layer.
(8b1)	5,600 acre-feet per year in all layers.
(8b2)	11,200 acre-feet per year in all layers.
(8b3)	16,800 acre-feet per year in all layers
(8b4)	22,400 acre-feet per year in all layers.
(8c1)	5,600 acre-feet per year in upper layer.
(8d1)	5,600 acre-feet per year in middle layer.

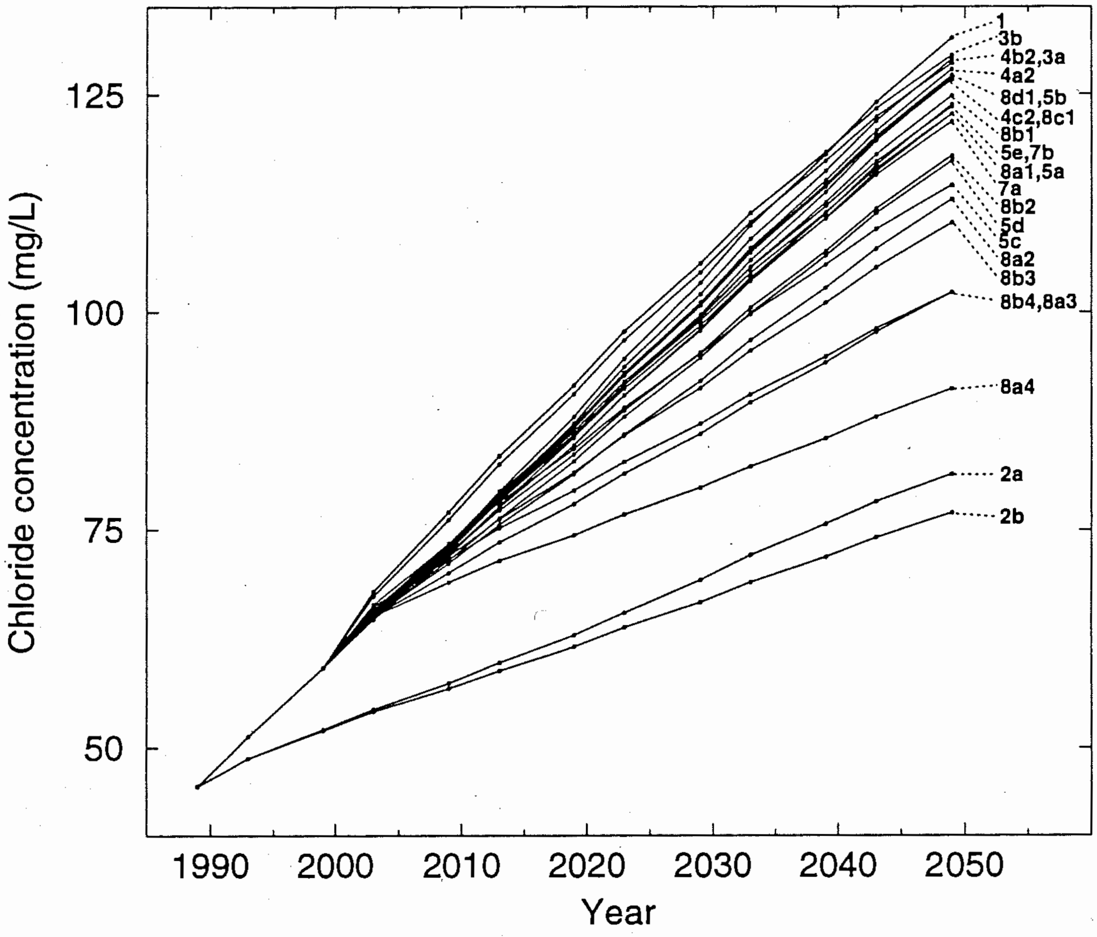

Figure 30.—Predicted average chloride concentration in the Wichita well field area for predictive simulations, 1989-2049.

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APPENDIX A

Corroborative Figures Mentioned in this Report

Table A-1.—Summary of simulations

Reference simulations	**Results**
Calibration (1940-1989): Considered transport of chloride in the Equus Beds aquifer. Sources considered are: the Arkansas River, deep natural saltwater, and oil field brine. Calibration performed by attempting to match chloride breakthrough curves of measured data at various locations.	Reasonable representation of actual conditions in the primary areas of interest from the Arkansas River and the Burrton Oil Field area to the Wichita well field area. The model appears to over-predict the rate of chloride movement in the upper layer.
Base projection (1990-2049): Projection of conditions existing at the end of the calibration simulation to the year 2049. *Boundary conditions, initial conditions, and stresses*: Same as those existing at the end of the calibration simulation in 1989.	*Water elevations*: Cone of depression centered over the Wichita well field area. *Chloride movement*: Plumes migrating from the Arkansas River and Burrton Oil Field area toward the Wichita well field area. Predicted chloride concentrations are as high as 400 mg/L in the southern part and 300 mg/L extreme northwest part of the well field by 2049.
Simulations of individual sources	**Results**
Arkansas River (1940-2049): Saltwater flowing from the river to the aquifer was considered as the only source of chloride. Chloride concentrations in the river varied from 480 mg/L to 630 mg/L from 1940 to 1989 and were constant at 630 mg/L from 1990 to 2049. *Initial conditions*: No chloride present in aquifer in 1940.	Water from the river accounts for the majority of chloride in the upper layer. Significant vertical movement of chloride from the river to the middle and lower model layers. Chloride plume in all layers expanding toward the Wichita well field area.
Deep natural saltwater (1940-2049). Natural chloride located around a low or trough in the bedrock surface near the course of the Arkansas River was considered as the only source of chloride. *Boundary conditions*: Constant concentration cells in the lower layer represent chloride in the trough below the river. *Initial conditions*: The concentration of chloride ranges from 900 to 4,000 mg/L in the constant concentration cells.	Chloride is moving from the trough to the east toward the Wichita well field primarily in the lower layer, with some movement upward into the middle layer.

Table A-1.—Summary of simulations (continued)

Simulations of individual sources (continued)	Results (continued)
Burrton Oil Field brine (1940-2049). Brine from oil field operations that was disposed into surface pits from the 1930's to 1940's considered as the only source of chloride. *Initial conditions*: Chloride placed in upper and middle model layers.	Movement of the brine is primarily to the east toward the Wichita well field and Little Arkansas River. Significant vertical movement of chloride into the lower layer from the middle layer.
Management simulations (1990-2049)	**Results**
Investigate the impacts of Arkansas River flow on the aquifer. (2a) Divert Arkansas River upstream of study area. *Stresses*: No flow in Arkansas River during simulation. (2b) Divert Arkansas River upstream of study area and eliminate underflow entering study area below Arkansas River. *Stresses*: No flow in Arkansas River during simulation. *Boundary conditions*: Constant head cells eliminated in upper and middle model layers below Arkansas River at the northwest boundary of the model.	These simulations demonstrate the importance of the Arkansas River acting as a water supply for the aquifer. *Water elevations*: (2a) Predicted to fall as much as 25 feet near the river with an average drop of about 13 feet within the Wichita well field zone. (2b) Greater impacts than simulation 2a. *Chloride movement*: (2a) Little movement of the chloride plume that originated from the river toward the Wichita well field, because the river has been removed as a water and chloride source. (2b) Results similar to simulation 2a.
Install pumping wells to intercept oil field saltwater. Install pumping wells strategically located to remove chloride from the aquifer. *Stresses*: Twenty wells located in the middle and lower model layers (10 each layer) pumping a total of: (4a2) 3,200 acre-feet per year (100/gallons per minute/well) (4b2) 1,600 acre-feet per year (50/gallons per minute/well) (4c2) 6,400 acre-feet per year (200/gallons per minute/well)	*Water elevations*: All simulations resulted in a cone of depression centered at the pumping wells. Maximum water elevation drops of around 3, 7, and 15 feet as withdrawal rates increase. *Chloride movement*: Effective in minimizing the impact of the Burrton oil field saltwater on the Wichita well field area. *Brine zone*: Average chloride concentrations decrease as withdrawal rates increase by as much as 30 percent from that predicted by the base projection.

Table A-1.—Summary of simulations (continued)

Management simulations (1990-2049) (continued)	**Results (continued)**
Eliminate pumping near Arkansas River in an area from the Little Arkansas River to approximately 33 miles north. Pumping in this area may become undesirable as chloride concentrations increase in the aquifer. *Stresses*: Eliminated pumping within this area in the: (3a) upper model layer (15,300 acre-feet per year) and (3b) upper and middle model layers (18,500 acre-feet per year)	*Water elevations*. Minimal impacts. *Chloride movement*. Minimal impacts. *River zone*. Rate of chloride concentration increase is only slightly less than that of the base projection.
Place hydraulic barrier along Arkansas River by recharging better quality water between the Arkansas River and the Wichita well field to inhibit the movement of poor quality water from the river to the aquifer. *Stresses*: The water was recharged to the upper layer at the following rate, concentration, and location: (5a) 5,600 acre-feet per year, 150 mg/L, 1 mile north of Arkansas River. (5b) 2,800 acre-feet per year, 150 mg/L, 1 mile north of Arkansas River. (5c) 11,200 acre-feet per year, 150 mg/L, 1 mile north of Arkansas River. (5d) 5,600 acre-feet per year, 150 mg/L, 2 miles north of Arkansas River. (7a) 5,600 acre-feet per year, 50 mg/L, 1 mile north of Arkansas River. (7b) 5,600 acre-feet per year, 250 mg/L, 1 mile north of Arkansas River. (5e) Alternatively, withdrawals were reduced in the lower model layer by 5,600 acre-feet per year in the southern portion of the Wichita well field.	*Water elevations*: Minimal impact with a maximum rise of 3 feet at the recharge location. *Chloride movement*: In general, effective in inhibiting the movement of chloride from the river. *River zone*: Average chloride concentrations are decreased from the base projection by as much as 23 percent at the highest recharge rate. The decreases in average concentration are less for lower recharge rates. The predicted concentrations are relatively insensitive to the concentrations of recharge water and the areas of recharge considered. Reducing withdrawals within the Wichita well field was less effective in reducing chloride concentration from that predicted in the base projection.

Table A-1.—Summary of simulations (continued)

Management simulations (1990-2049) (continued)	Results (continued)
Reduce pumping within the Wichita well field to lessen the water quality impact from chloride sources. *Stresses*: Pumping was reduced within the well field area by the following total amount: (8a1) 5,600 acre-feet per year, lower layer (8a2) 11,200 acre-feet per year, lower layer (8a3) 16,800 acre-feet per year, lower layer (8a4) 22,400 acre-feet per year, lower layer (8b1) 5,600 acre-feet per year, all layers (8b2) 11,200 acre-feet per year, all layers (8b3) 16,800 acre-feet per year, all layers (8b4) 22,400 acre-feet per year, all layers (8c1) 5,600 acre-feet per year, upper layer (8d1) 5,600 acre-feet per year, middle layer	*Water elevations*: Increased for all simulations with the largest increases centered in the Wichita well field area. *Chloride movement*: In general, decreases the impacts from chloride sources. Larger reductions in withdrawals have a greater impact in reducing average chloride concentrations. Average concentrations are relatively insensitive to the model layer in which withdrawals are reduced.

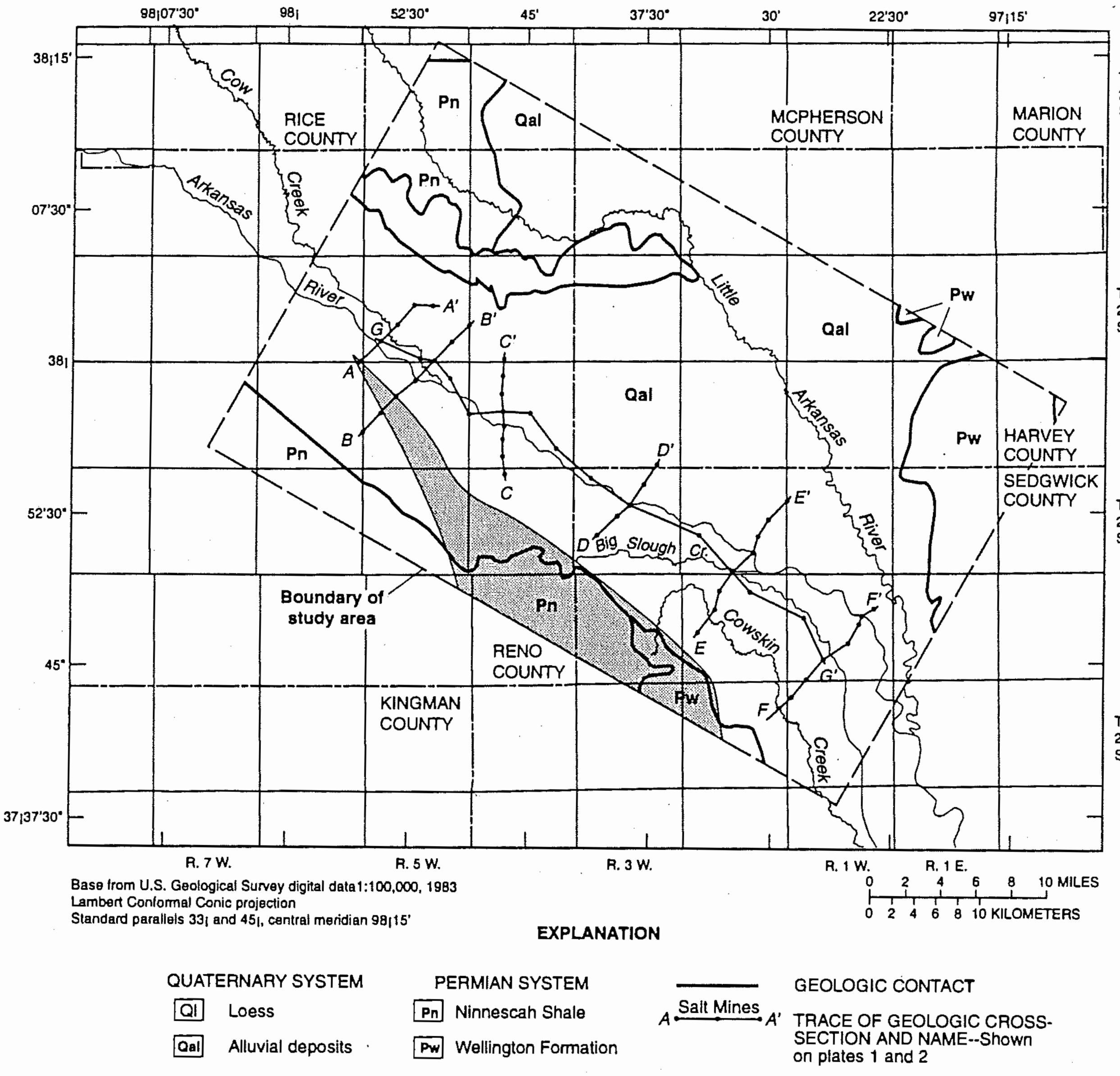
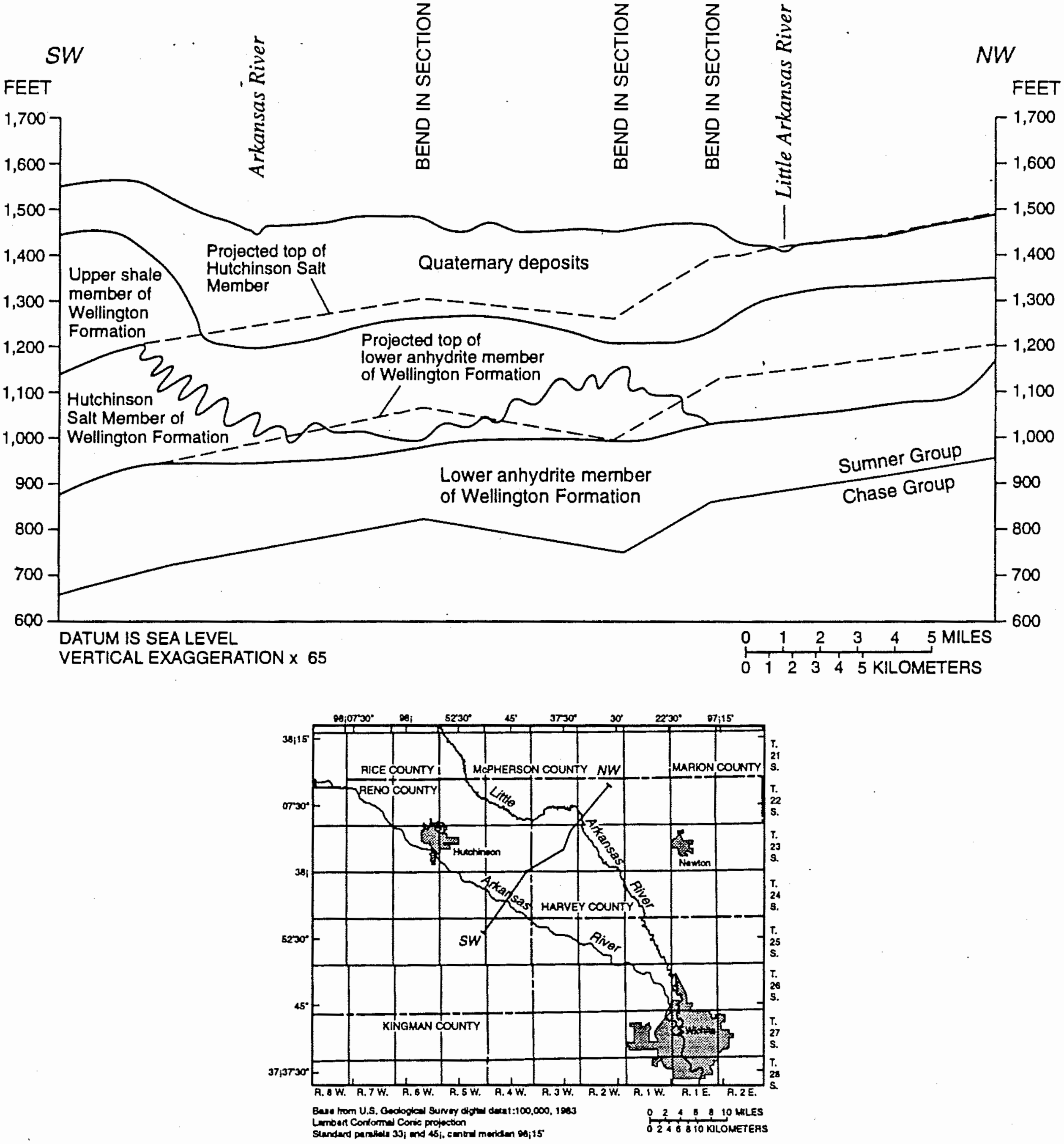


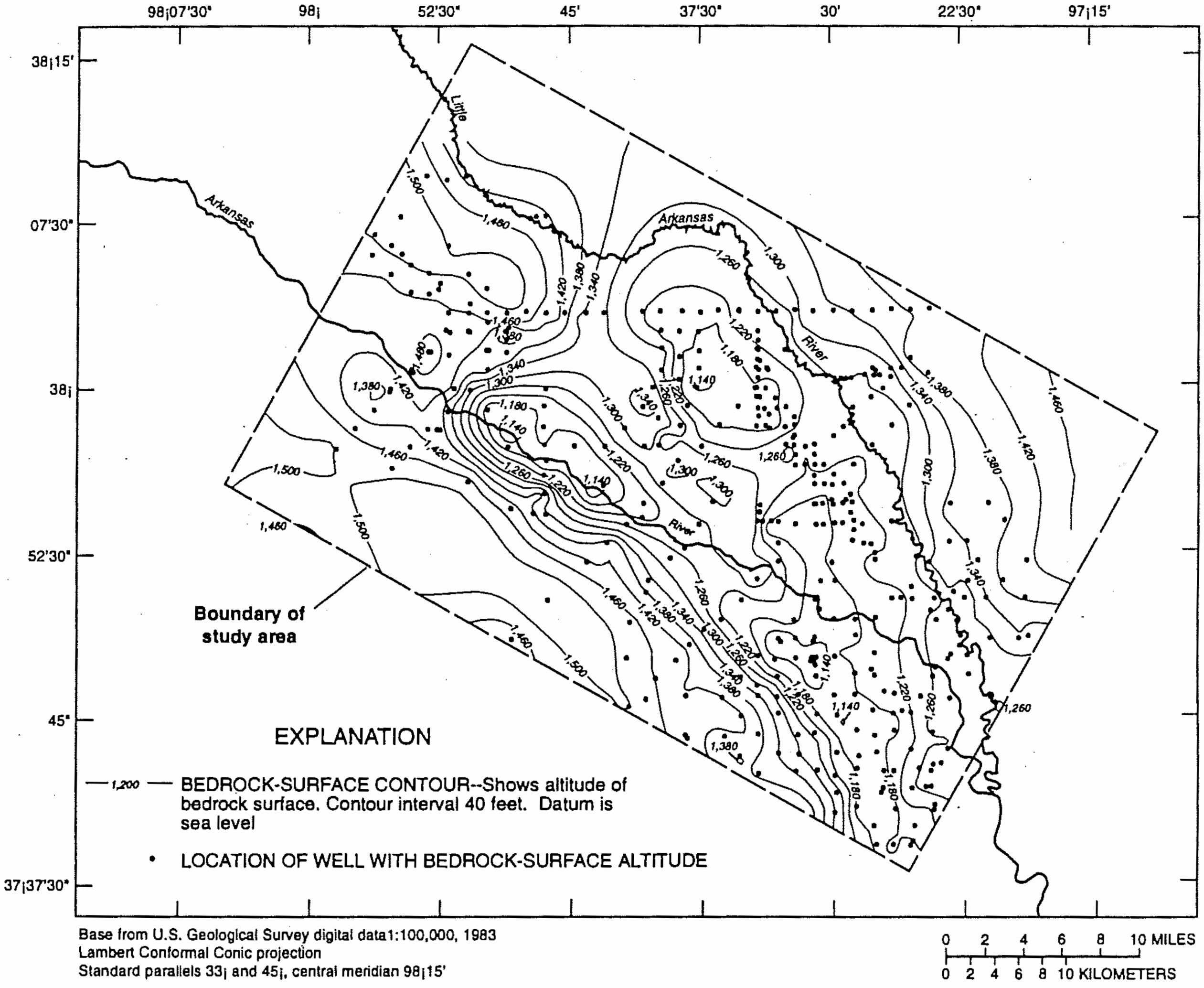
Figure A-1.—Areal geology, traces of geologic cross sections, and cross-section names.



Base from U.S. Geological Survey digital data1:100,000, 1983
Lambert Conformal Conic projection
Standard parallels 33° and 45°, central meridian 98°15'

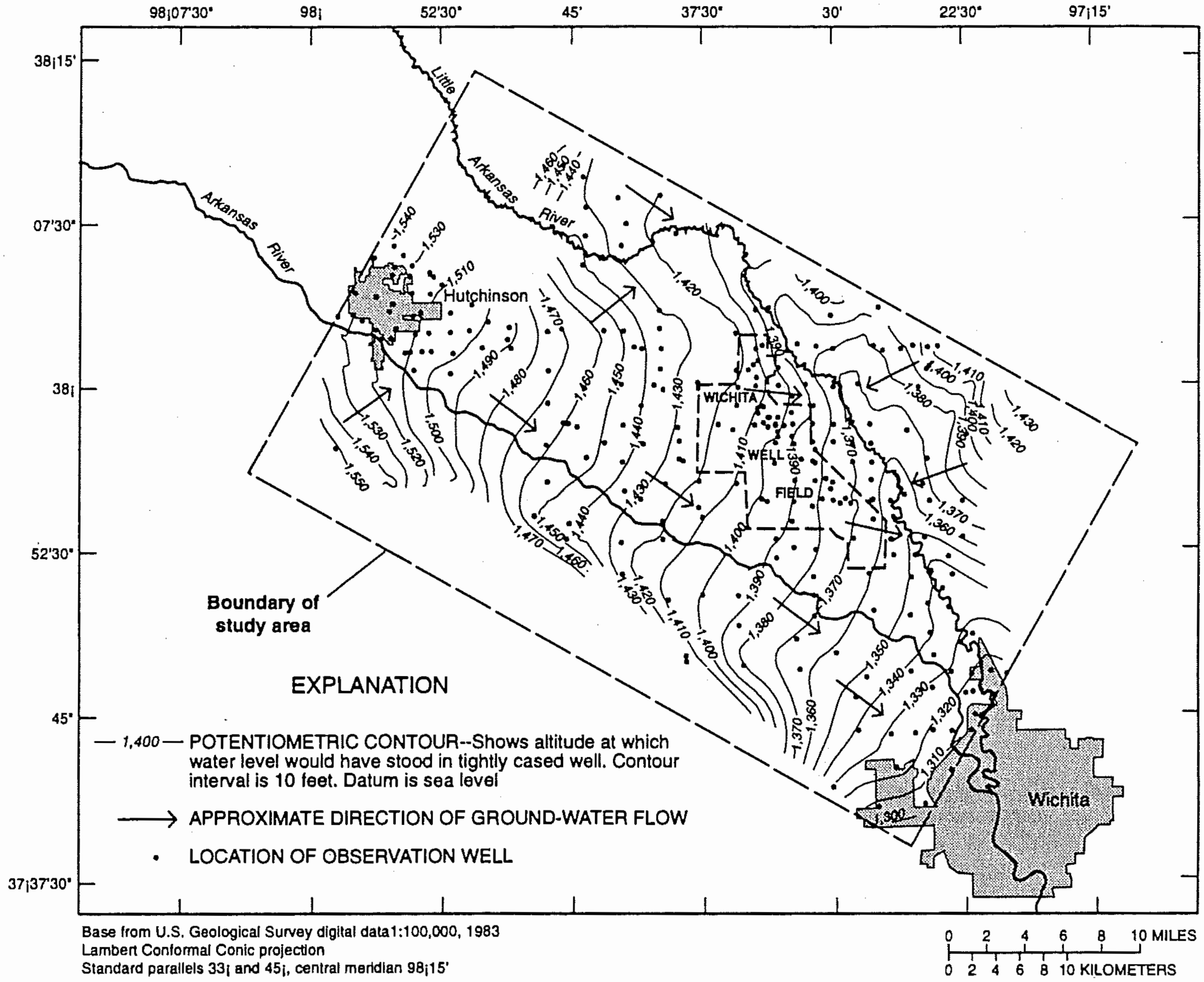
Index map

Figure A-2.—Geologic section showing present and projected past extent of the Hutchinson Salt Member (Myers et al., in review).



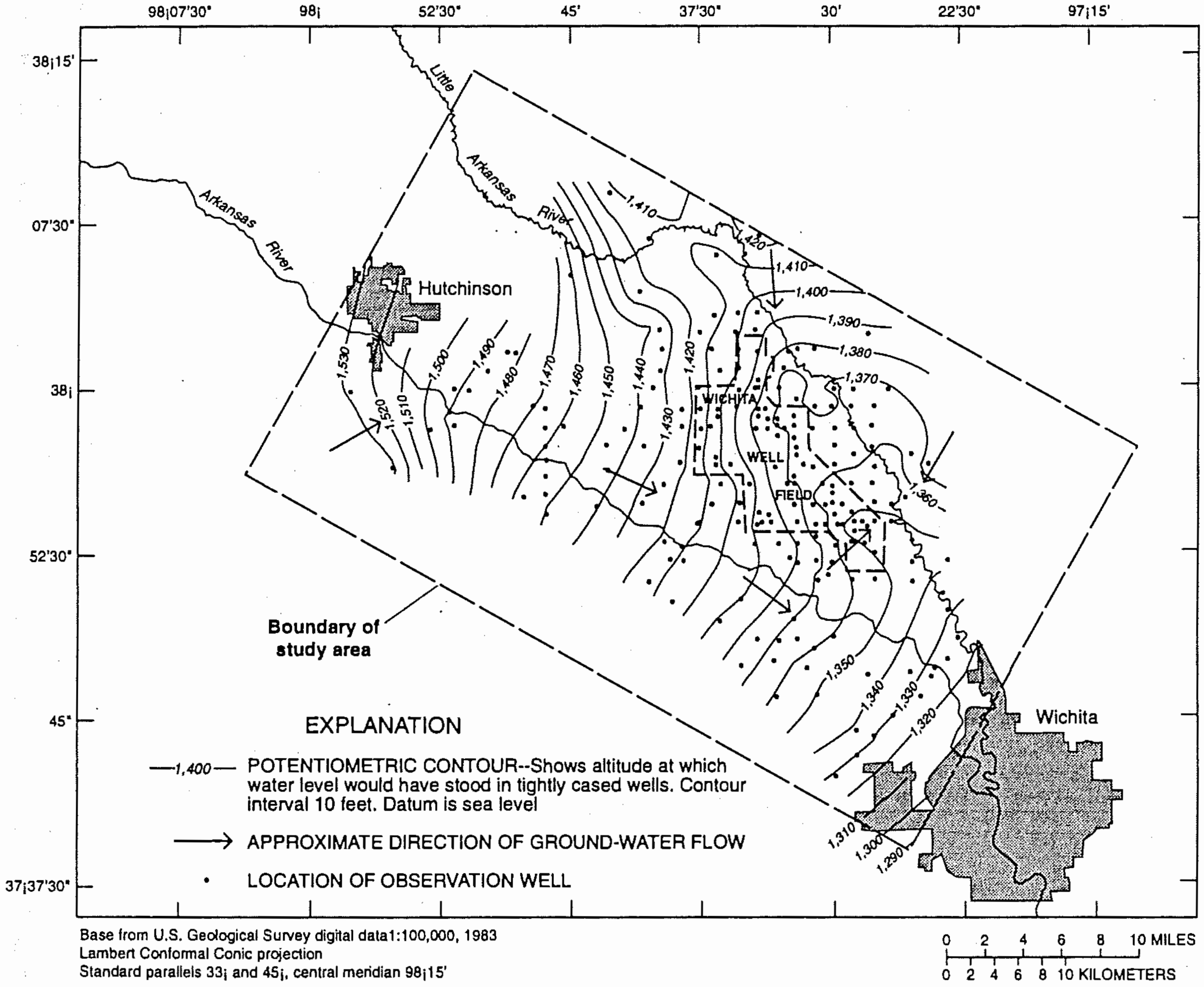
Base from U.S. Geological Survey digital data1:100,000, 1983
Lambert Conformal Conic projection
Standard parallels 33¡ and 45¡, central meridian 98¡15'

Figure A-3.—Altitude of bedrock surface (from Myers et al., in review).



Base from U.S. Geological Survey digital data1:100,000, 1983
Lambert Conformal Conic projection
Standard parallels 33¡ and 45¡, central meridian 98¡15'

Figure A-4.—Potentiometric surface in the Equus Beds aquifer, 1940 (Myers et al., in review).



Base from U.S. Geological Survey digital data1:100,000, 1983
Lambert Conformal Conic projection
Standard parallels 33¡ and 45¡, central meridian 98¡15'

Figure A-5.—Potentiometric surface in the Equus Beds aquifer, 1989 (Myers et al., in review).

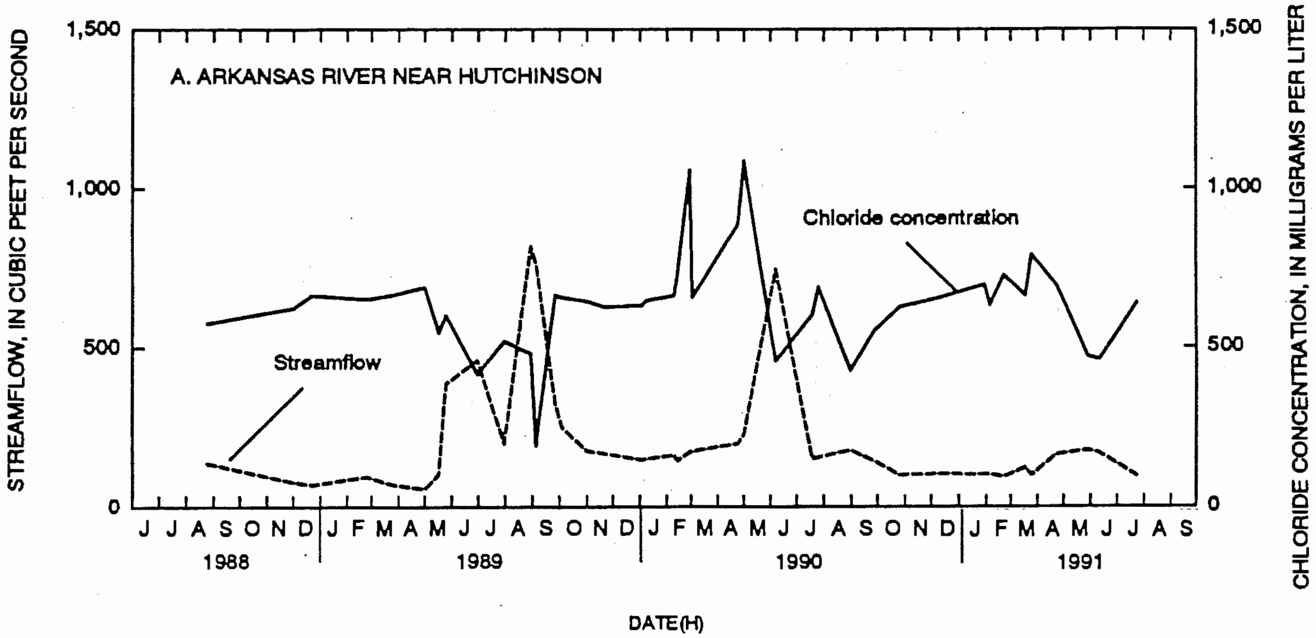


Figure A-6a.—Streamflow and chloride concentration at the Arkansas River near Hutchinson gauging station, August 1988-July 1991 (Myers et al., in review).

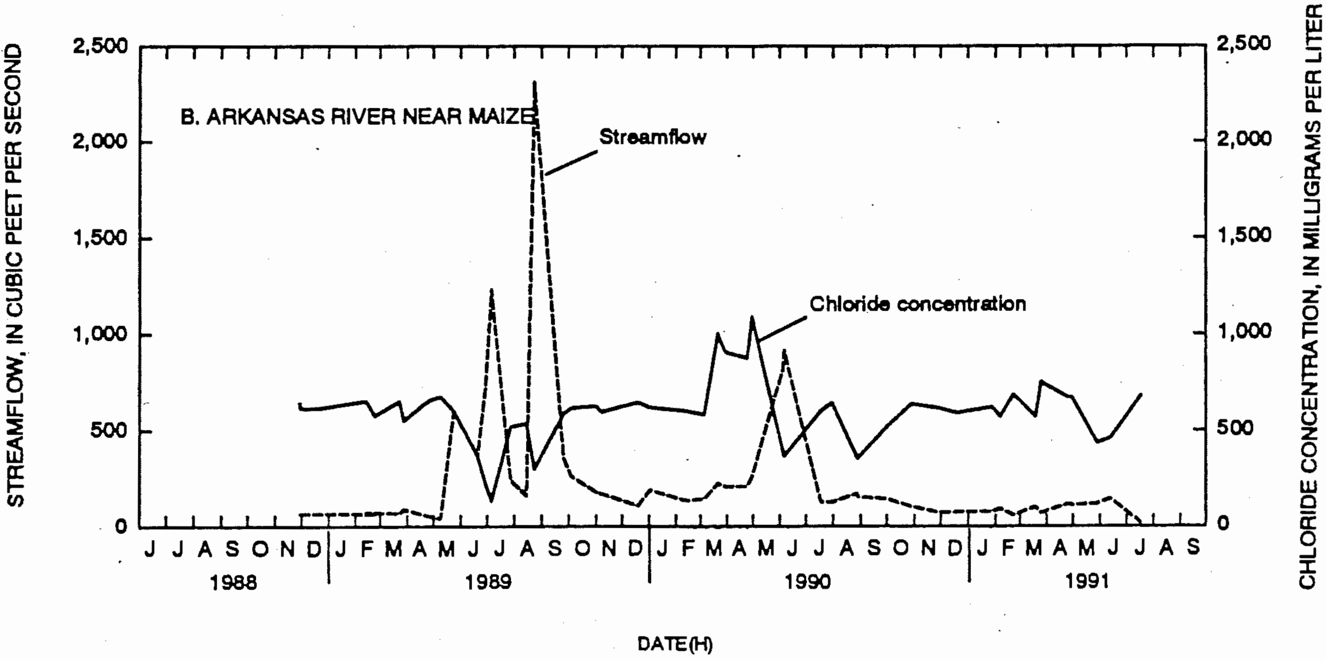


Figure A-6b.—Streamflow and chloride concentration at the Arkansas River near Maize gauging station, November 1988-July 1991 (Myers et al., in review).

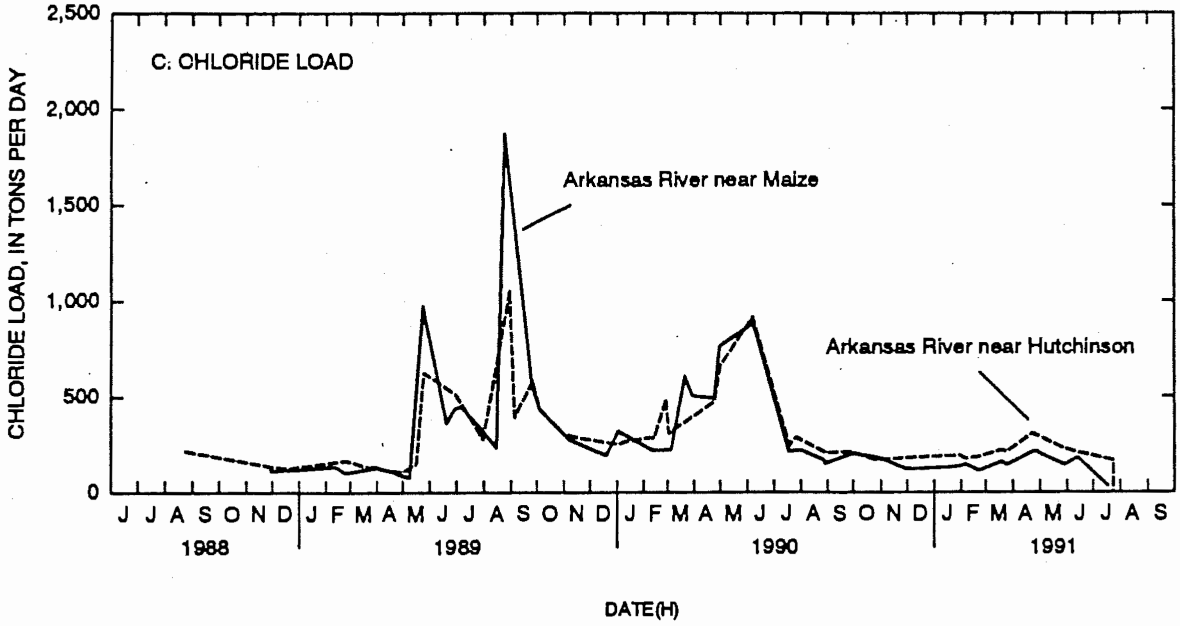


Figure A-6c.—Load calculated from streamflow and chloride concentration data (figures a. and b.) (Myers et al., in review).

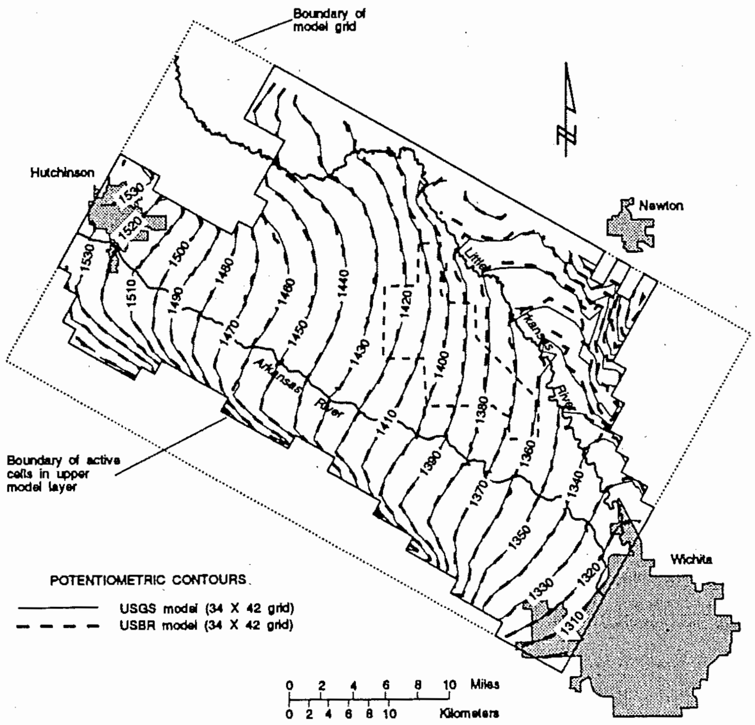


Figure A-7a.—Comparison of steady-state predicted heads by the U.S. Geological Survey flow model and regridded flow model for the upper model layer, 1940.

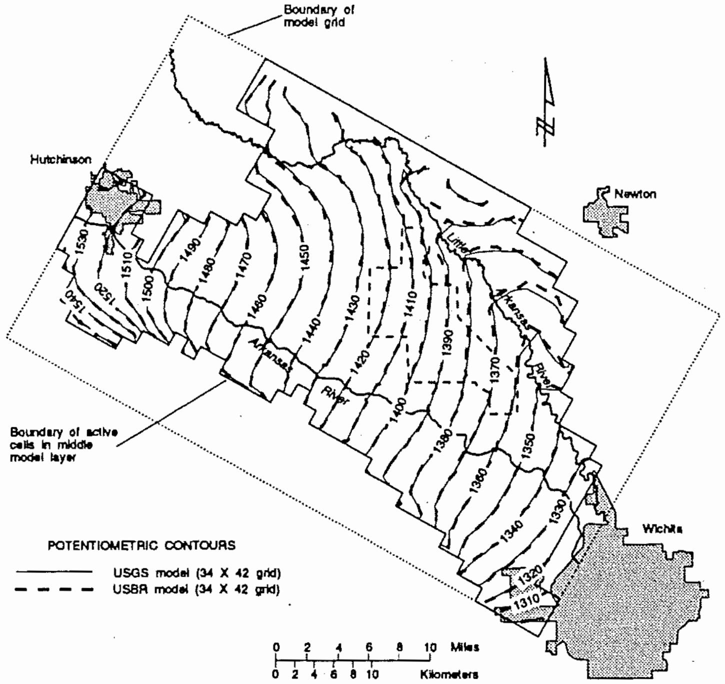


Figure A-7b.—Comparison of steady-state predicted heads by the U.S. Geological Survey flow model and regridded flow model for the middle model layer, 1940.

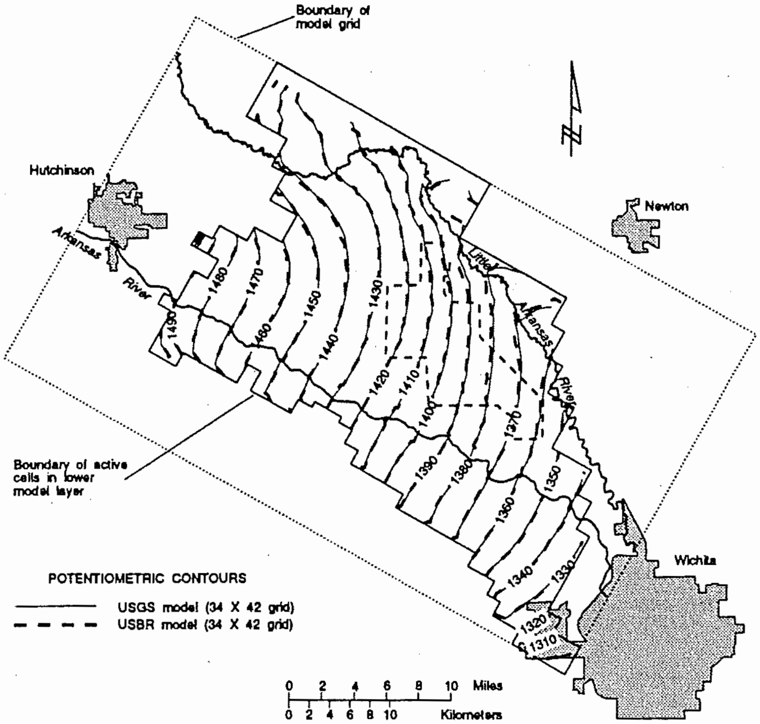


Figure A-7c.—Comparison of steady-state predicted heads by the U.S. Geological Survey flow model and regridded flow model for the lower model layer, 1940.

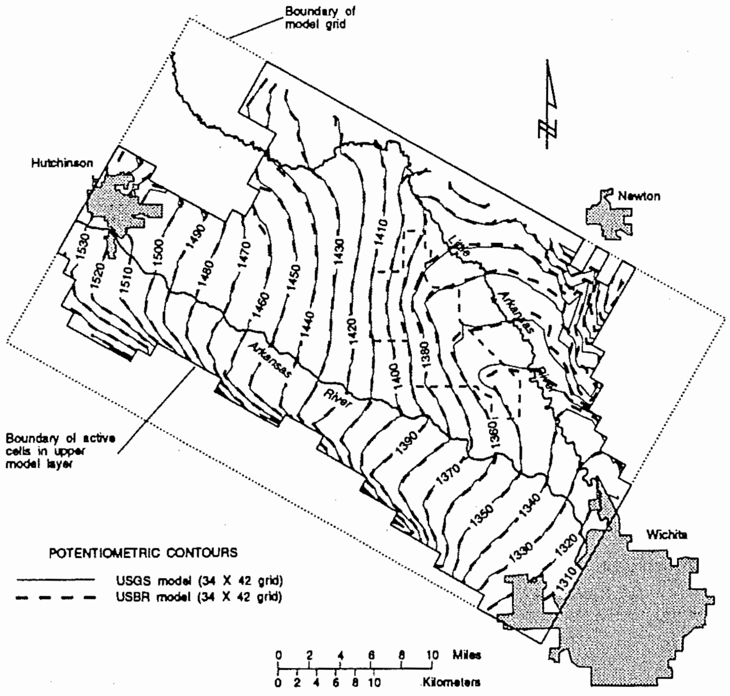


Figure A-8a.—Comparison of transient predicted heads by the U.S. Geological Survey flow model and regridded flow model for the upper model layer, 1989.

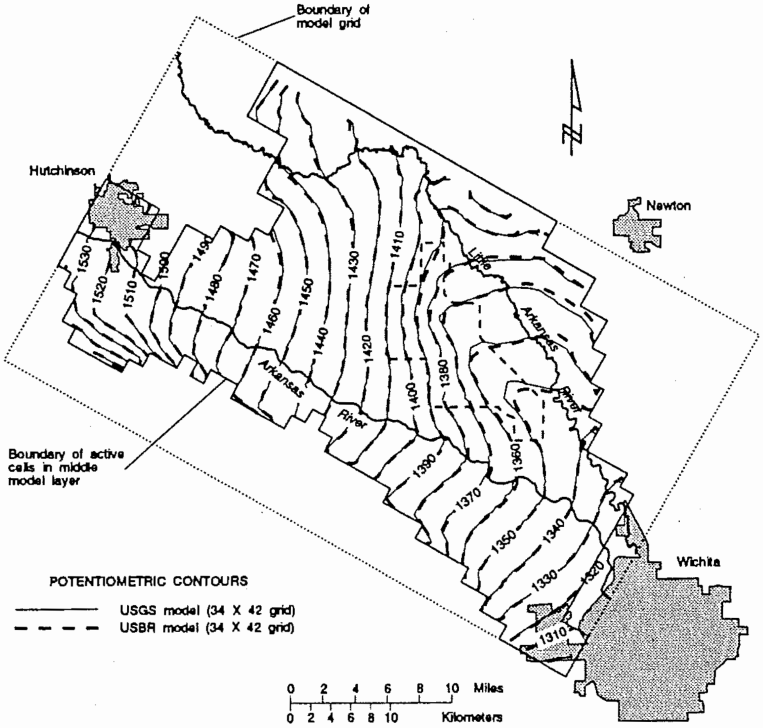


Figure A-8b.—Comparison of transient predicted heads by the U.S. Geological Survey flow model and regridded flow model for the middle model layer, 1989.

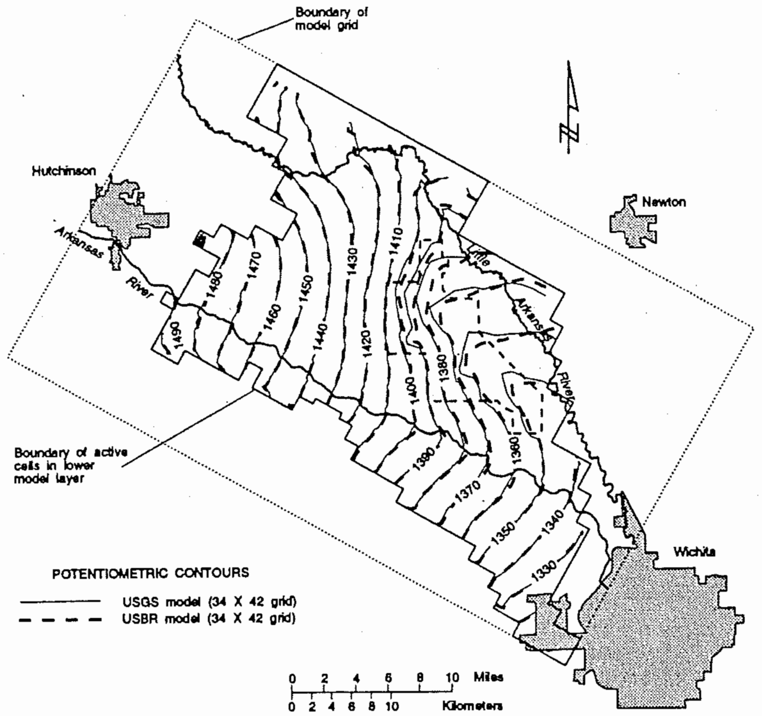


Figure A-8c.—Comparison of transient predicted heads by the U.S. Geological Survey flow model and regridded flow model for the lower model layer, 1989.

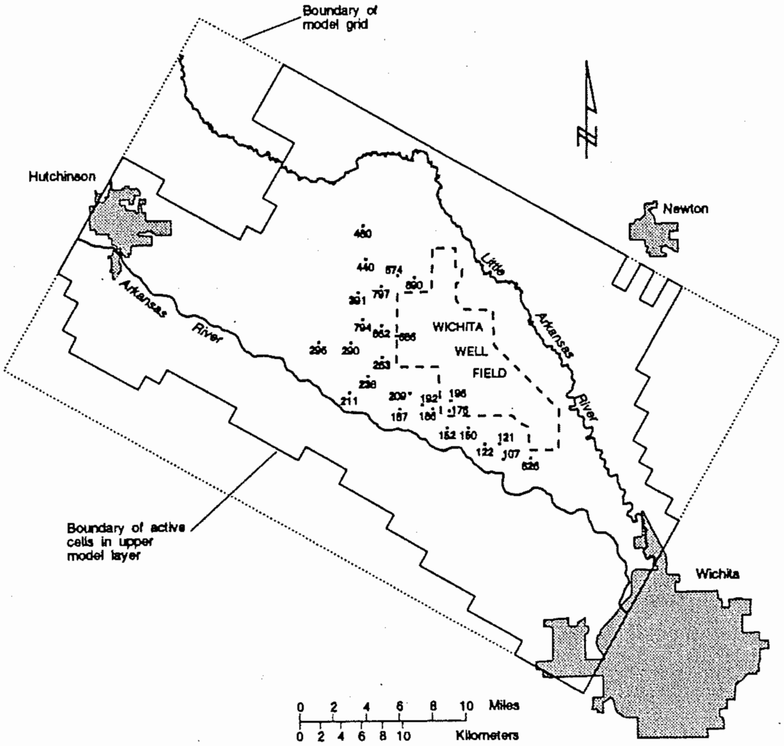


Figure A-9a.—Locations having well data used in the model calibration for the upper model layer.

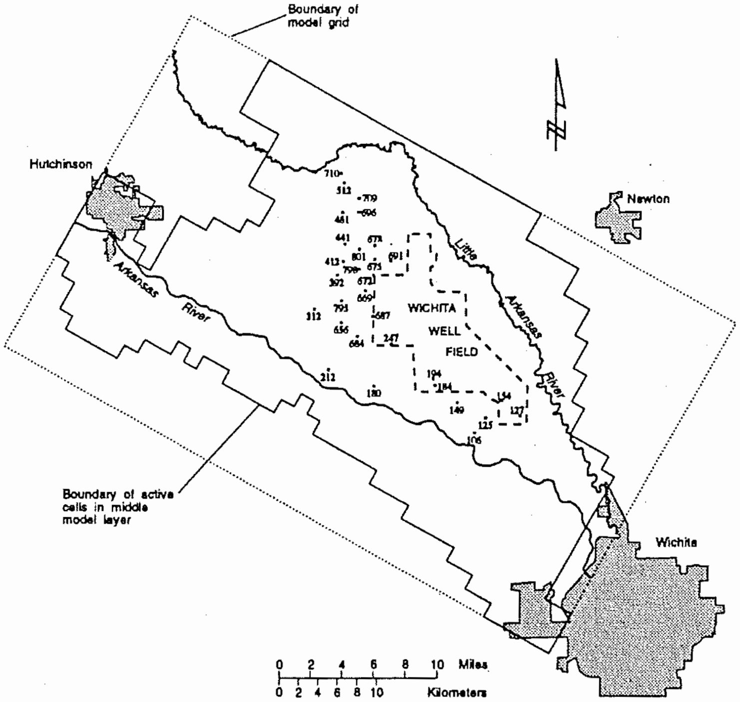


Figure A-9b.—Locations having well data used in the model calibration for the middle model layer.

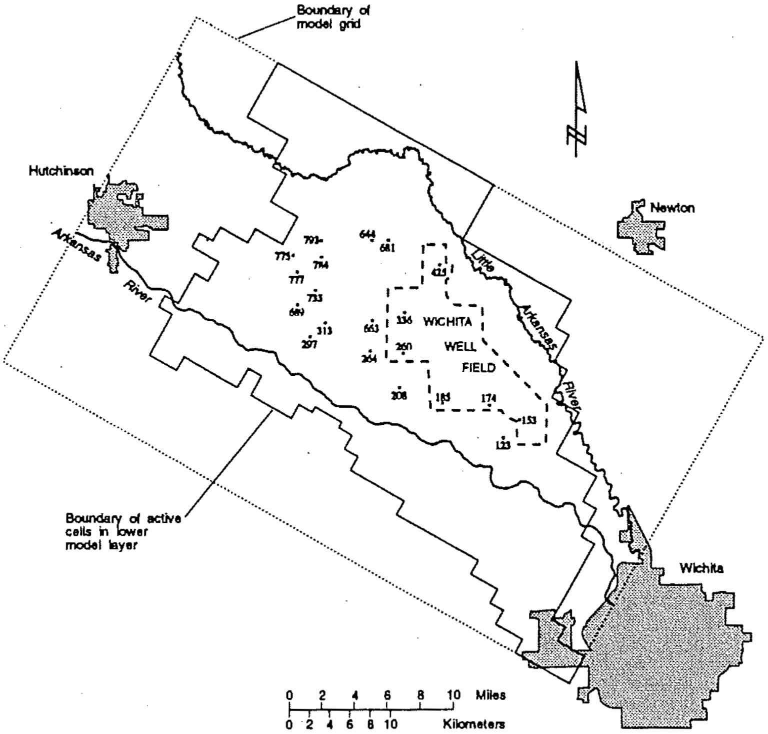


Figure A-9c.—Locations having well data used in the model calibration for the lower model layer.

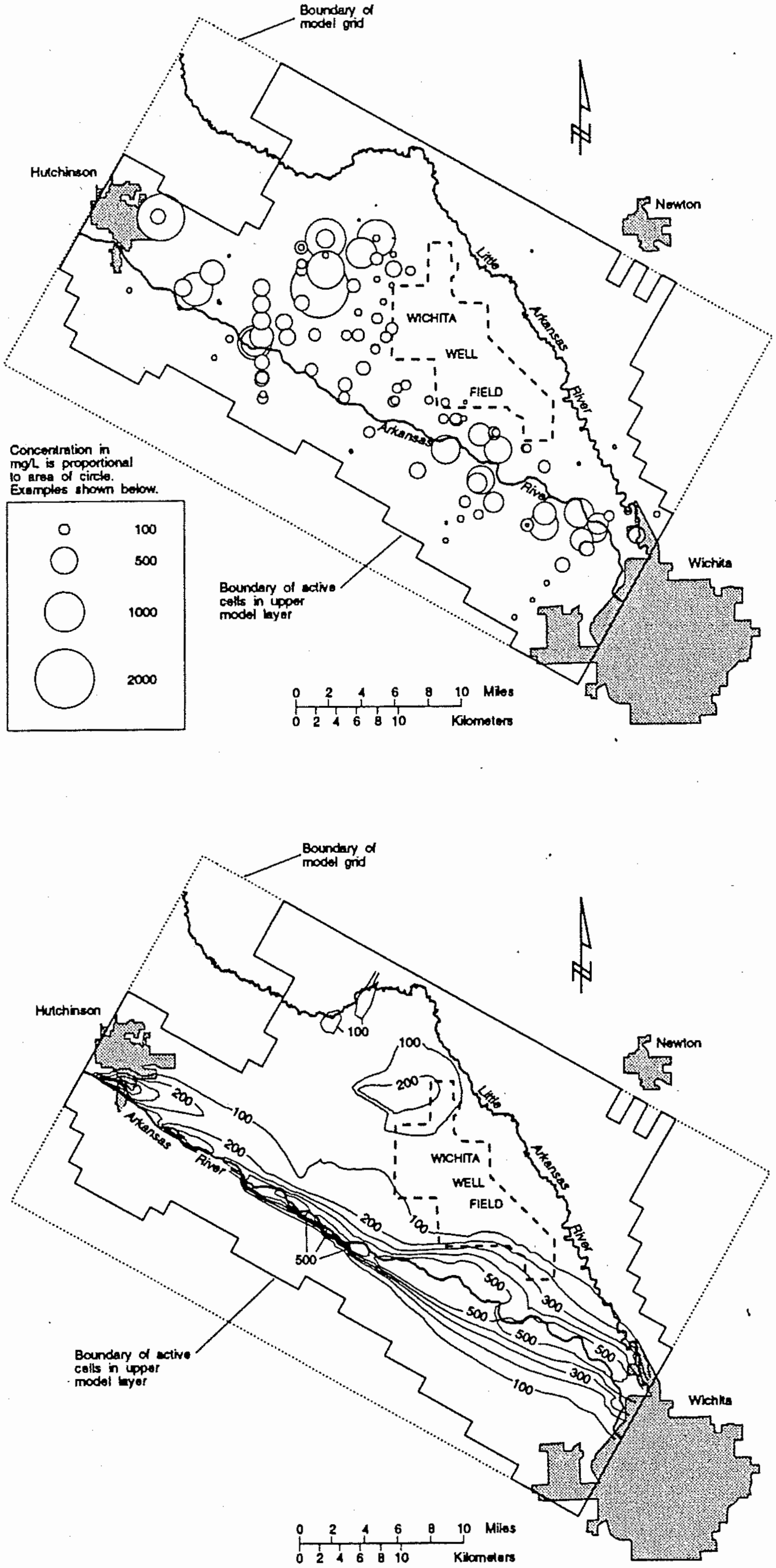


Figure A-10a.—Average chloride concentrations of measured data in (1986-1992) in the Equus Beds aquifer and predicted chloride distribution for the upper model layer.

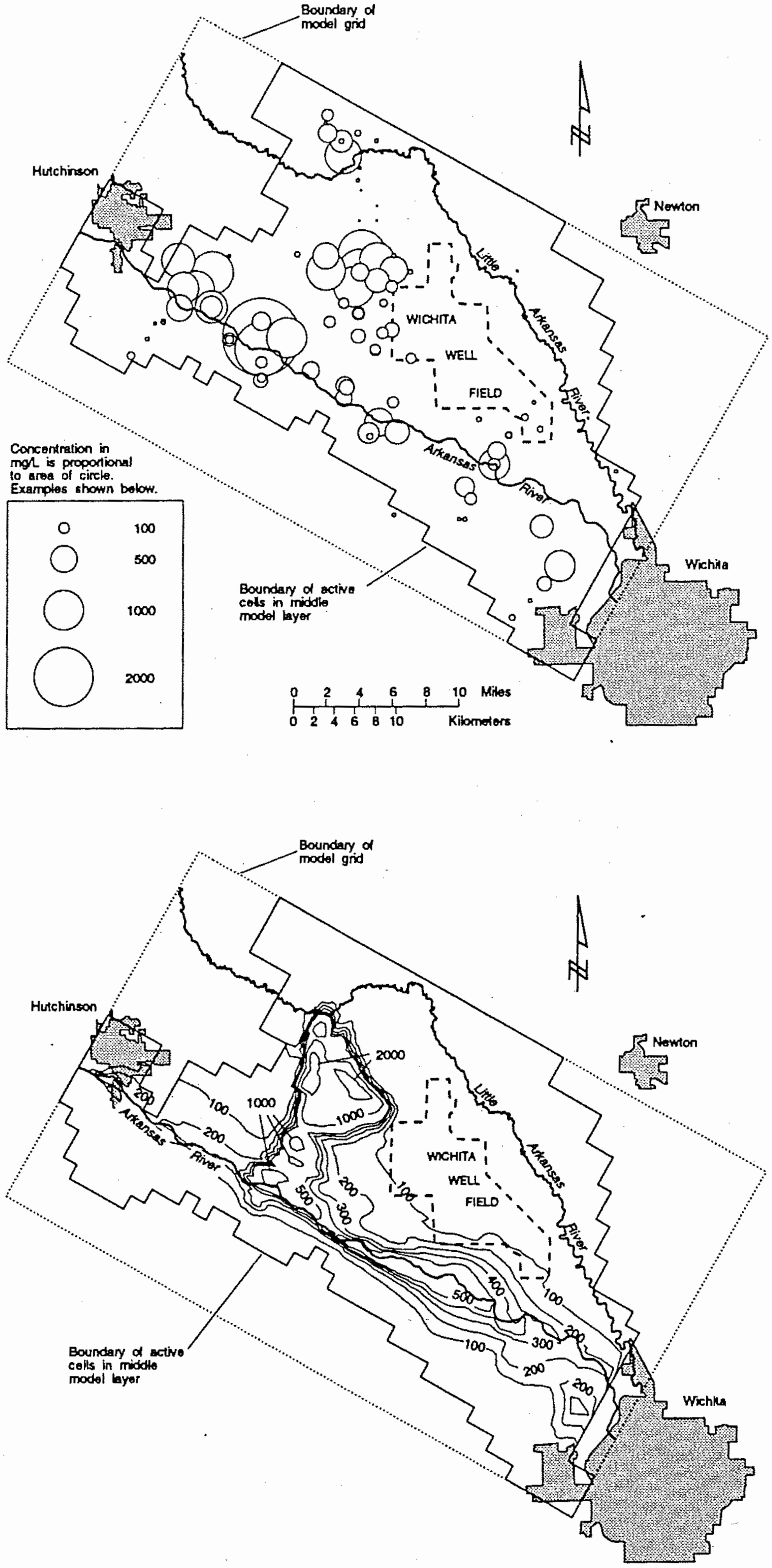


Figure A-10b.—Average chloride concentrations of measured data in (1986-1992) in the Equus Beds aquifer and predicted chloride distribution for the middle model layer.

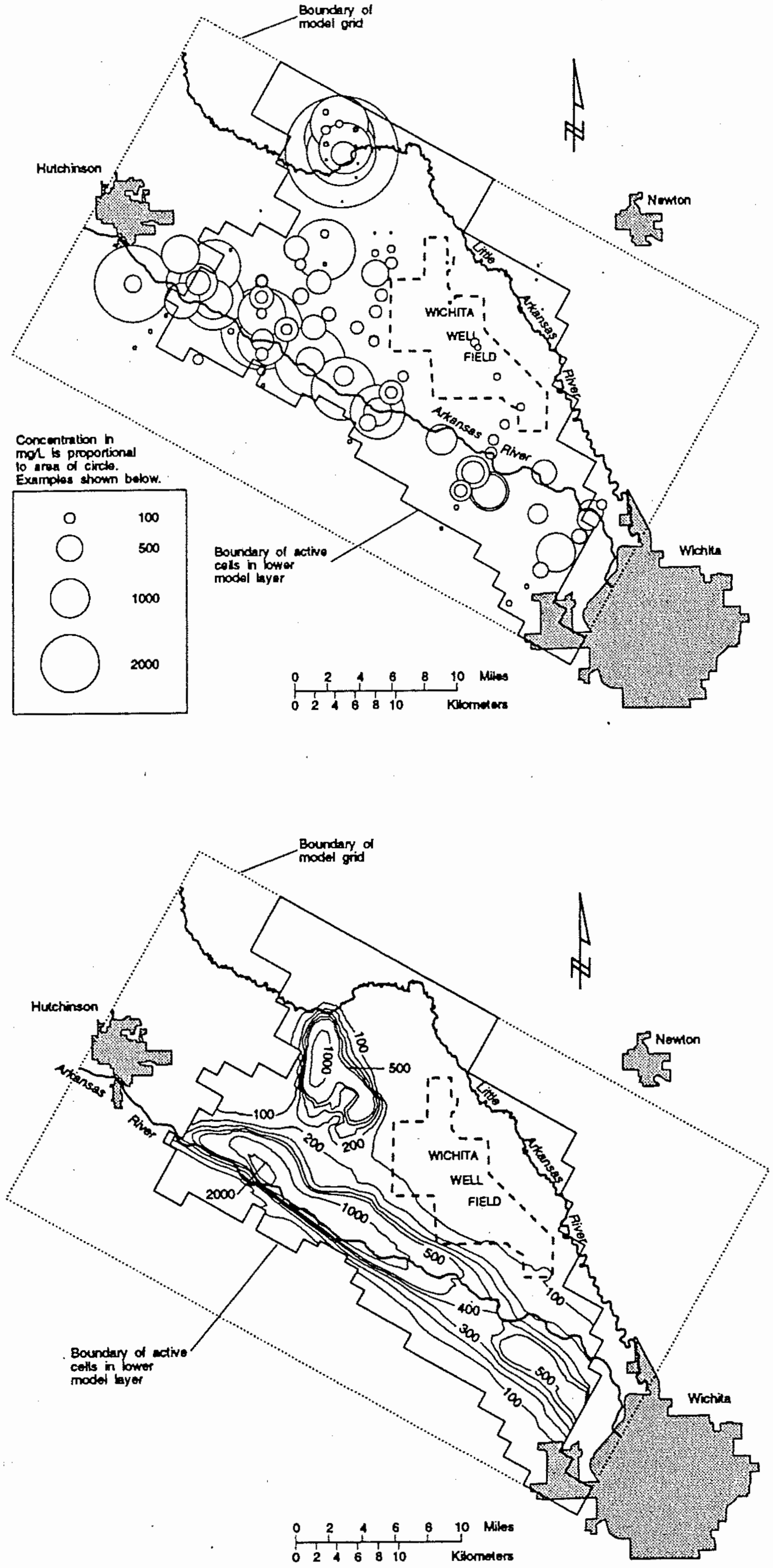


Figure A-10c.—Average chloride concentrations of measured data in (1986-1992) in the Equus Beds aquifer and predicted chloride distribution for the lower model layer.

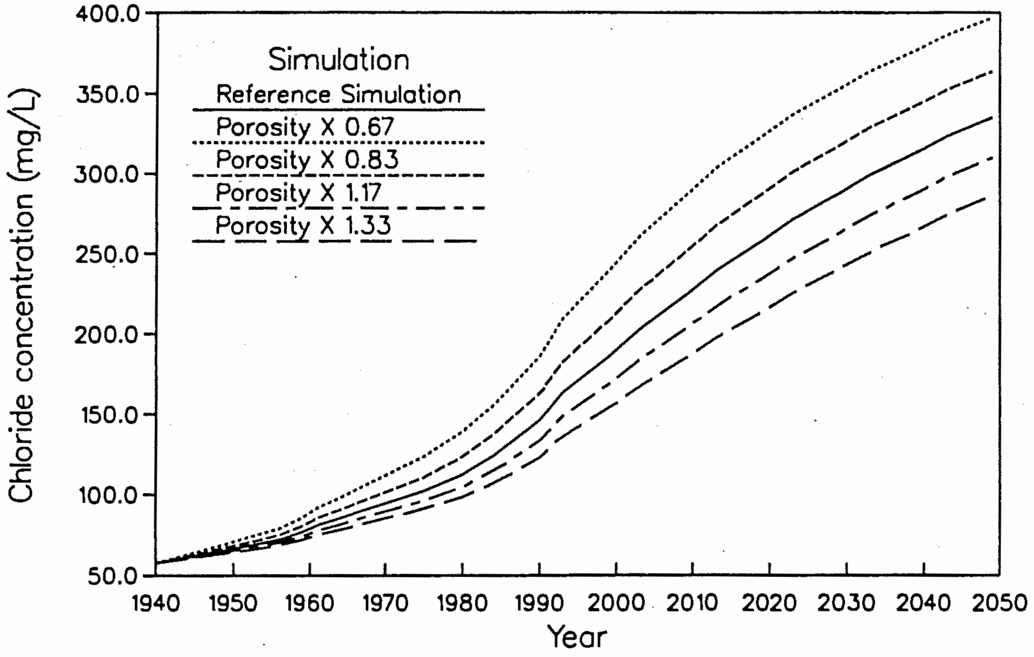


Figure A-11a.—Predicted average chloride concentration in the river zone for varying effective porosity values.

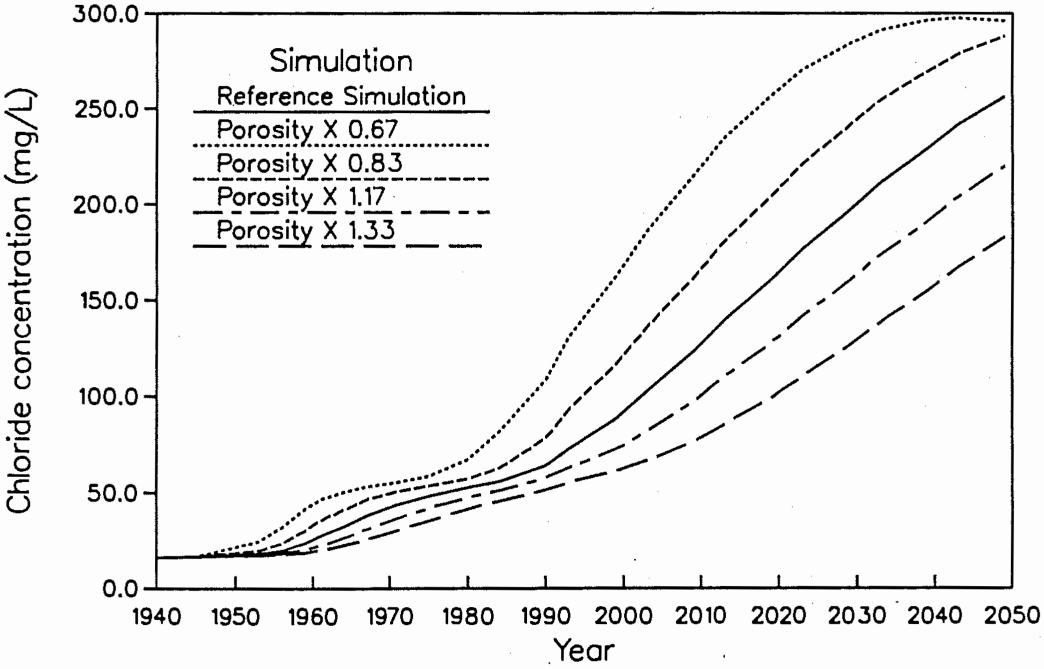


Figure A-11b.—Predicted average chloride concentration in the brine zone for varying effective porosity values.

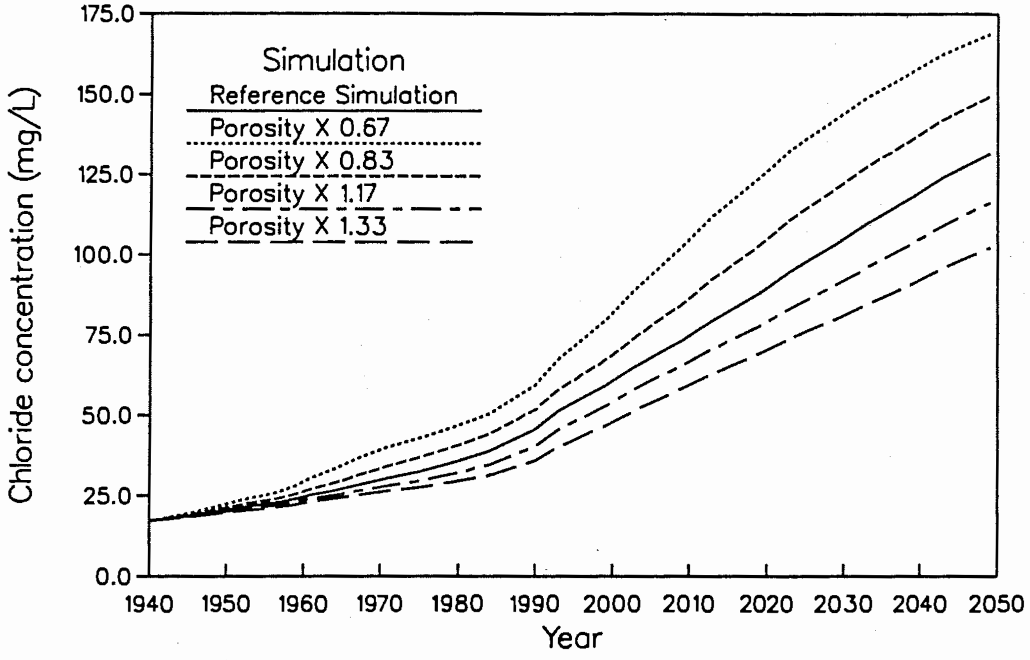


Figure A-11c.—Predicted average chloride concentration in the Wichita well field area for varying effective porosity values.

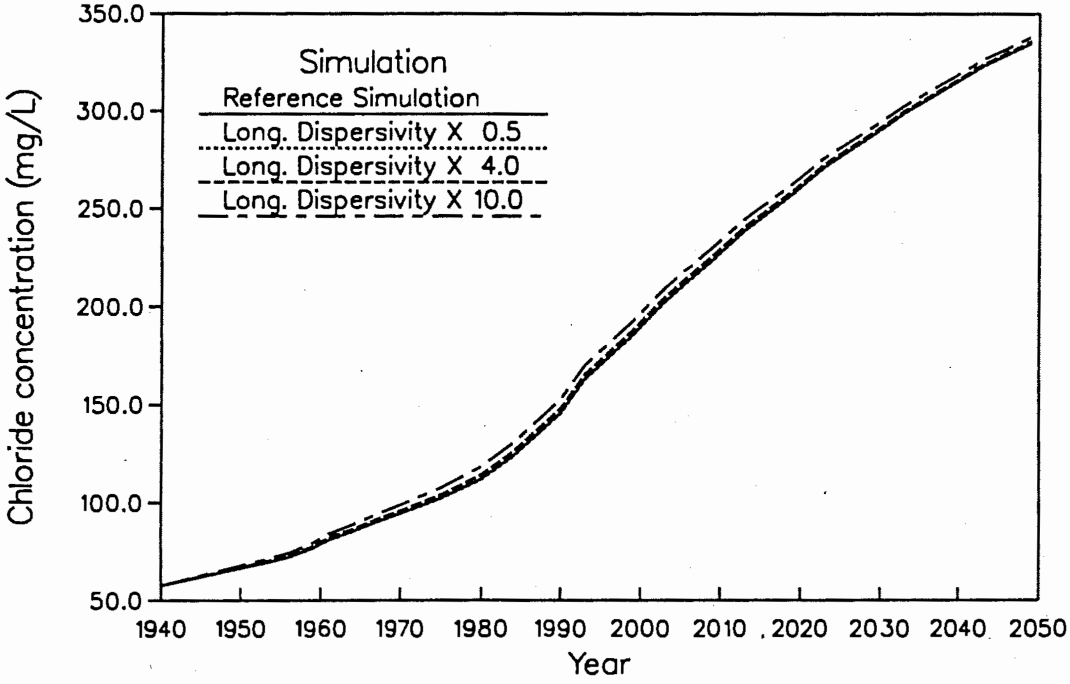


Figure A-12a.—Predicted average chloride concentration in the river zone for varying longitudinal dispersivity values.

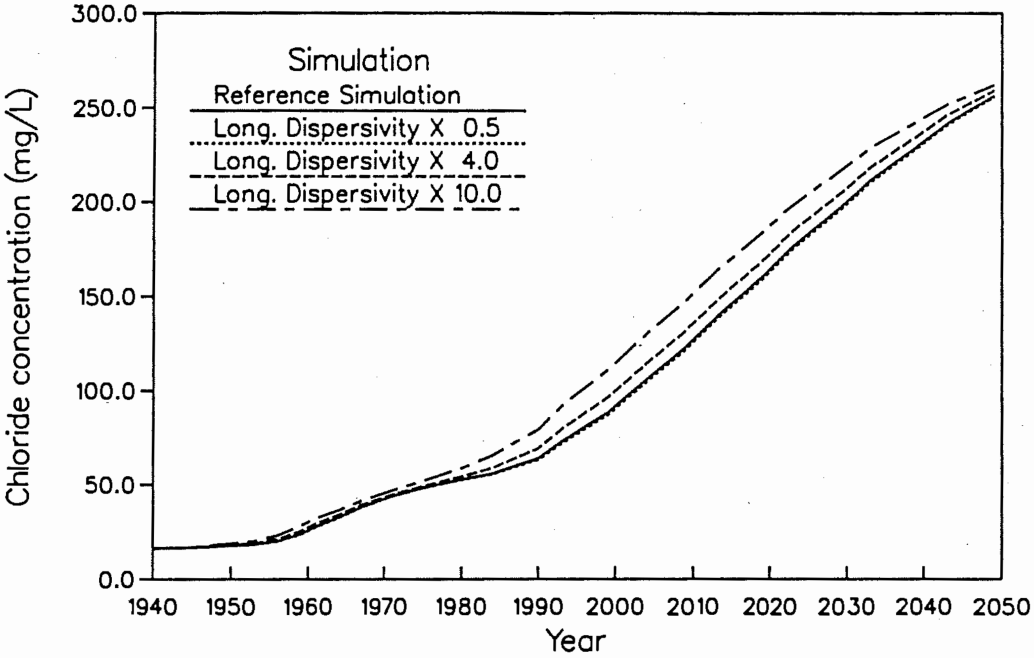


Figure A-12b.—Predicted average chloride concentration in the brine zone for varying longitudinal dispersivity values.

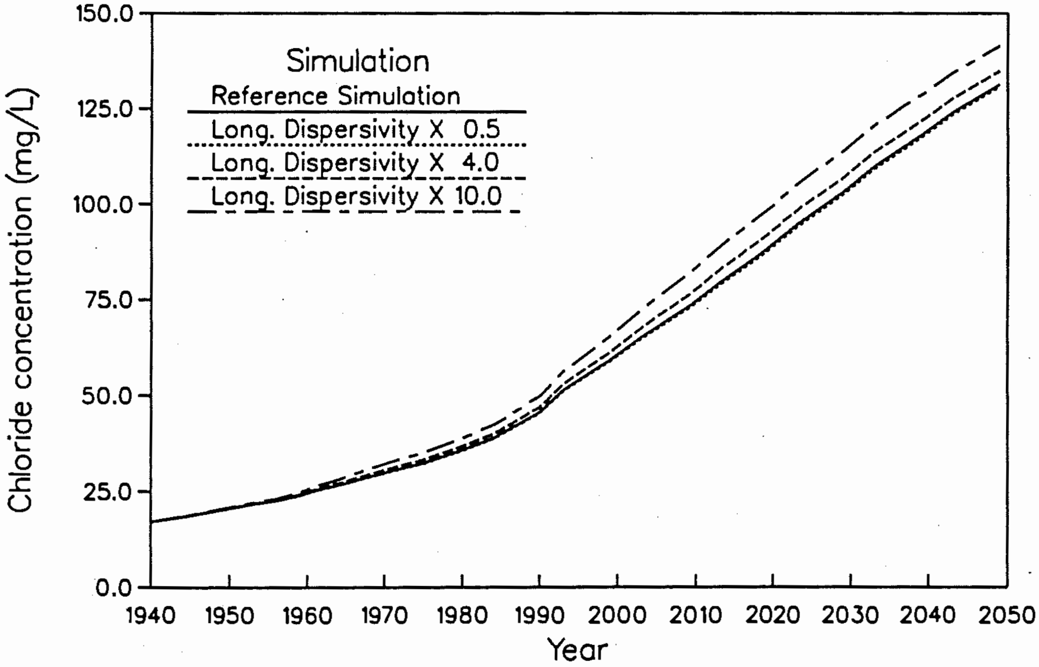


Figure A-12c.—Predicted average chloride concentration in the Wichita well field area for varying longitudinal dispersivity values.

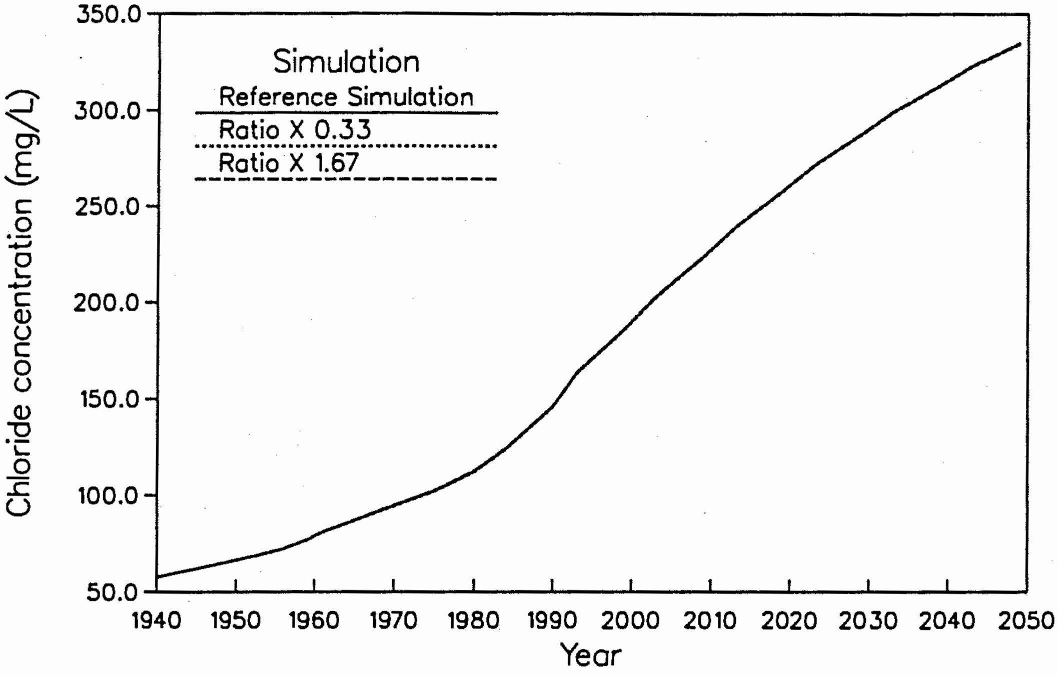


Figure A-13a.—Predicted average chloride concentration in the river zone for varying the ratio of lateral to longitudinal dispersivity values.

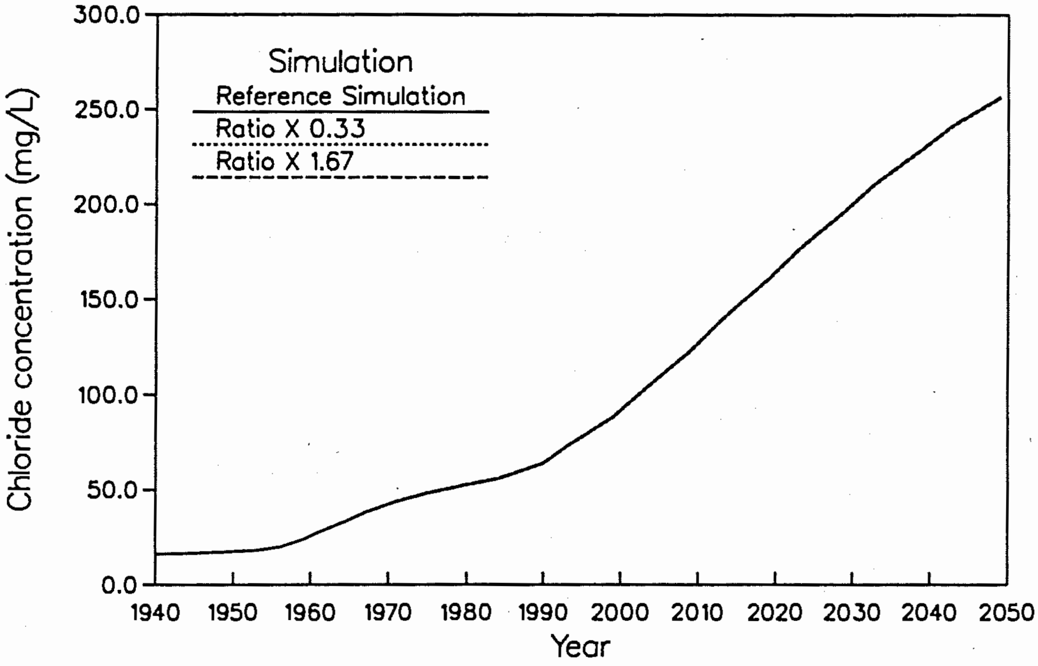


Figure A-13b.—Predicted average chloride concentration in the brine zone for varying the ratio of lateral to longitudinal dispersivity values.

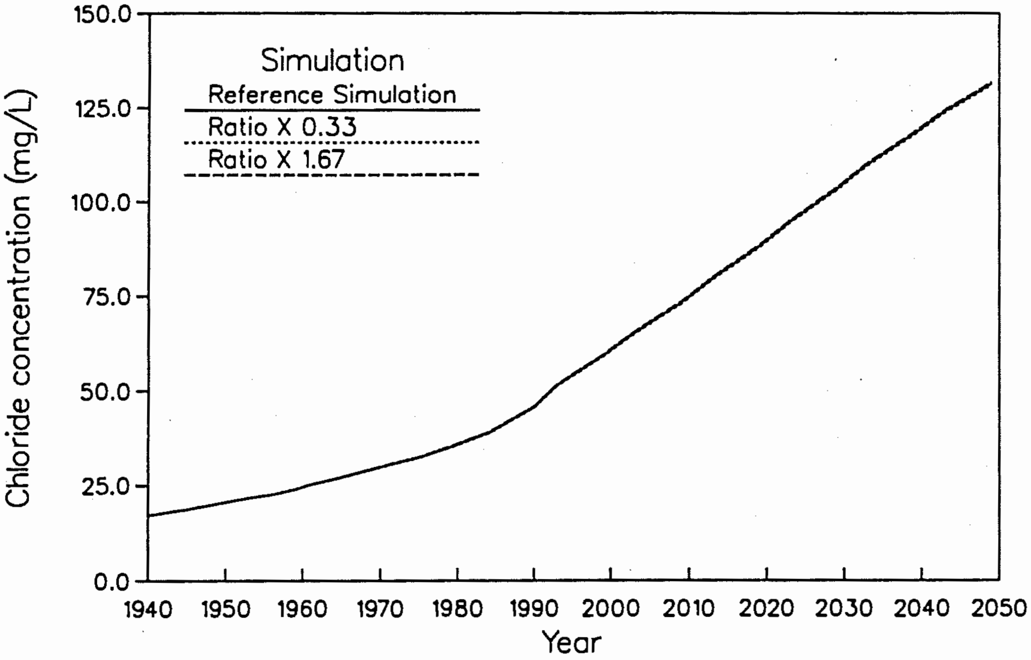


Figure A-13c.—Predicted average chloride concentration in the Wichita well field area for varying the ratio of lateral to longitudinal dispersivity values.

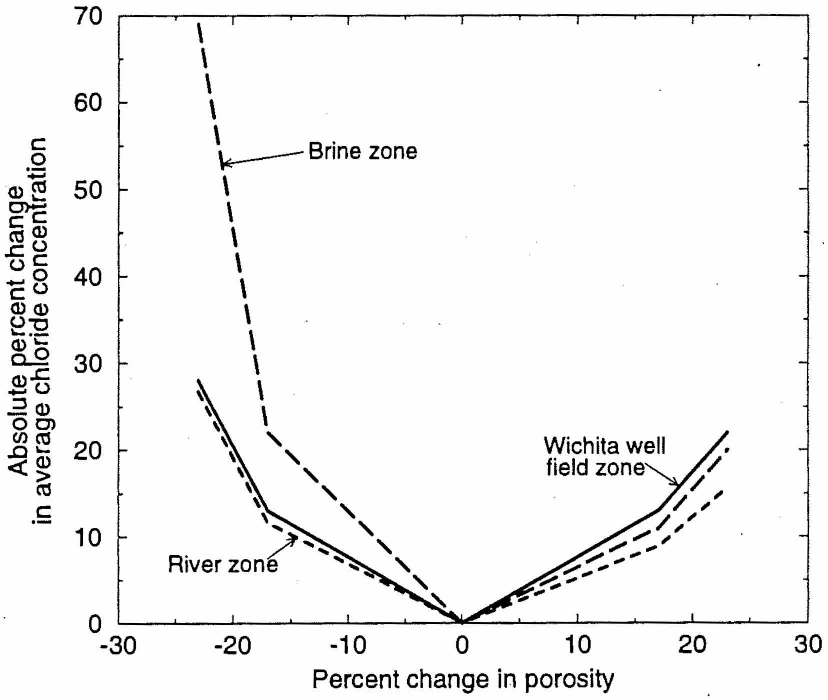


Figure A-14a.—Absolute percent change in predicted average chloride concentration versus percent change in porosity, 1989.

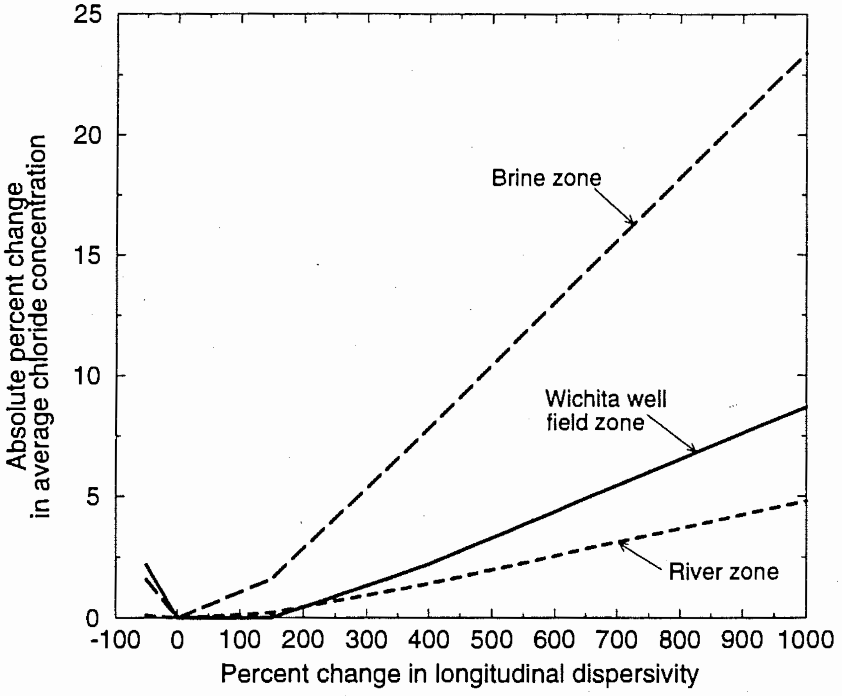


Figure A-14b.—Absolute percent change in predicted average chloride concentration versus percent change in longitudinal dispersivity, 1989.

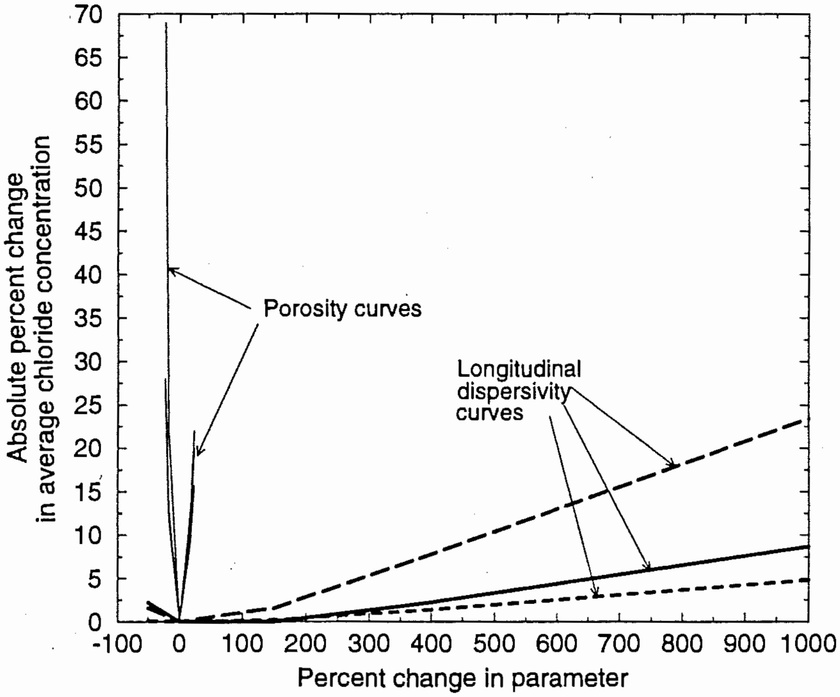


Figure A-14c.—Absolute percent change in predicted average chloride concentration versus percent change in porosity and longitudinal dispersivity, 1989.

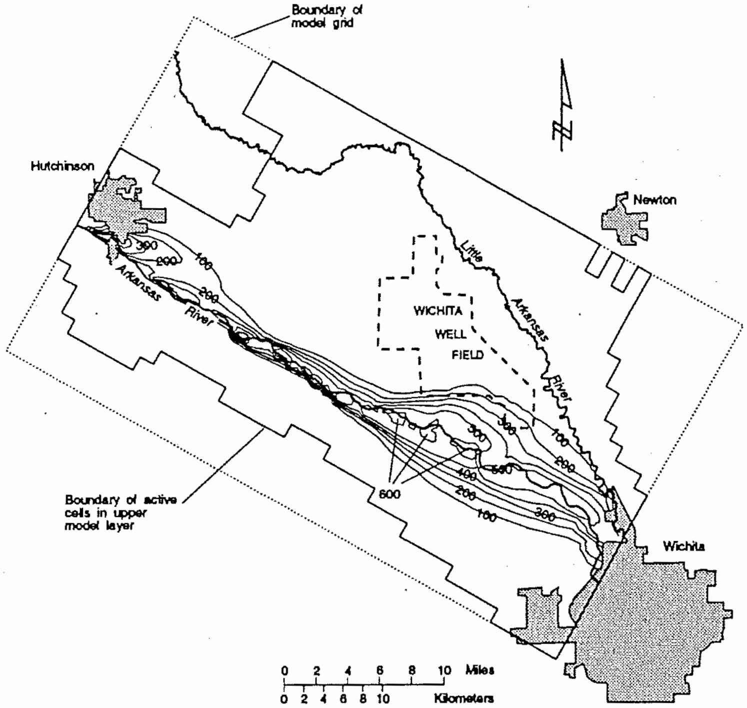


Figure A-15a.—Predicted chloride distribution in 1989 with the Arkansas River as the only chloride source for the upper model layer.

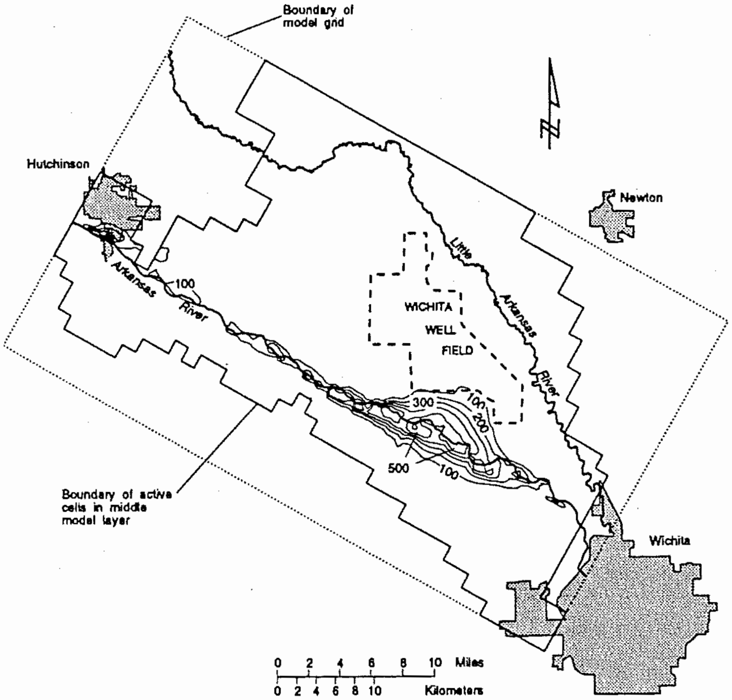


Figure A-15b.—Predicted chloride distribution in 1989 with the Arkansas River as the only chloride source for the middle model layer.

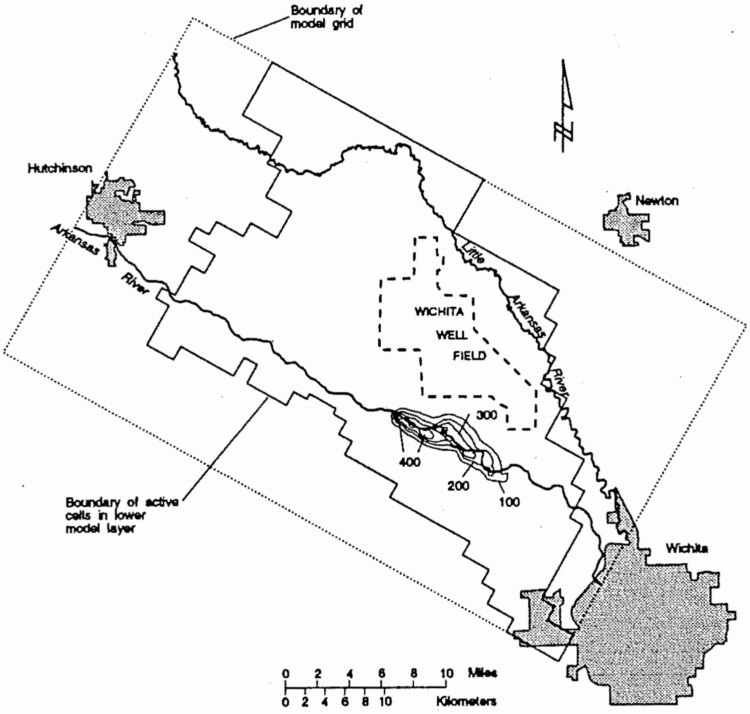


Figure A-15c.—Predicted chloride distribution in 1989 with the Arkansas River as the only chloride source for the lower model layer.

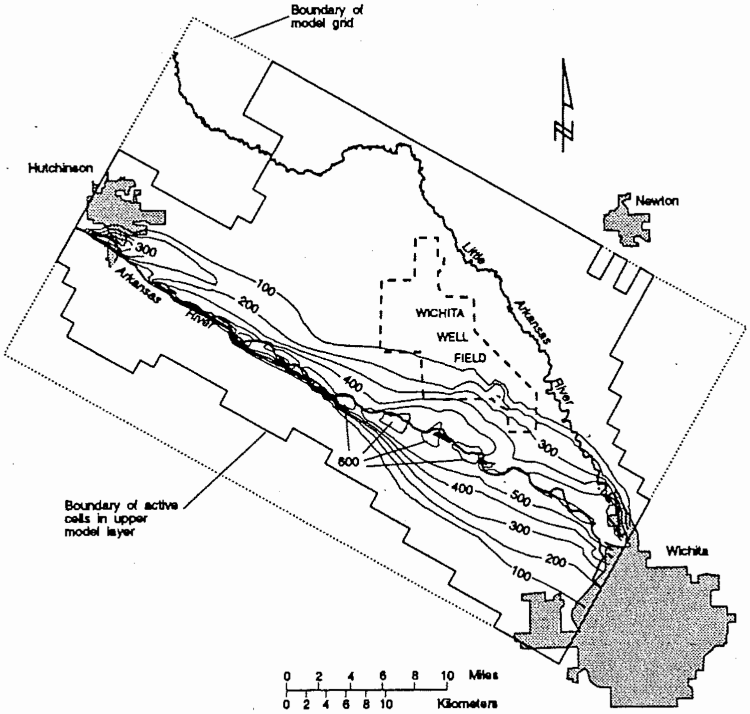


Figure A-16a.—Predicted chloride distribution in 2049 with the Arkansas River as the only chloride source for the upper model layer.

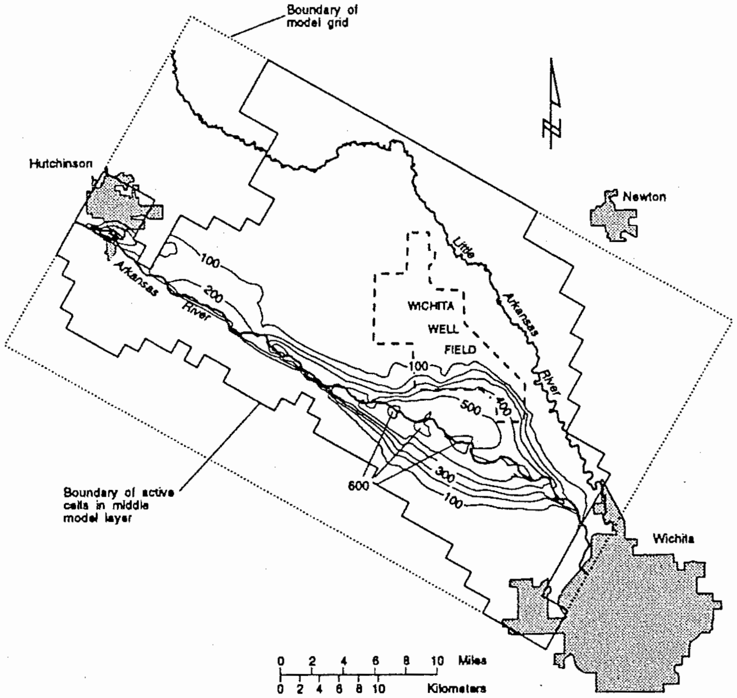


Figure A-16b.—Predicted chloride distribution in 2049 with the Arkansas River as the only chloride source for the middle model layer.

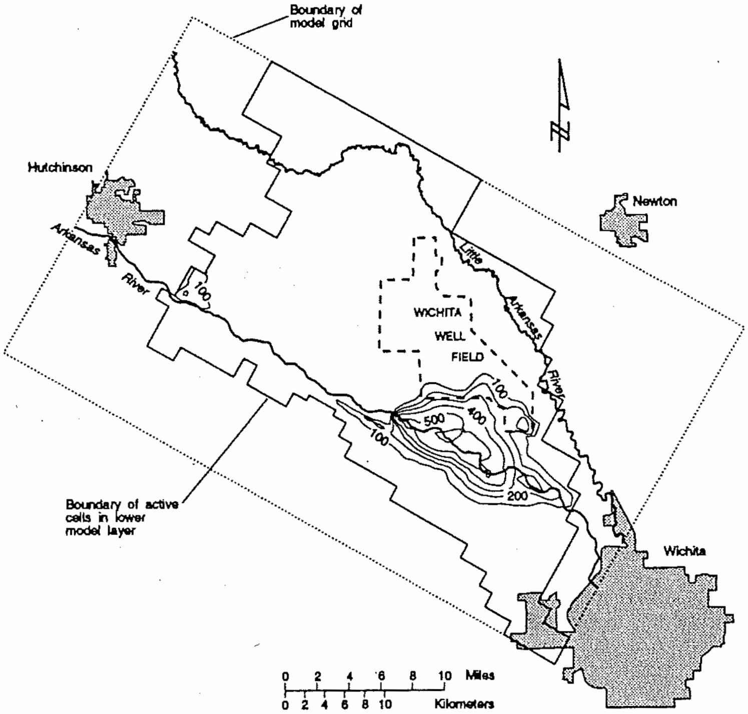


Figure A-16c.—Predicted chloride distribution in 2049 with the Arkansas River as the only chloride source for the lower model layer.

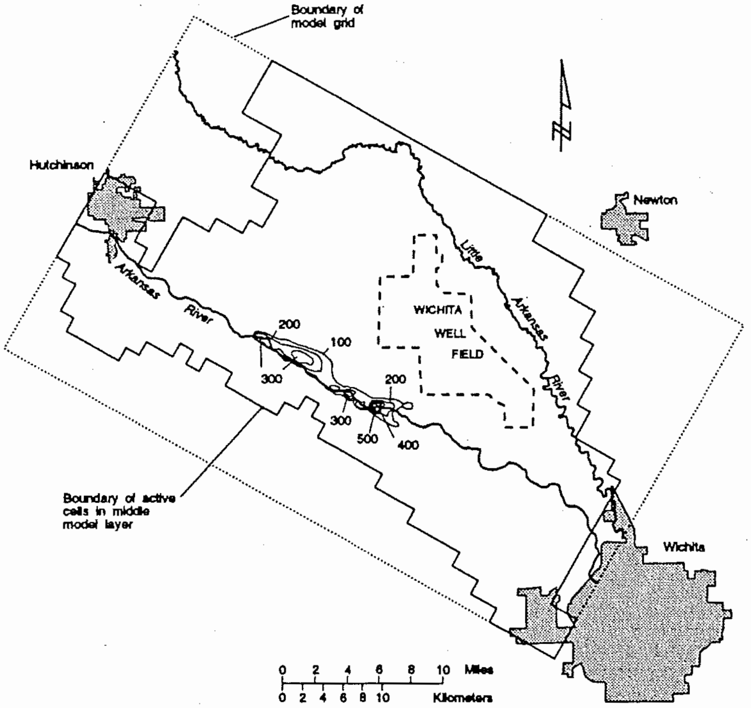


Figure A-17a.—Predicted chloride distribution in 1989 with saltwater intruding from the deep natural saltwater as the only chloride source for the middle model layer.

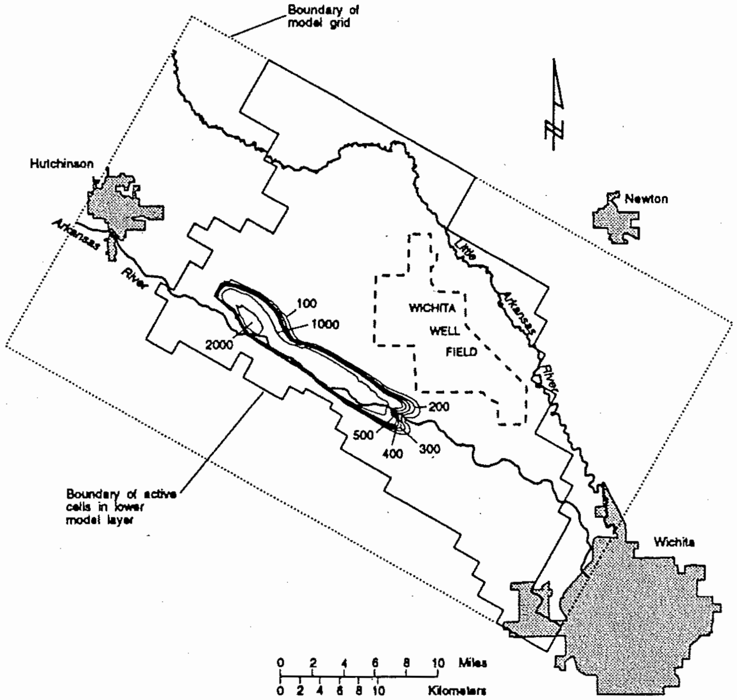


Figure A-17b.—Predicted chloride distribution in 1989 with saltwater intruding from the deep natural saltwater as the only chloride source for the lower model layer.

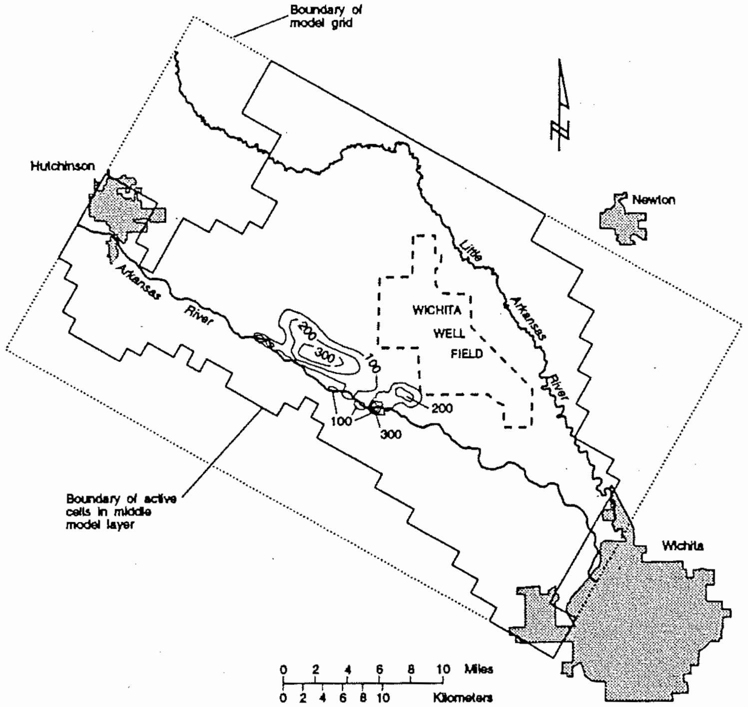


Figure A-18a.—Predicted chloride distribution in 2049 with saltwater intruding from the deep natural saltwater as the only chloride source for the middle model layer.

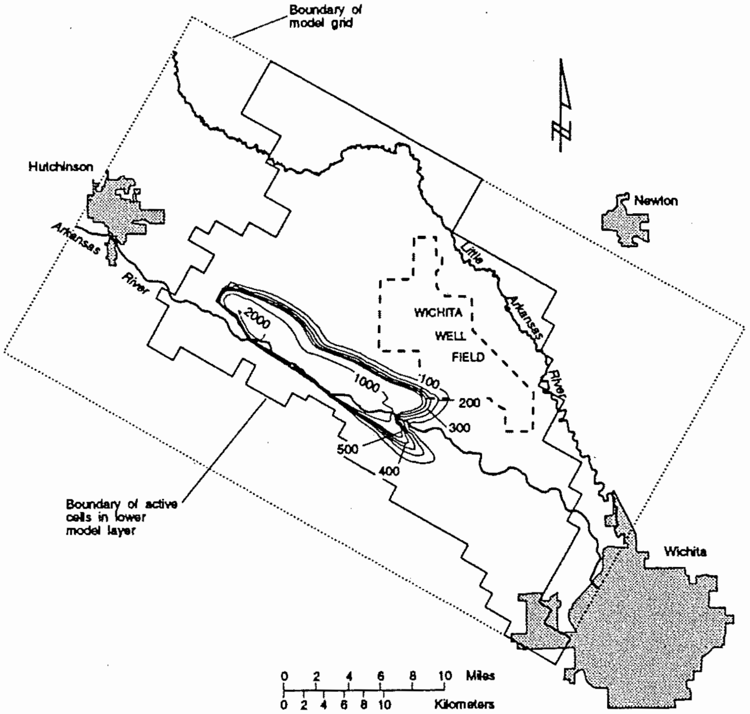


Figure A-18b.—Predicted chloride distribution in 2049 with saltwater intruding from the deep natural saltwater as the only chloride source for the lower model layer.

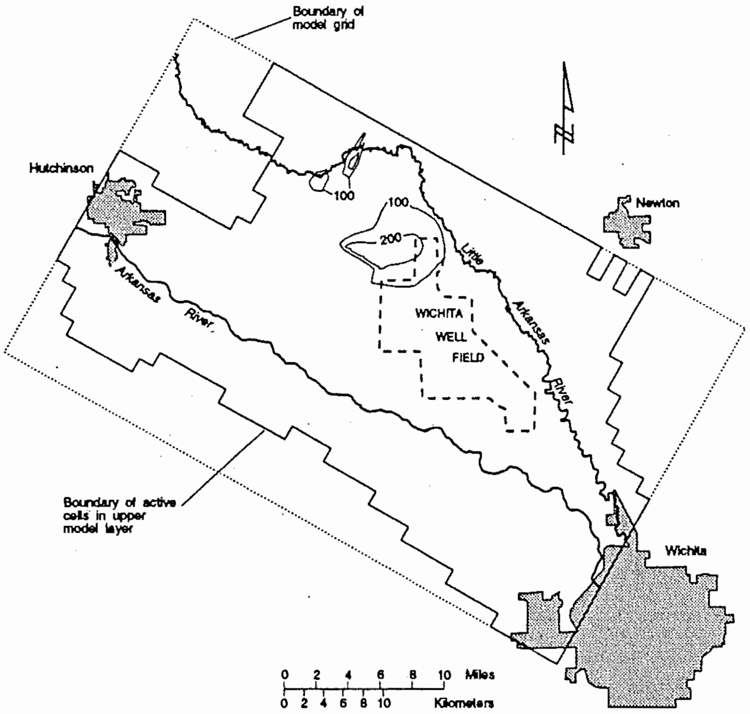


Figure A-19a.—Predicted chloride distribution in 1989 with oil field brine as the only chloride source for the upper model layer.

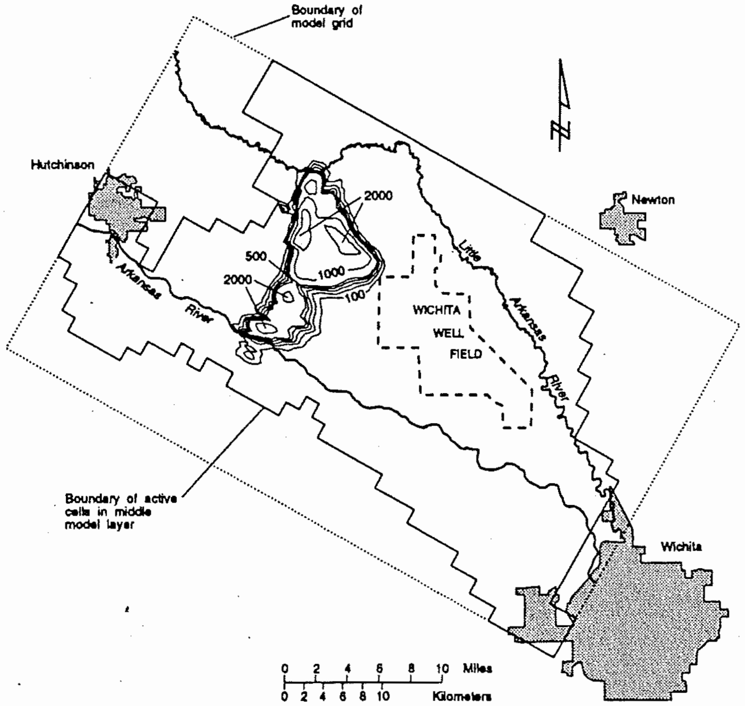


Figure A-19b.—Predicted chloride distribution in the 1989 with oil field brine as the only chloride source for the middle model layer.

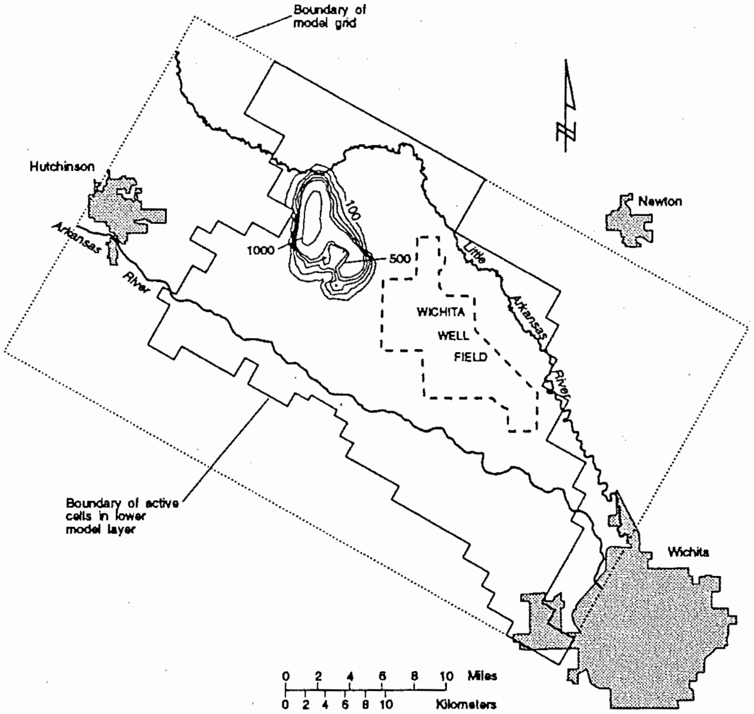


Figure A-19c.—Predicted chloride distribution in 1989 with oil field brine as the only chloride source for the lower model layer.

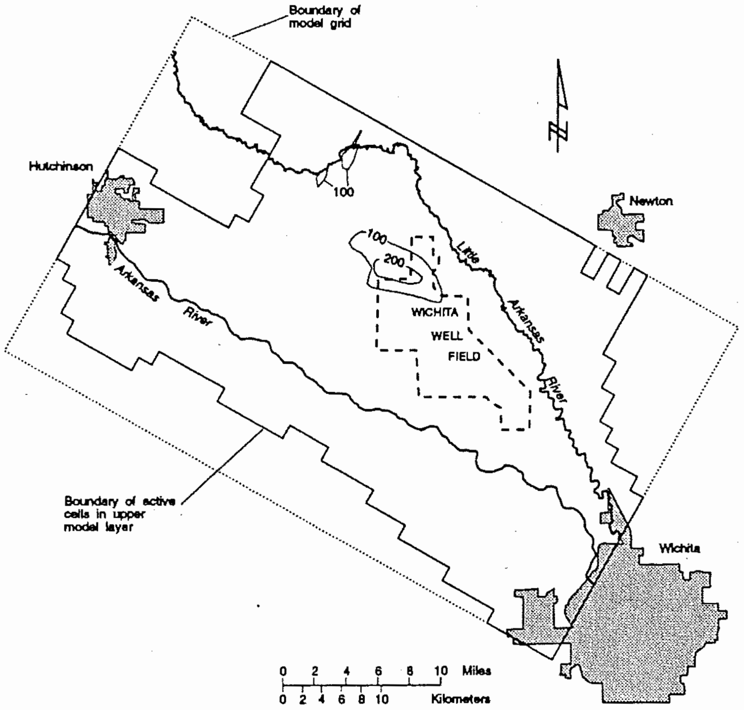


Figure A-20a.—Predicted chloride distribution in 2049 with oil field brine as the only chloride source for the upper model layer.

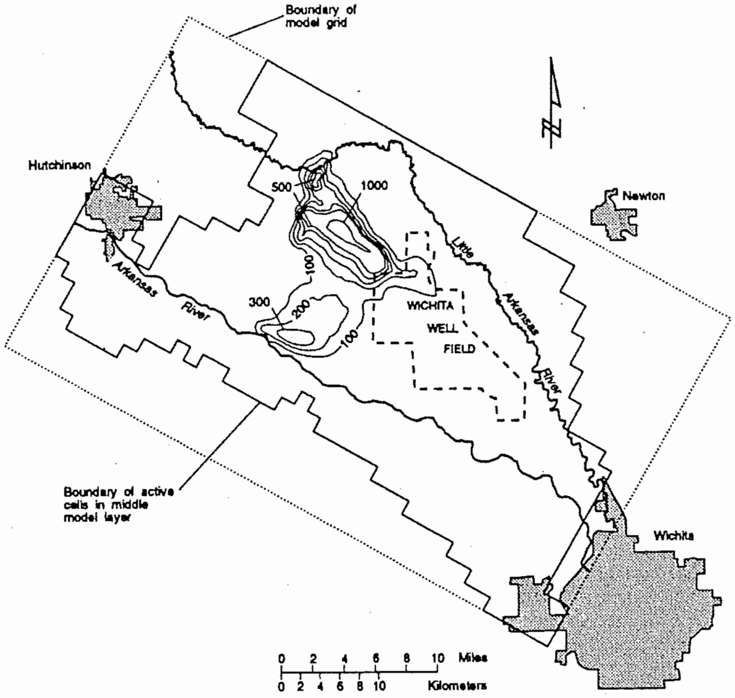


Figure A-20b.—Predicted chloride distribution in 2049 with oil field brine as the only chloride source for the middle model layer.

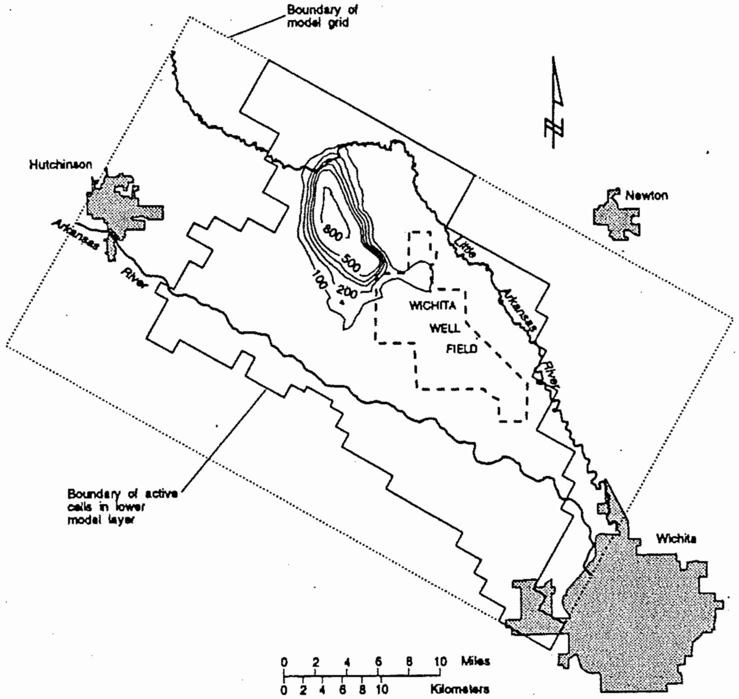


Figure A-20c.—Predicted chloride distribution in 2049 with oil field brine as the only chloride source for the lower model layer.

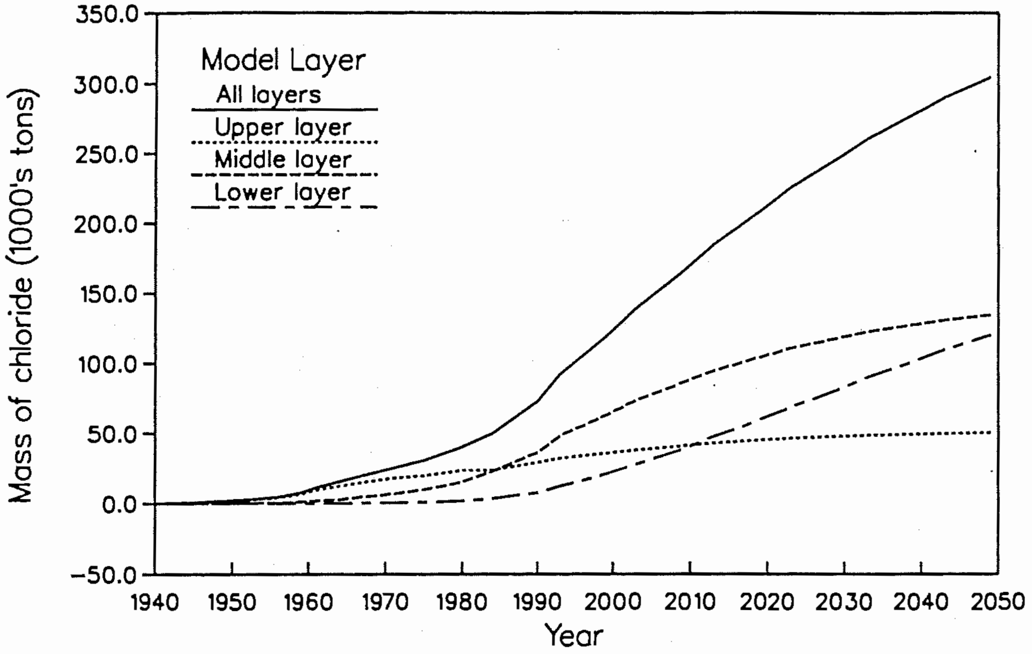


Figure A-21a.—Predicted chloride mass in the river zone with the Arkansas River as the only chloride source.

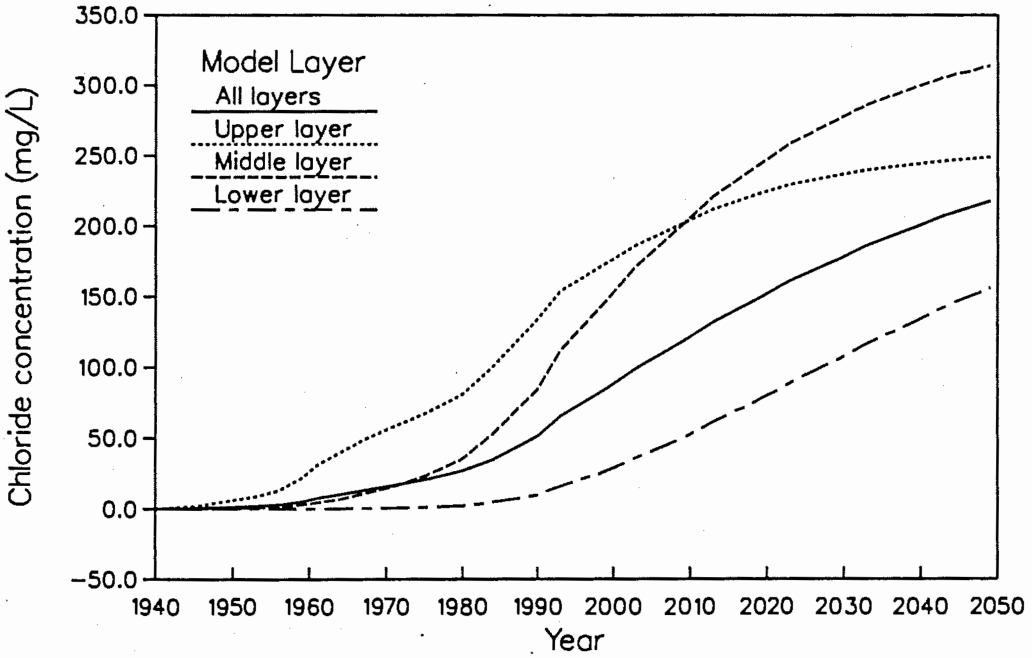


Figure A-21b.—Predicted average chloride concentration in the river zone with the Arkansas River as the only chloride source.

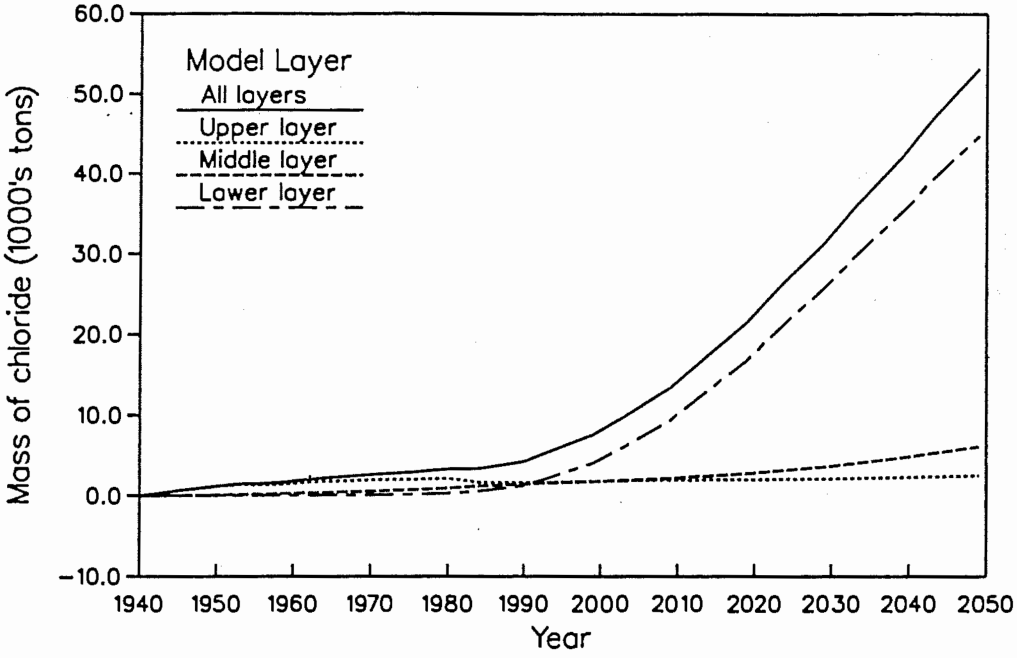


Figure A-22a.—Predicted chloride mass in the river zone with saltwater intruding from the deep natural saltwater as the only chloride source.

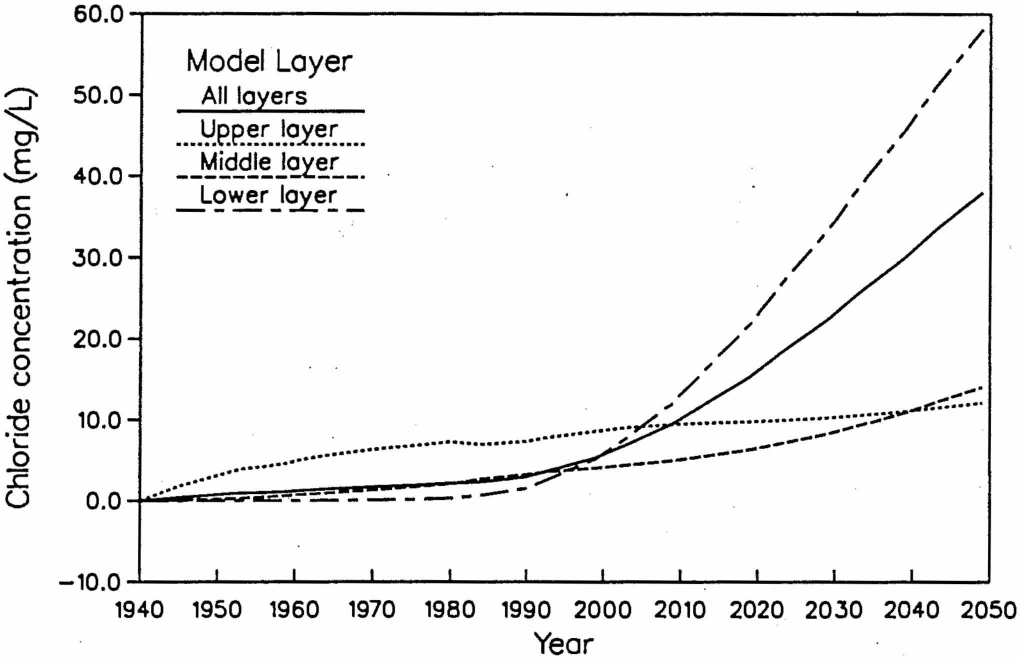


Figure A-22b.—Predicted average chloride concentration in the river zone with saltwater intruding from the deep natural saltwater as the only chloride source.

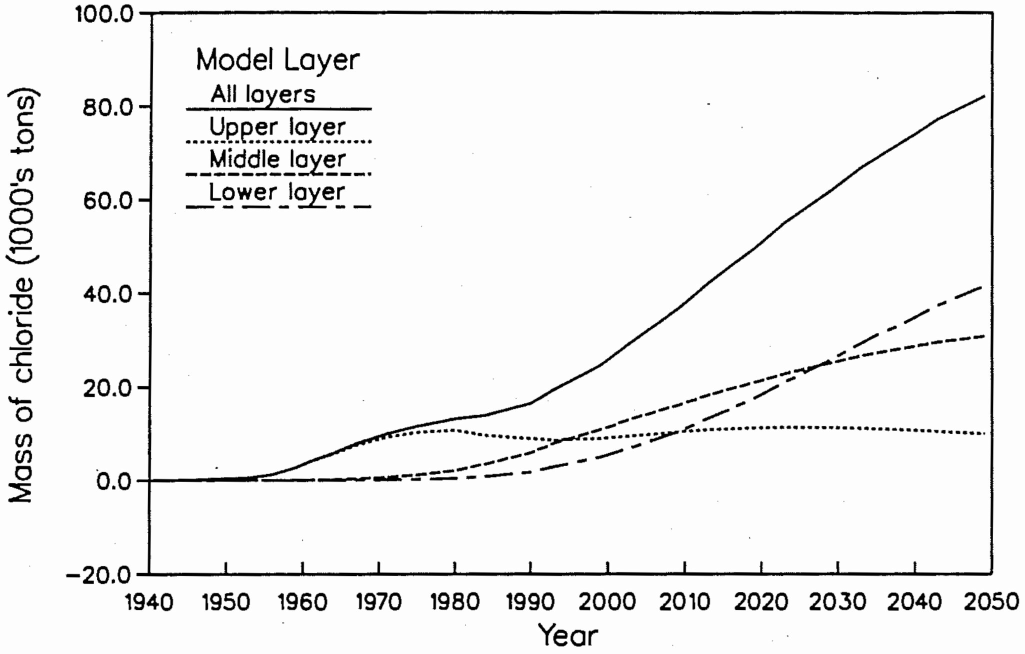


Figure A-23a.—Predicted chloride mass in the brine zone with oil field brine as the only chloride source.

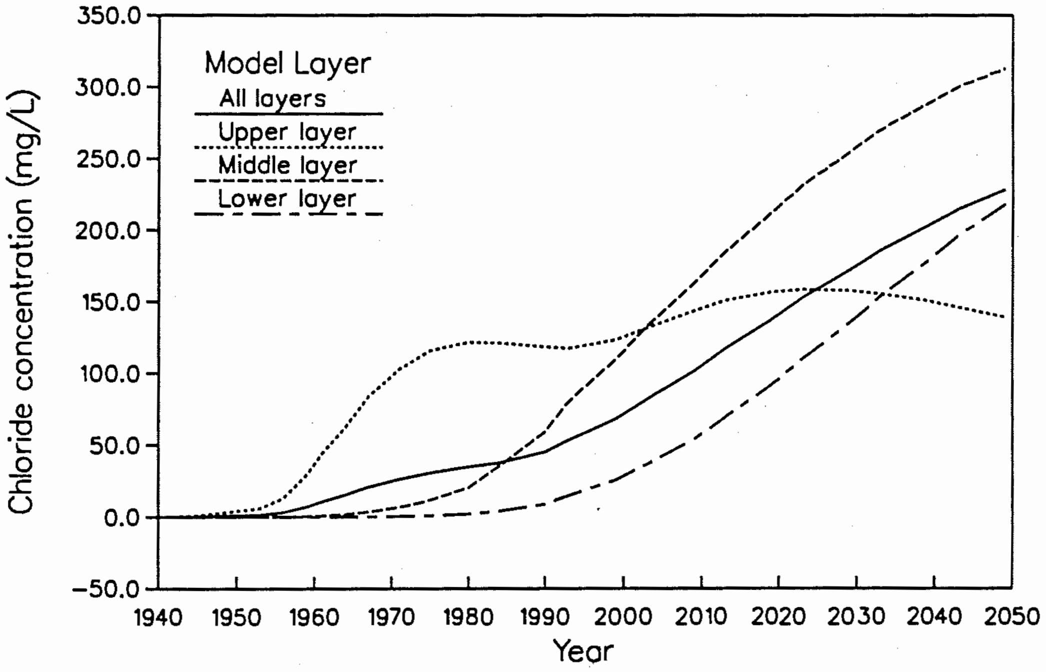


Figure A-23b.—Predicted average chloride concentration in the brine zone with oil field brine as the only chloride source.

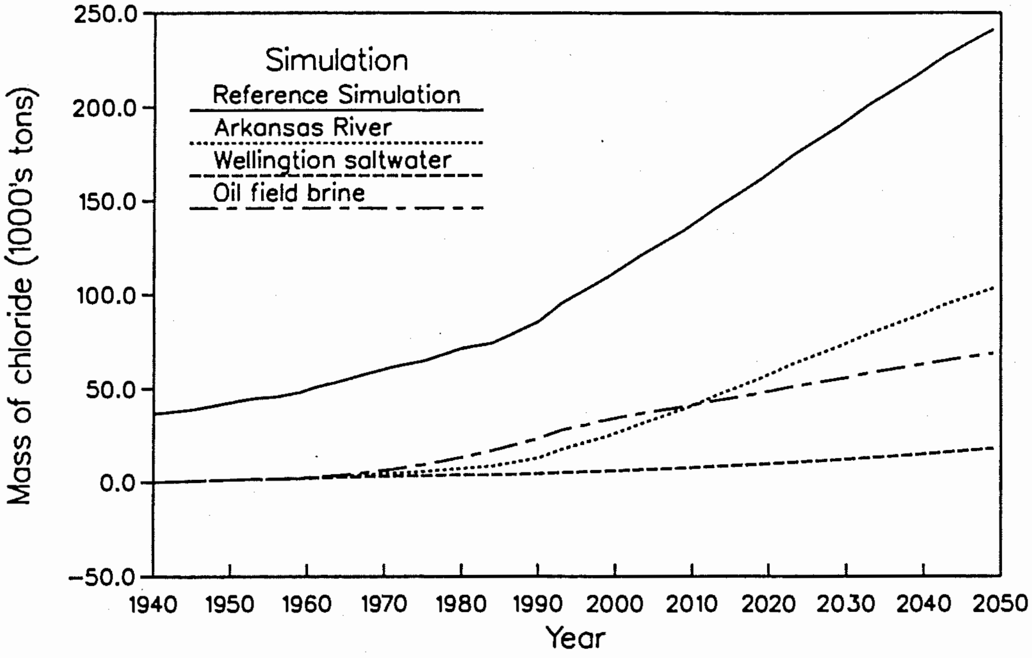


Figure A-24a.—Predicted chloride mass in the Wichita well field area for specific chloride source simulations.

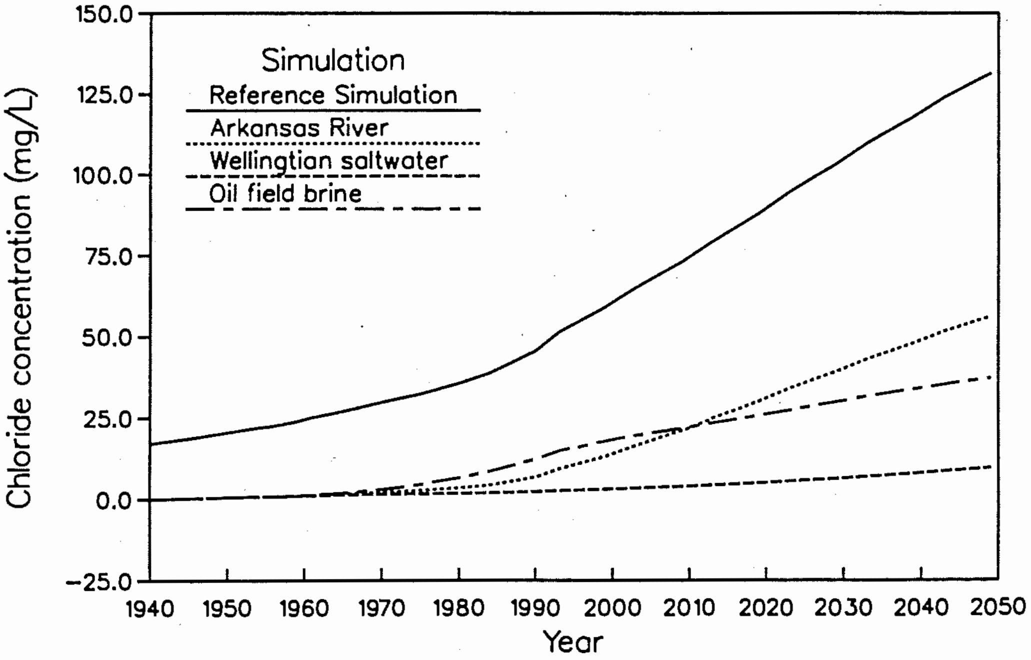


Figure A-24b.—Predicted average chloride concentration in the Wichita well field area for specific chloride source simulations.

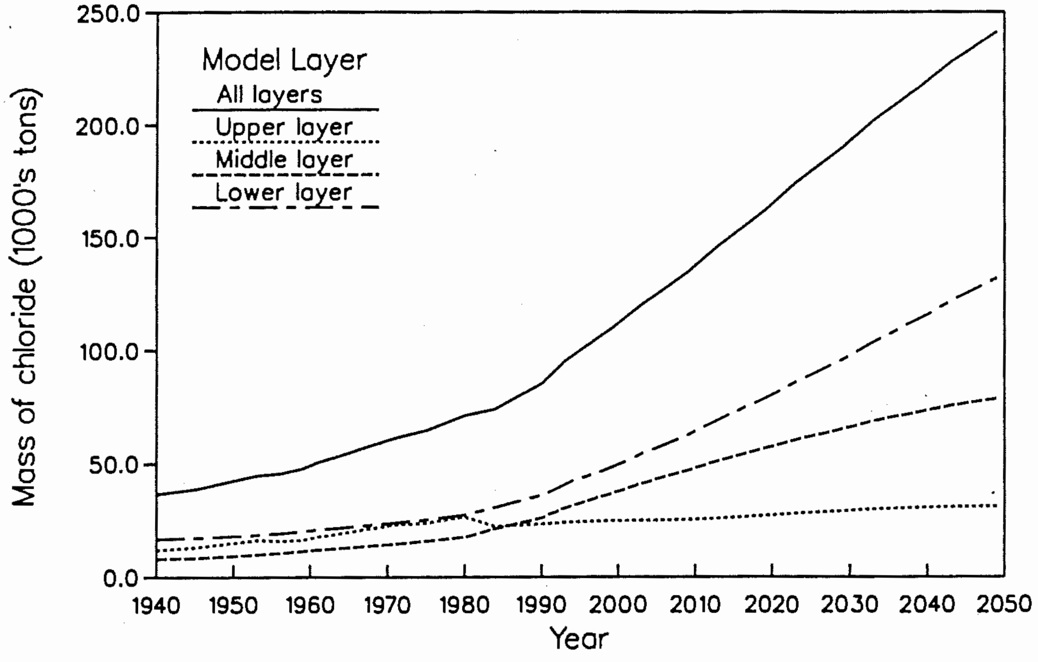


Figure A-25a.—Predicted chloride mass in the Wichita well field area for the reference simulation.

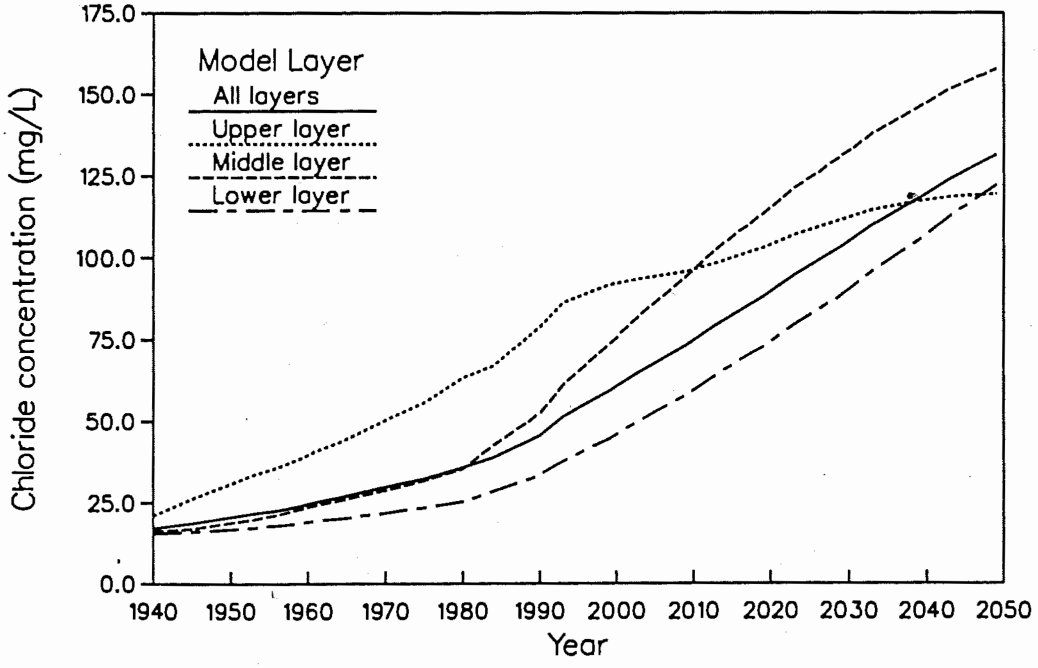


Figure A-25b.—Predicted average chloride concentration in the Wichita well field area for the reference simulation.

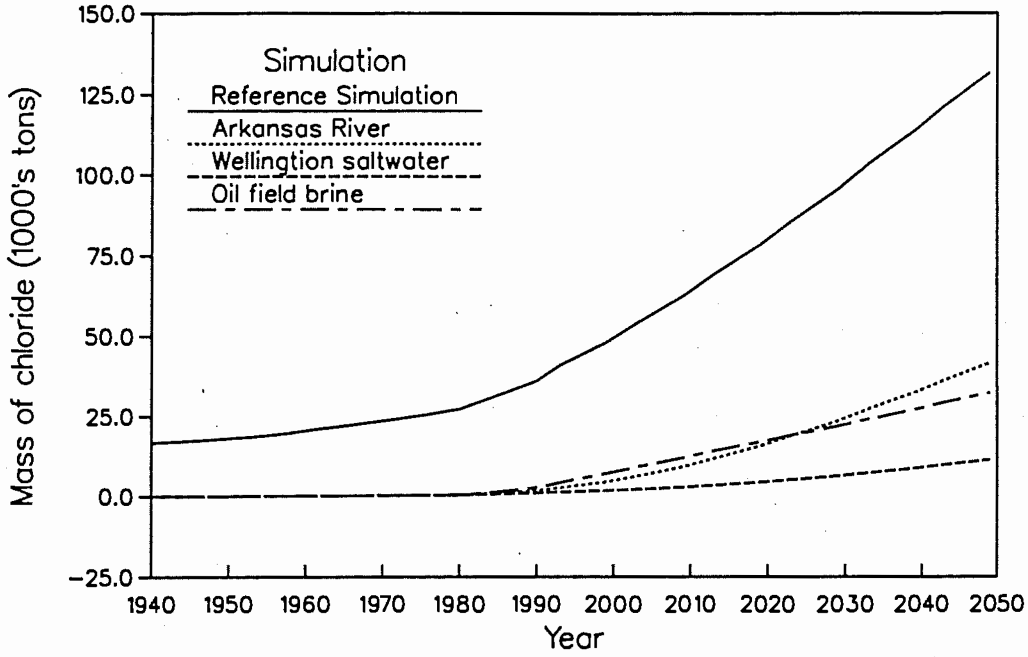


Figure A-26a.—Predicted chloride mass in the lower model layer of the Wichita well field zone for Arkansas River flow simulations.

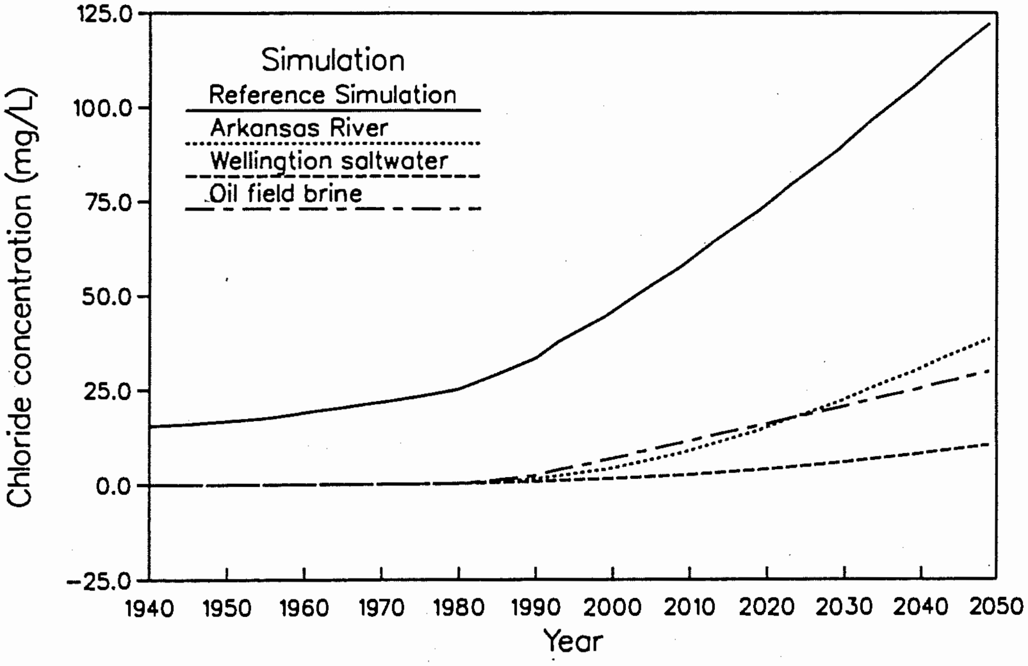


Figure A-26b.—Predicted average chloride concentration in the lower model layer of the Wichita well field zone for the Arkansas River flow simulations.

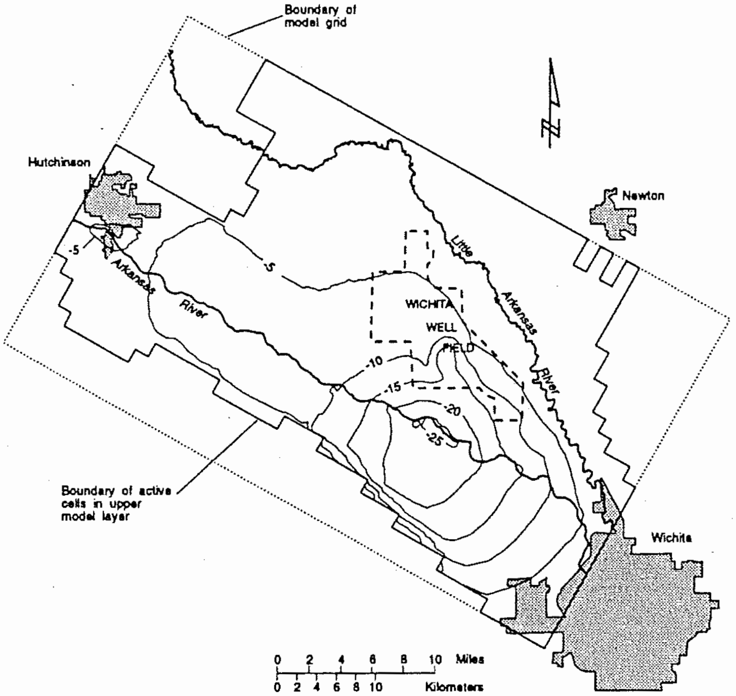


Figure A-27a.—Predicted water table elevation difference from the reference simulation for simulations: Arkansas River streamflow set to zero.

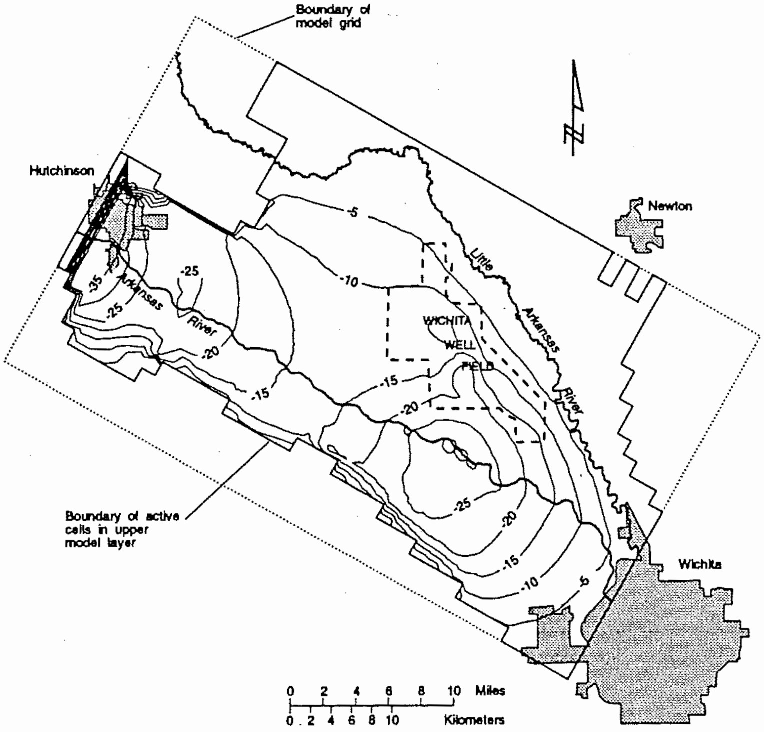


Figure A-27b.—Predicted water table elevation difference from the reference simulation for simulations: No-flow boundary and Arkansas River streamflow set to zero.

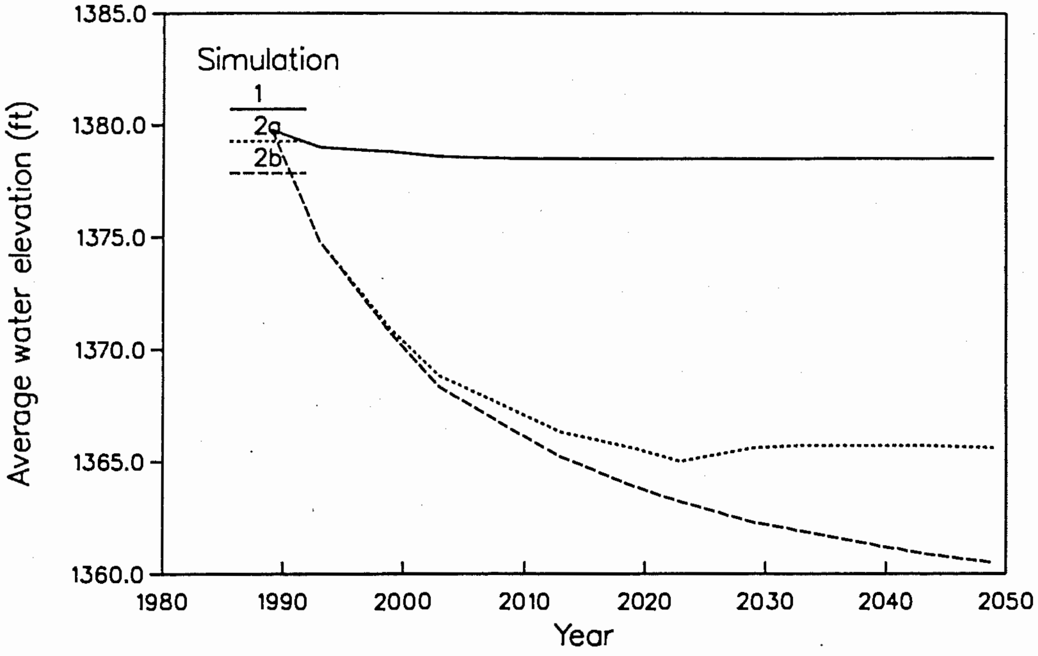


Figure A-28a.—Predicted average water table elevation for river zone for Arkansas River flow simulations.

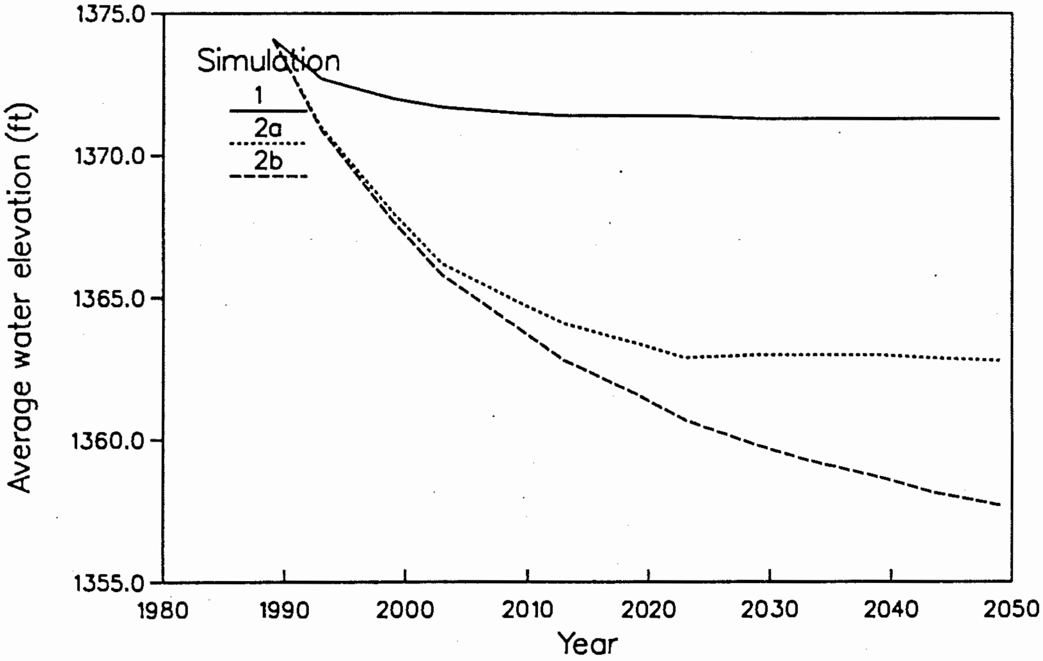


Figure A-28b.—Predicted average water table elevation for Wichita well field area for Arkansas River flow simulations.

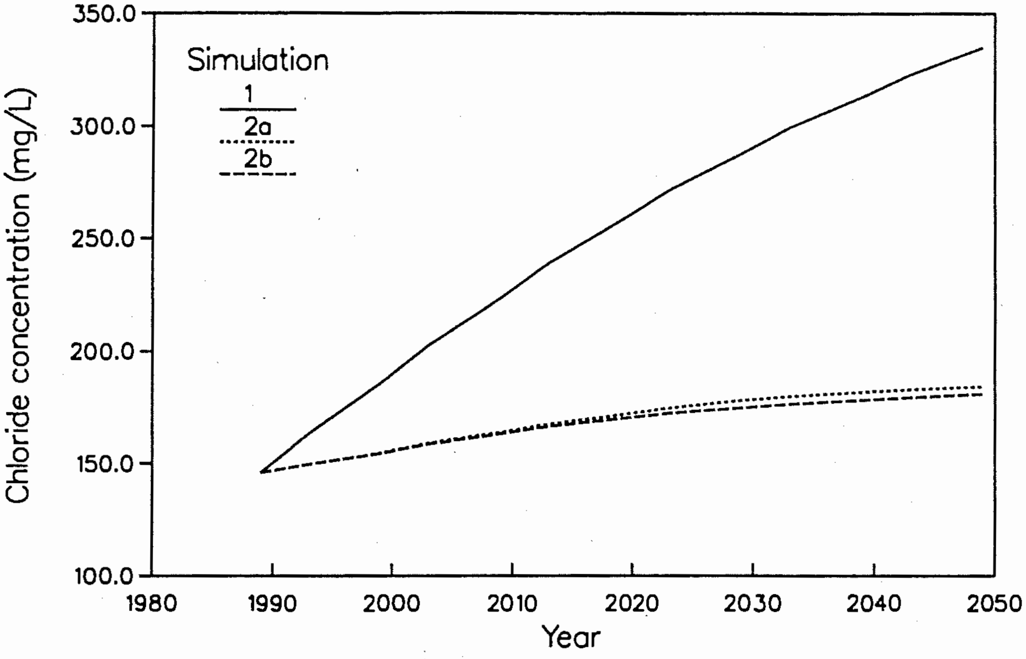


Figure A-29a.—Predicted average chloride concentration for river zone for Arkansas River flow simulations.

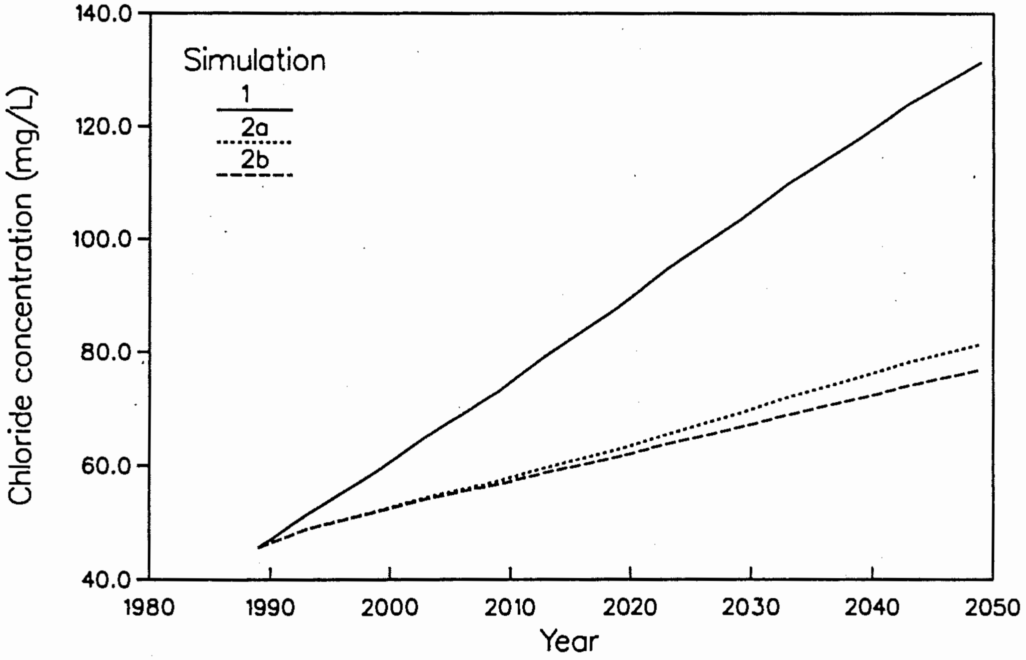


Figure A-29b.—Predicted average chloride concentration flow Wichita well field area for Arkansas River flow simulations.

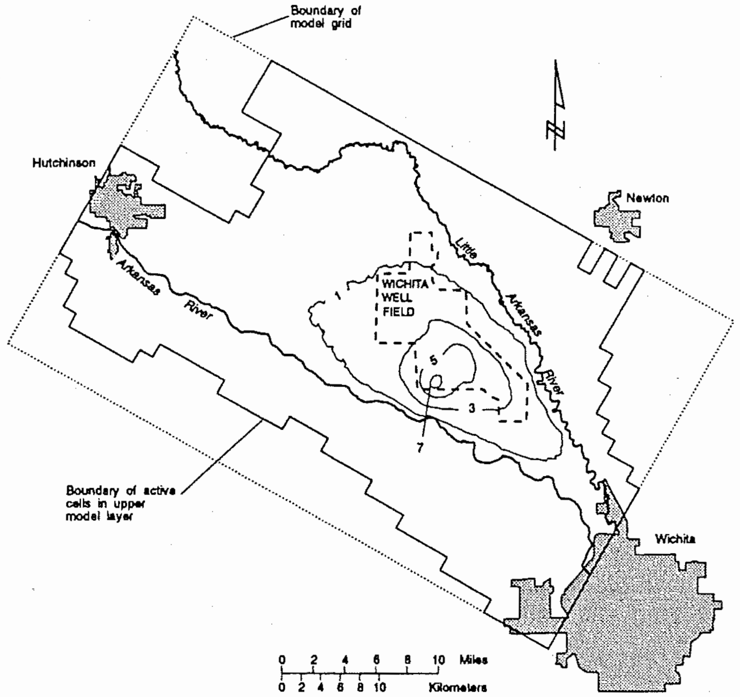


Figure A-30a.—Predicted water table elevation difference from the reference simulation for simulations: no pumping in upper model layer near the Arkansas River.

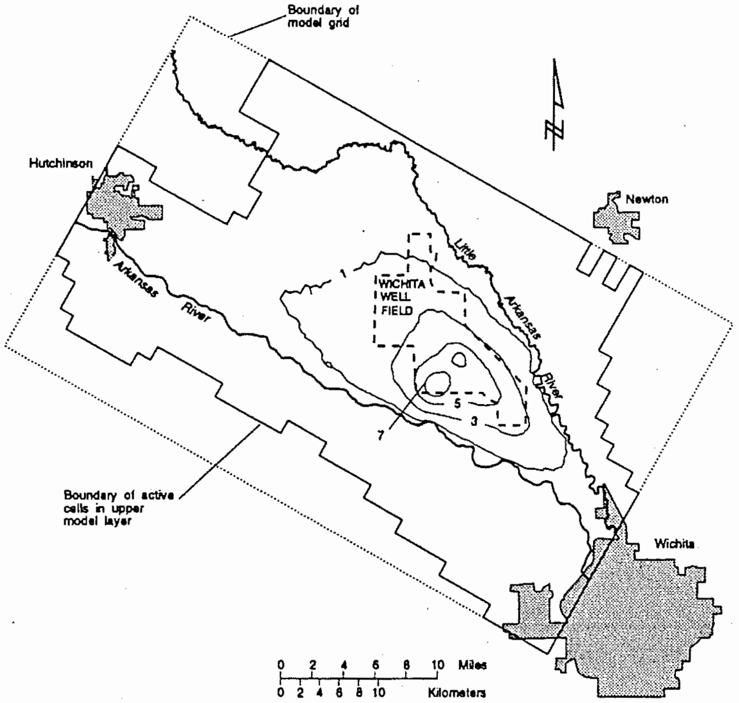


Figure A-30b.—Predicted water table elevation difference from the reference simulation for simulations: no pumping in upper and middle model layers near the Arkansas River.

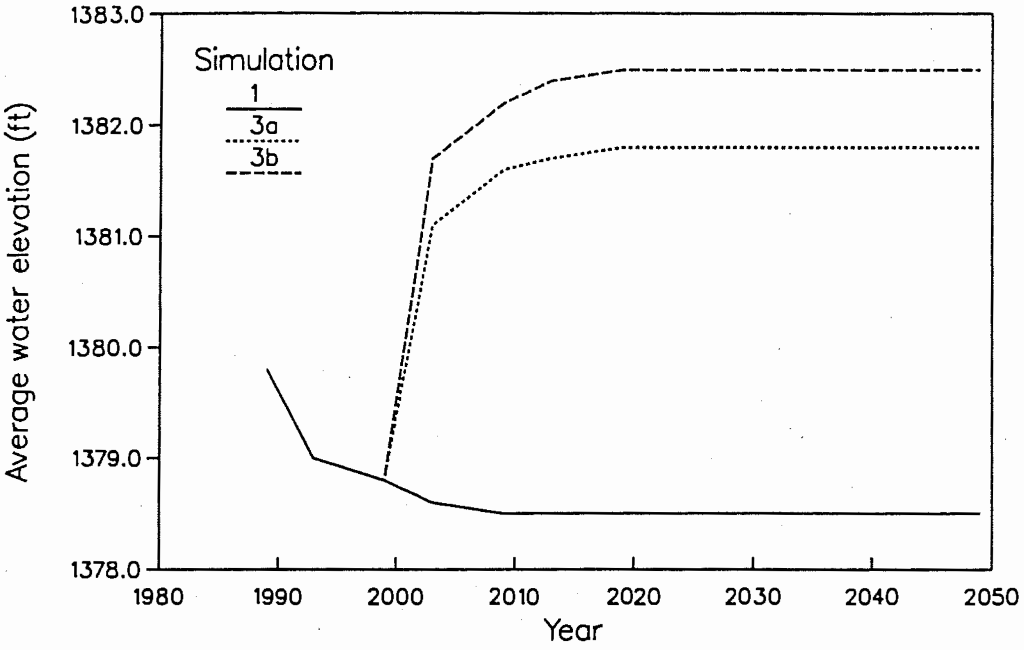


Figure A-31a.—Predicted average water table elevation in river zone for pumping near Arkansas River simulations.

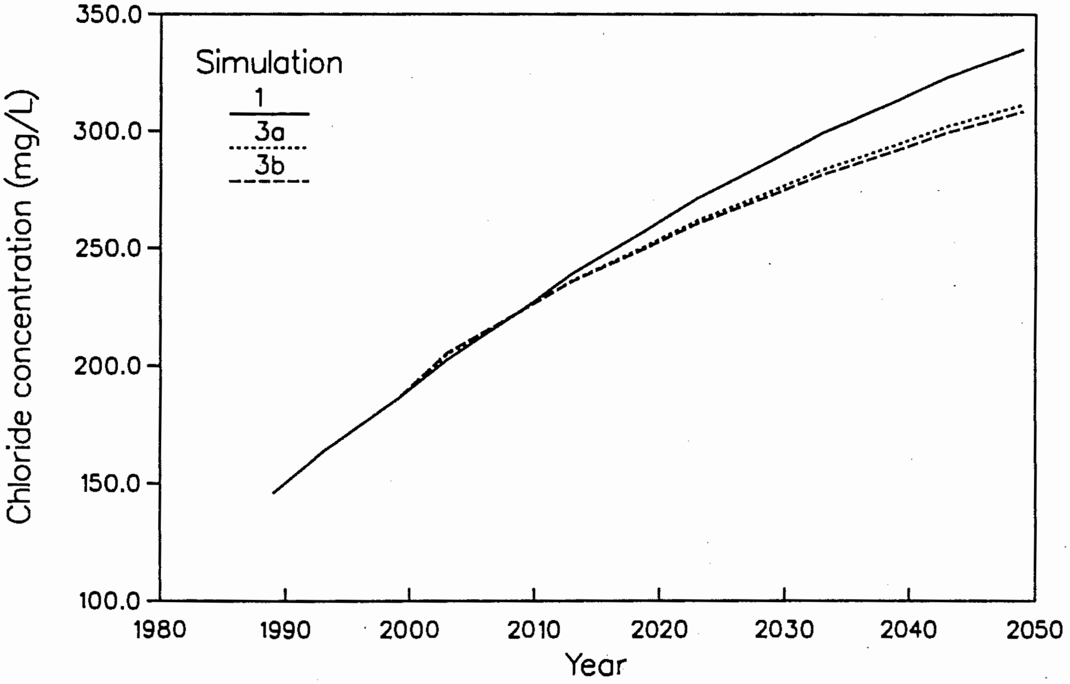


Figure A-31b.—Predicted average chloride concentration in river zone for pumping near Arkansas River simulations.

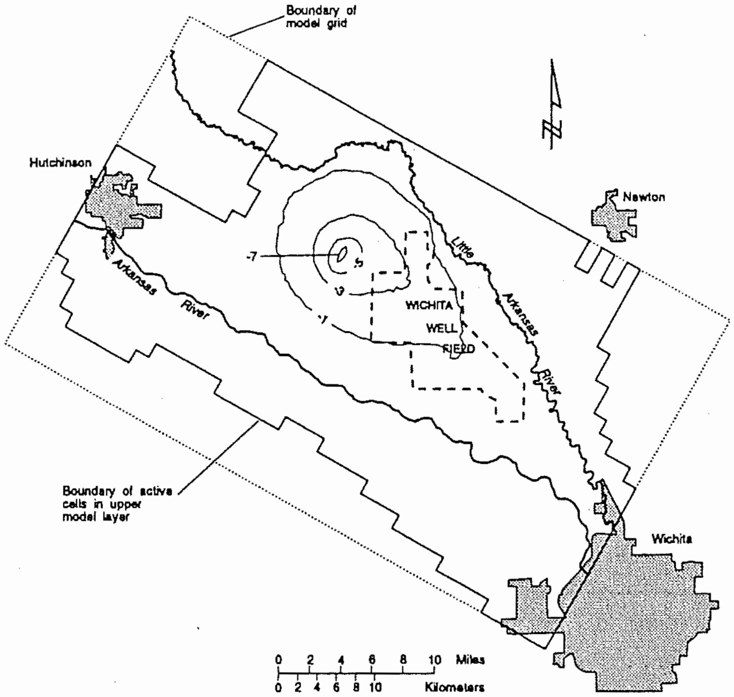


Figure A-32a.—Predicted water table elevation difference from the base projection for brine interception well withdrawal rates per well of 50 gpm.

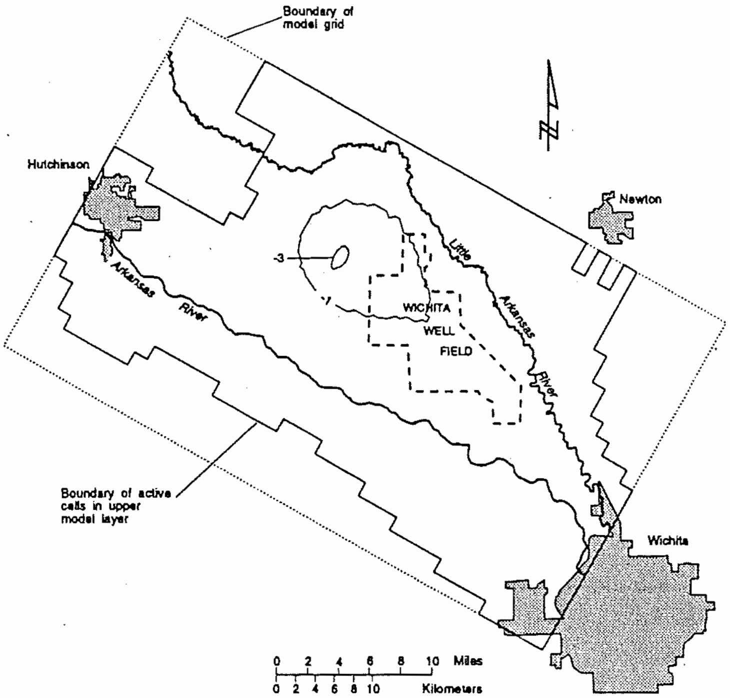


Figure A-32b.—Predicted water table elevation difference from the base projection for brine interception well withdrawal rates per well of 100 gpm.

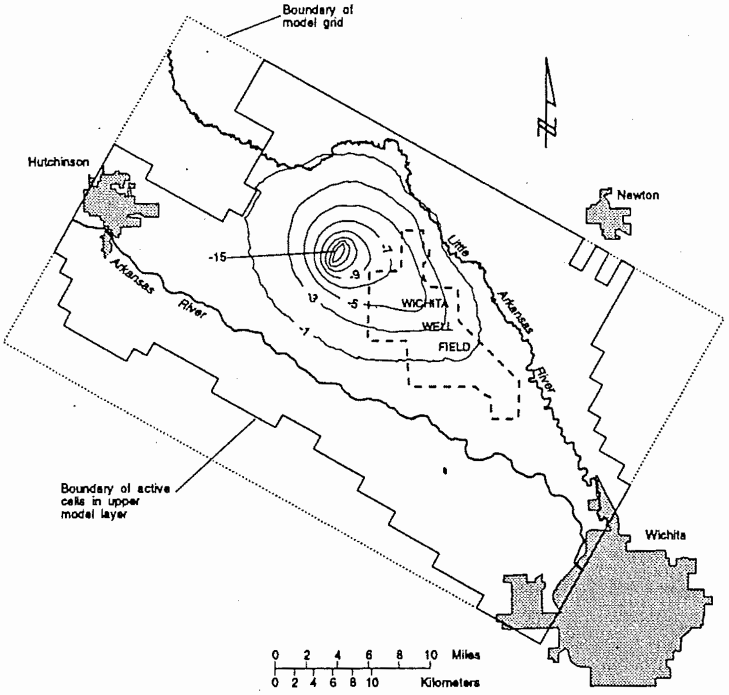


Figure A-32c.—Predicted water table elevation difference from the base projection for brine interception well withdrawal rates per well of 200 gpm.

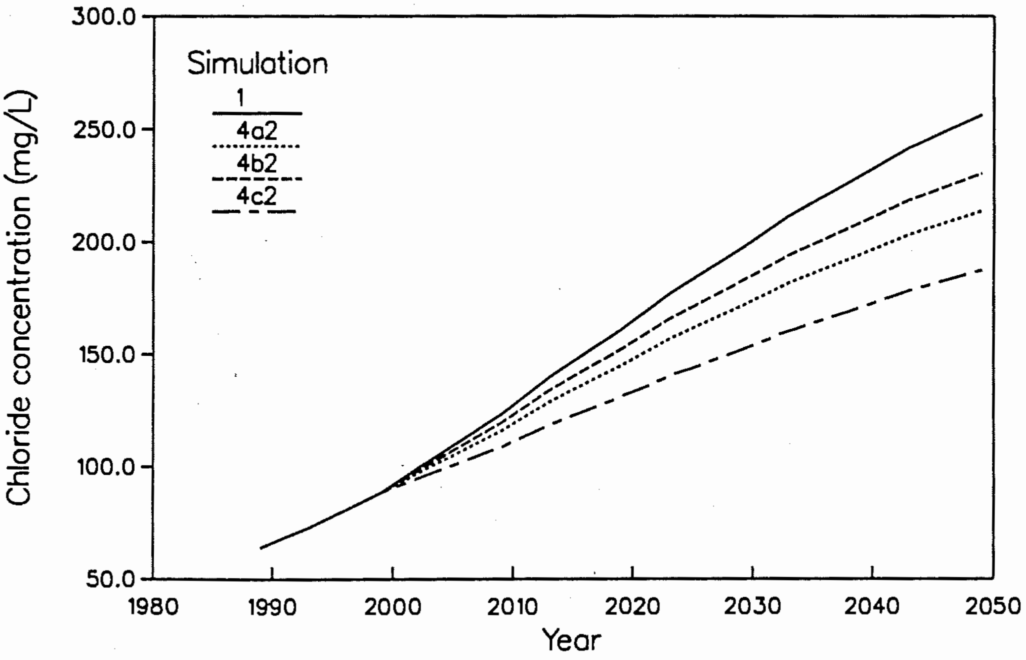


Figure A-33a.—Predicted average chloride concentration for the upper model layer in the brine zone for brine interception well simulations.

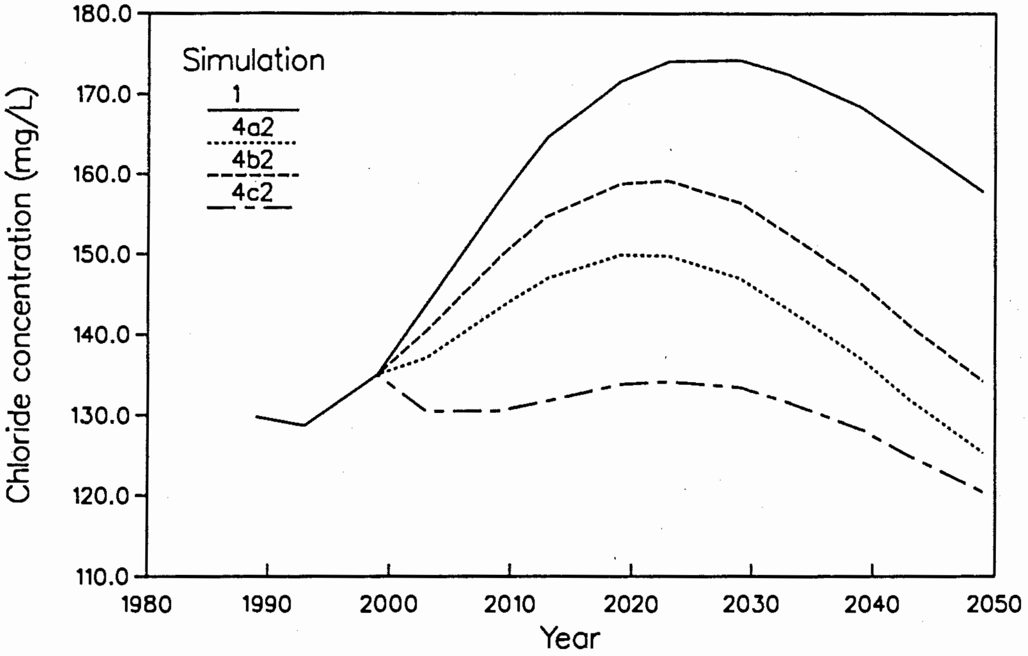


Figure A-33b.—Predicted average concentration for the middle model layer in the brine zone for brine interception well simulations.

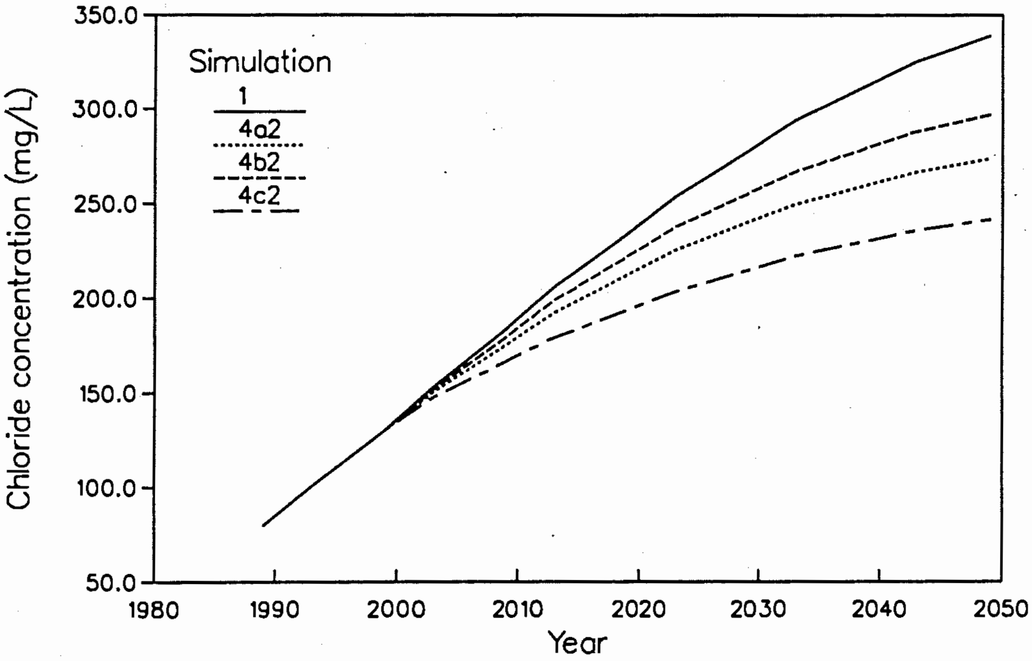


Figure A-33c.—Predicted average concentration for the lower model layer in the brine zone for brine interception well simulations.

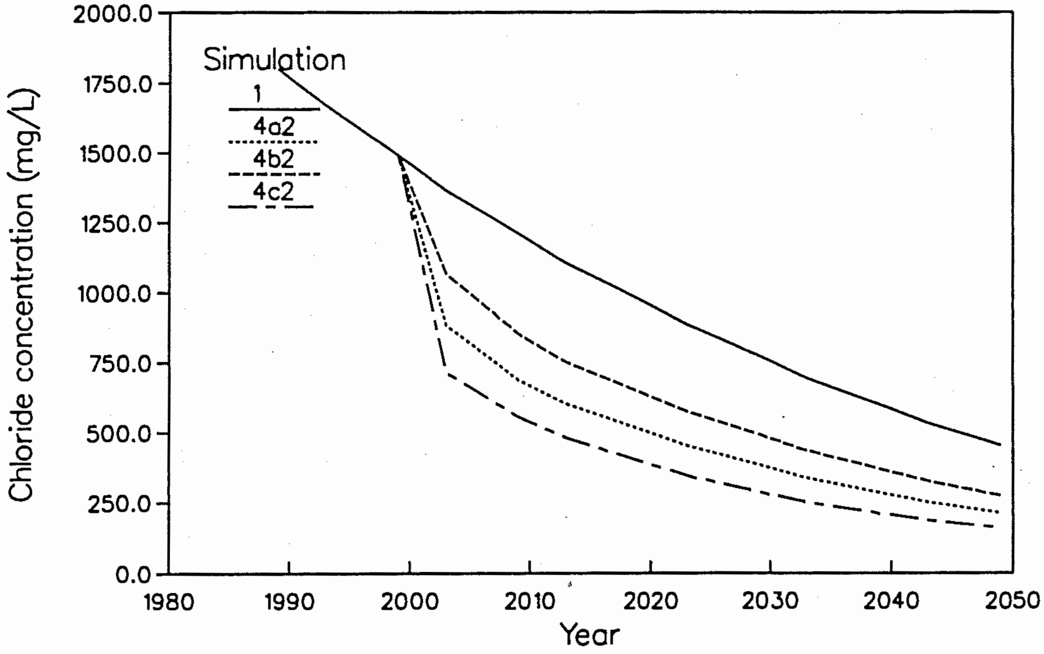


Figure A-34a.—Estimated average chloride concentration of water from brine interception wells installed in the middle model layer.

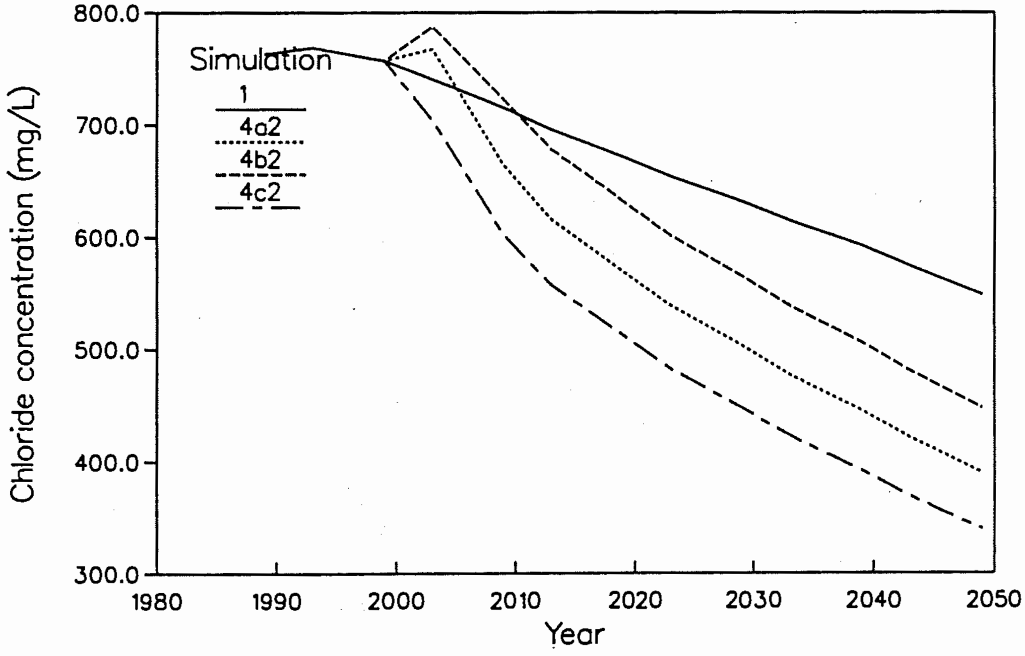


Figure A-34b.—Estimated average chloride concentration of water from brine interception wells installed in the lower model layer.

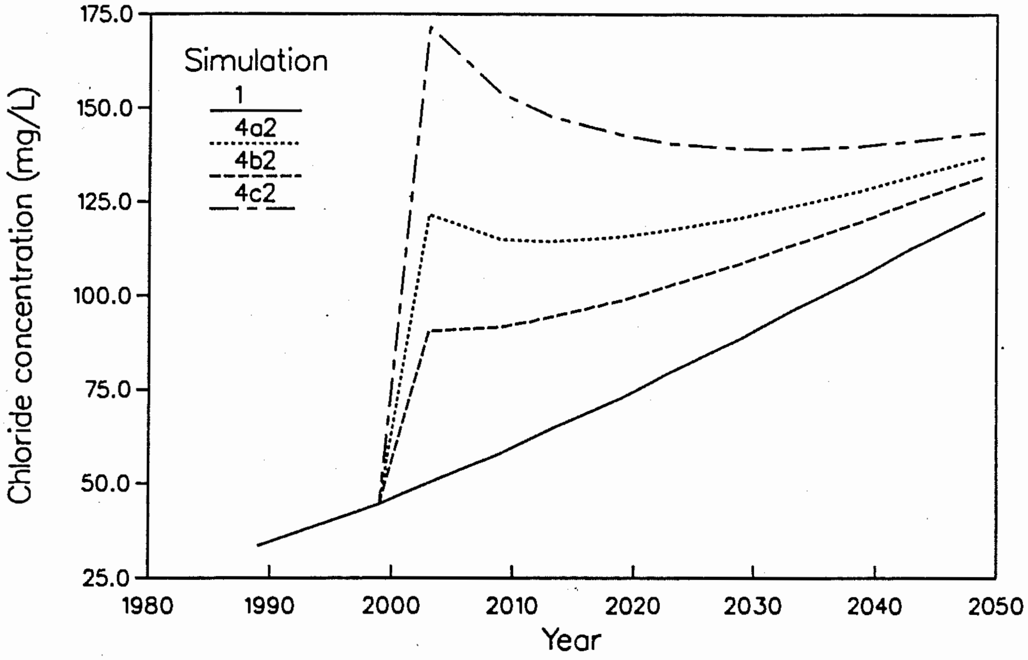


Figure A-34c.—Estimated average chloride concentration of water from blending brine interception well production with Wichita well field production.

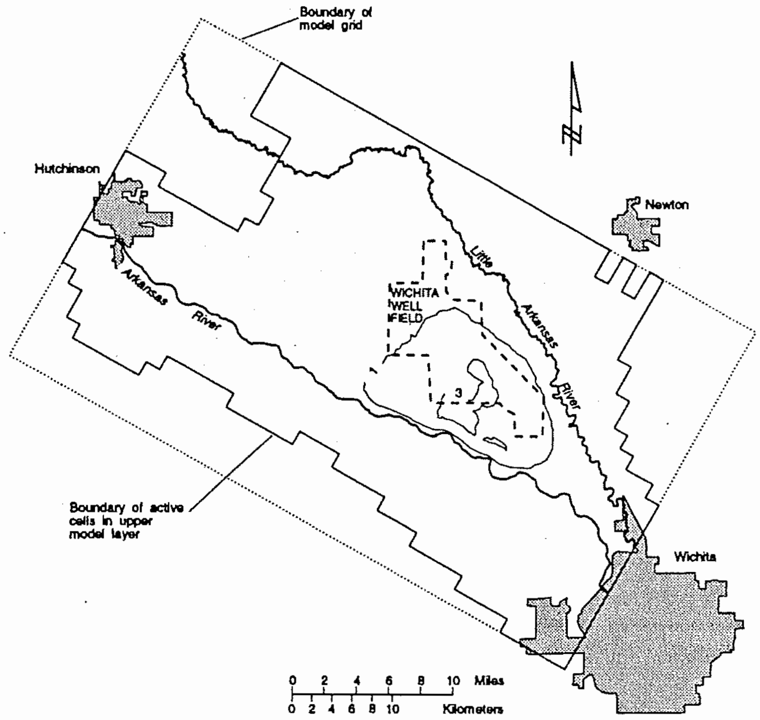


Figure A-35.—Predicted water table elevation difference from the reference simulation for simulation: hydraulic barrier at location nearest the river with recharge of 11,300 acre-feet/year.

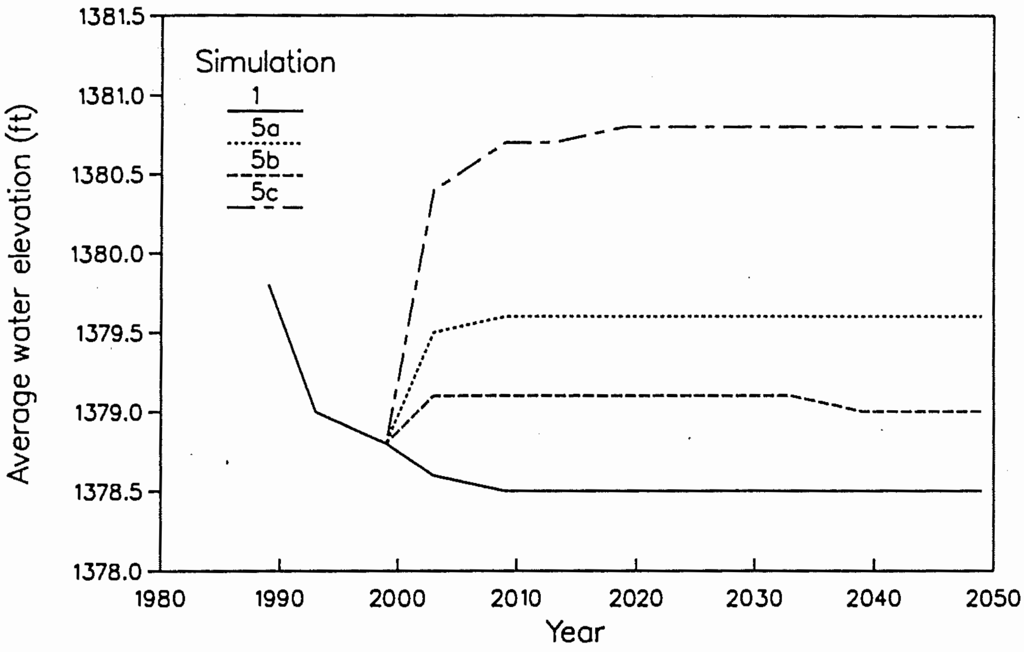


Figure A-36.—Predicted average water table elevation in the river zone for hydraulic barrier simulations at location nearest the river.

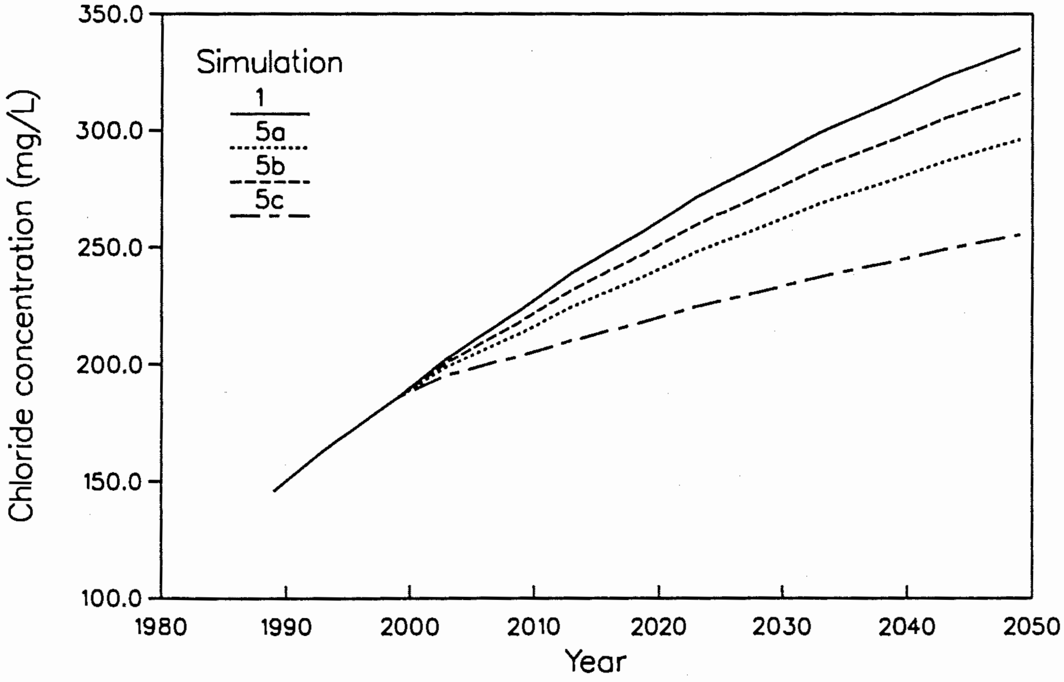


Figure A-37a.—Predicted average chloride concentration in river zone for hydraulic barrier simulations at location nearest the river.

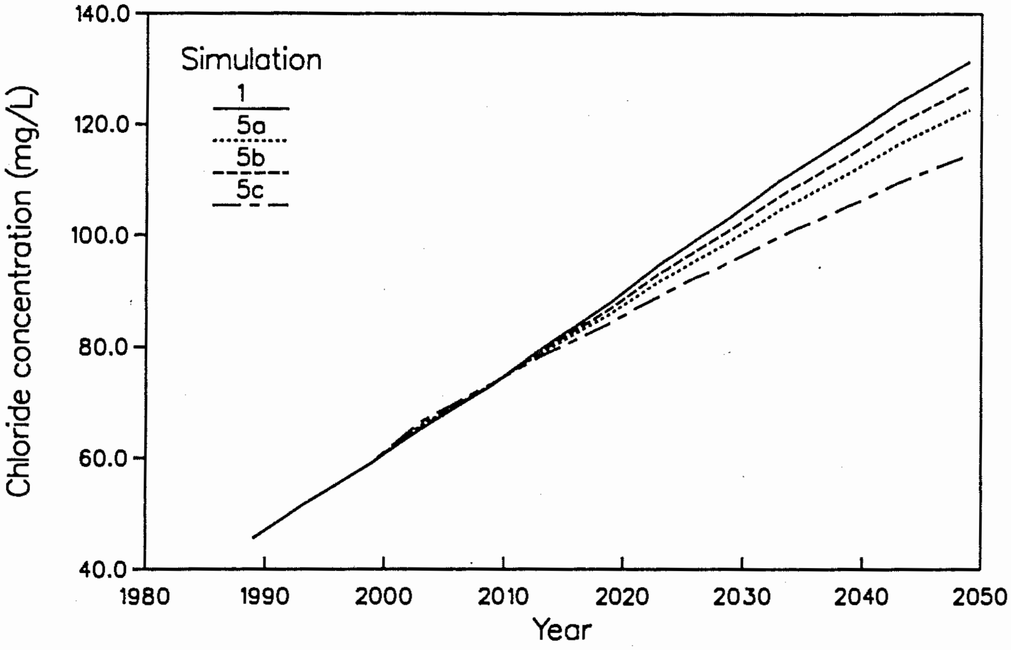


Figure A-37b.—Predicted average chloride concentration in Wichita well field zone for hydraulic barrier simulations at location nearest the river.

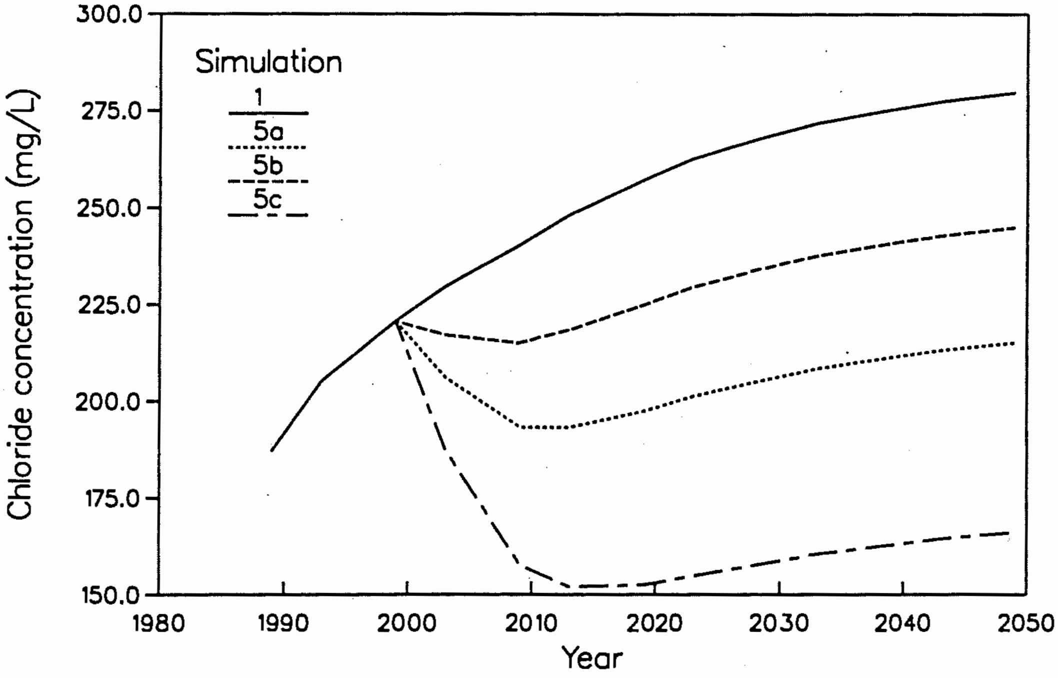


Figure A-38a.—Predicted average chloride concentration in the river zone for the upper model layer. Hydraulic barrier simulations at location nearest the river.

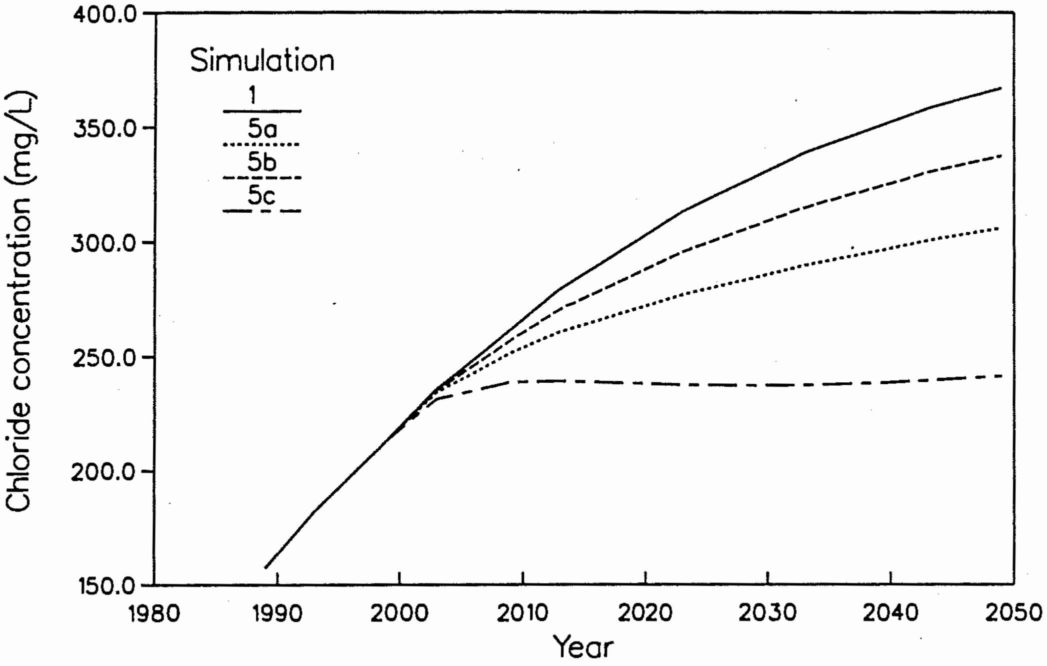


Figure A-38b.—Predicted average chloride concentration in the river zone for middle model layer. Hydraulic barrier simulations at location nearest the river.

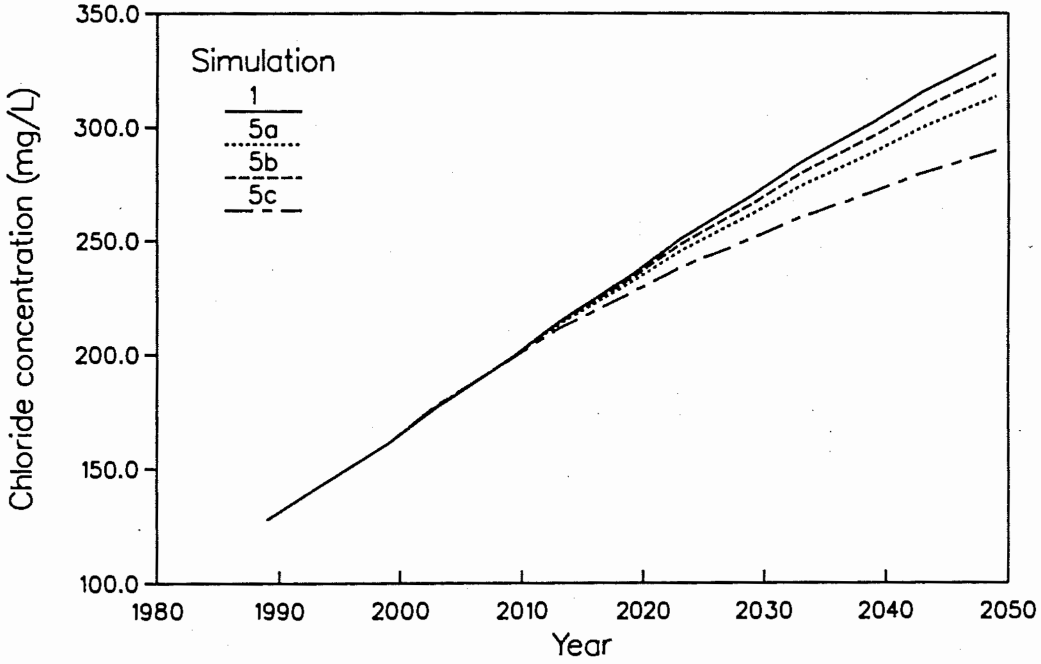


Figure A-38c.—Predicted average chloride concentration in the river zone for lower model layer. Hydraulic barrier simulations at location nearest the river.

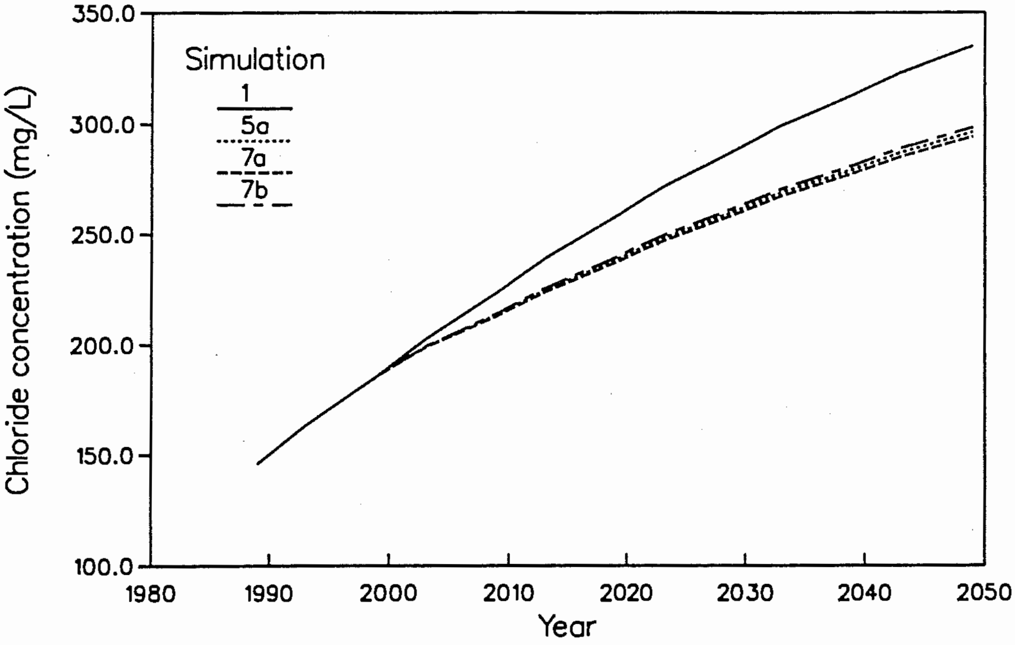


Figure A-39a.—Predicted average chloride concentration in the river zone for varying recharge water chloride concentration. Hydraulic barrier simulations at location nearest the river.

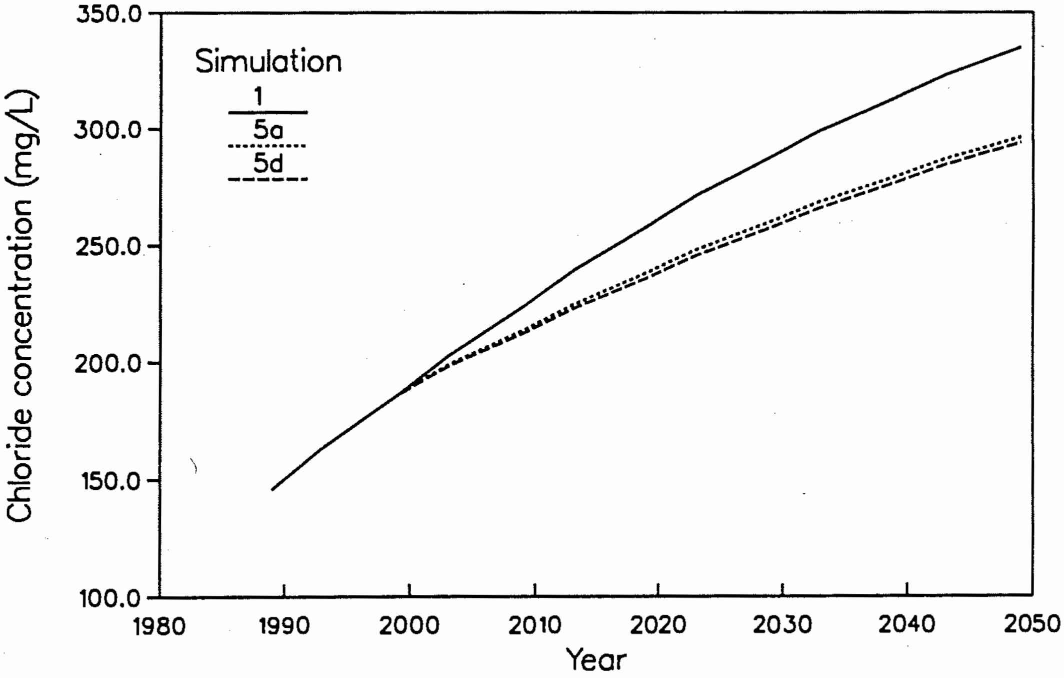


Figure A-39b.—Predicted average chloride concentration in the river zone for the two hydraulic barrier locations.

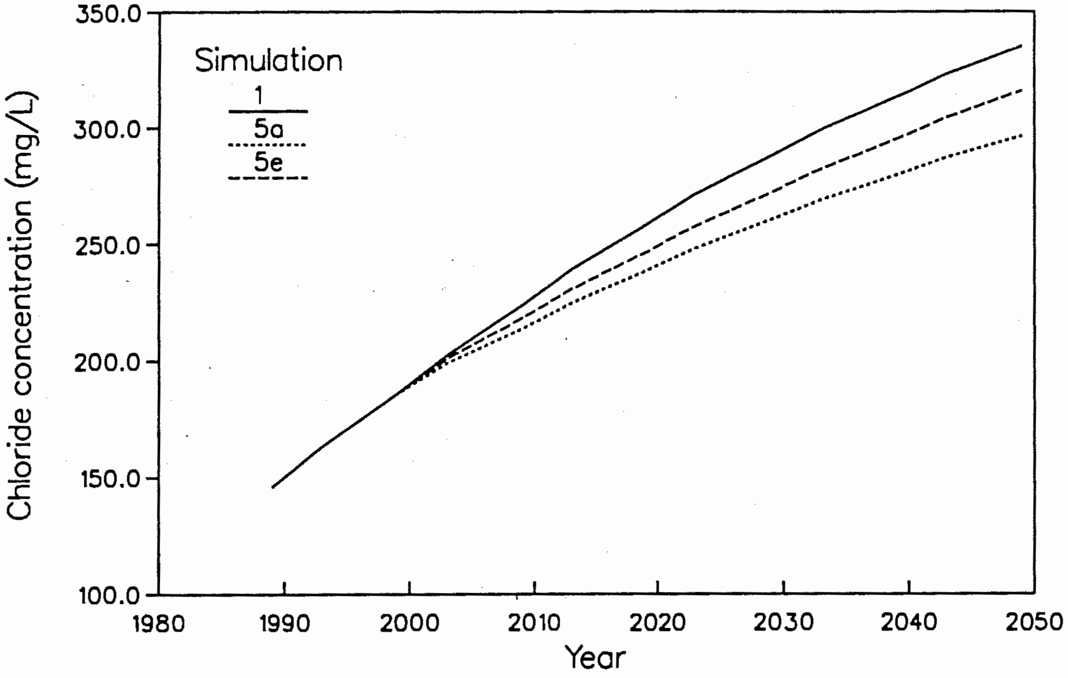


Figure A-40a.—Predicted average chloride concentration in the river zone. Comparison of hydraulic barrier and reduced pumping.

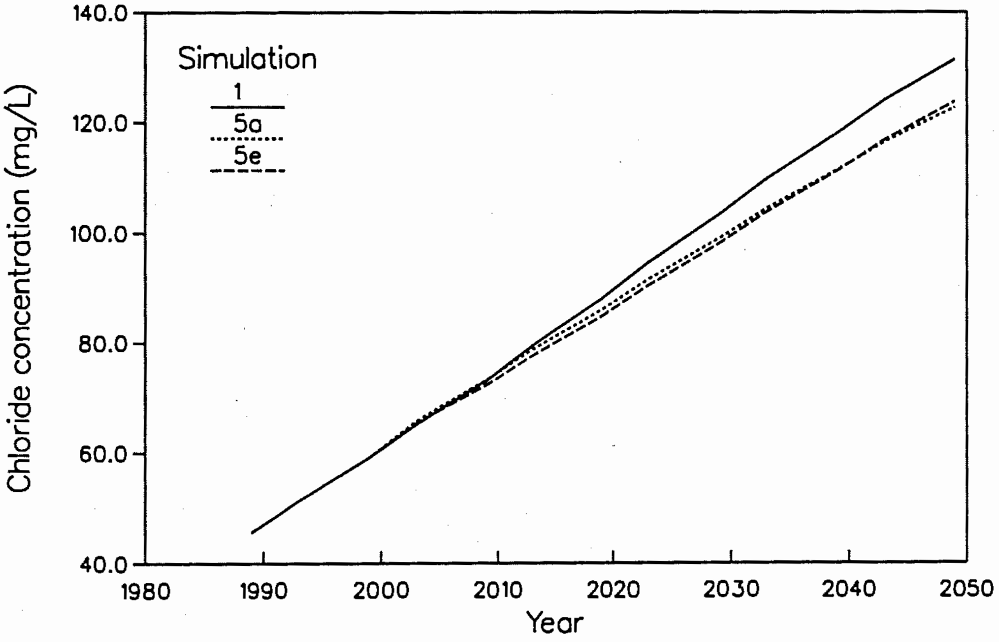


Figure A-40b.—Predicted average chloride concentration in the Wichita well field area. Comparison of hydraulic barrier and reduced pumping.

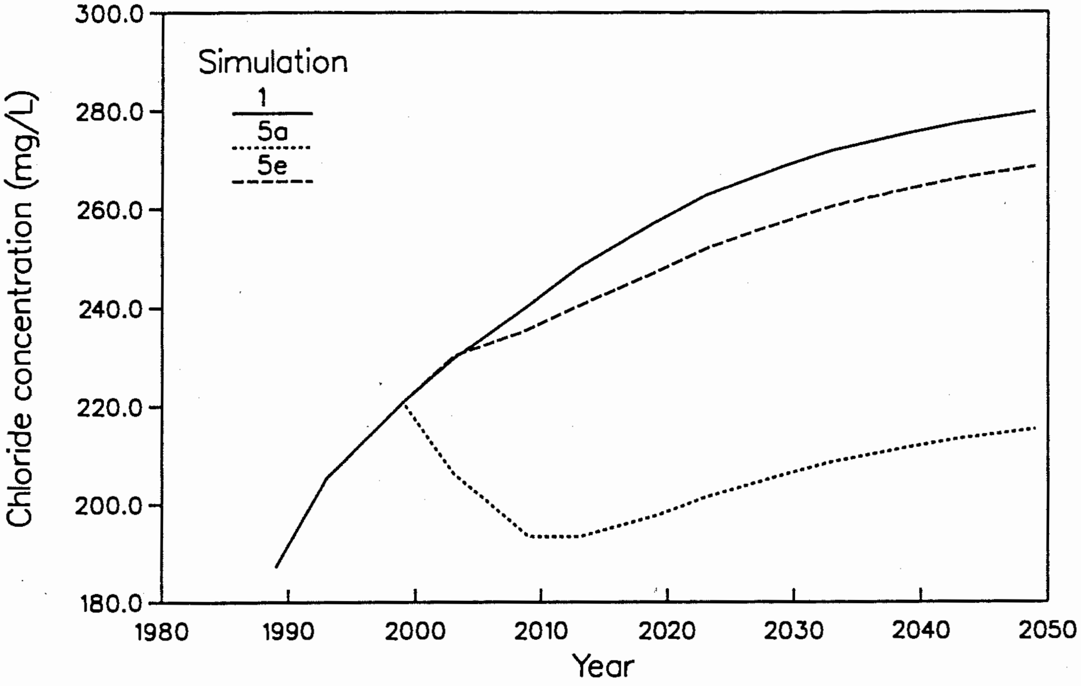


Figure A-41a.—Predicted average chloride concentration in the river zone for the upper model layer. Comparison of hydraulic barrier and reduced pumping.

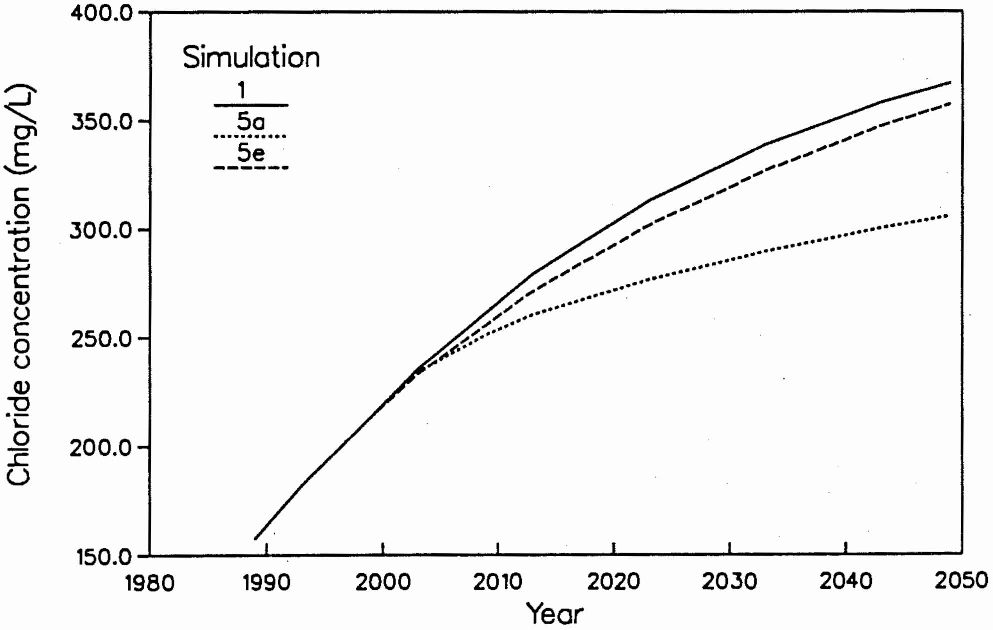


Figure A-41b.—Predicted average chloride concentration in the river zone for the middle model layer. Comparison of hydraulic barrier and reduced pumping.

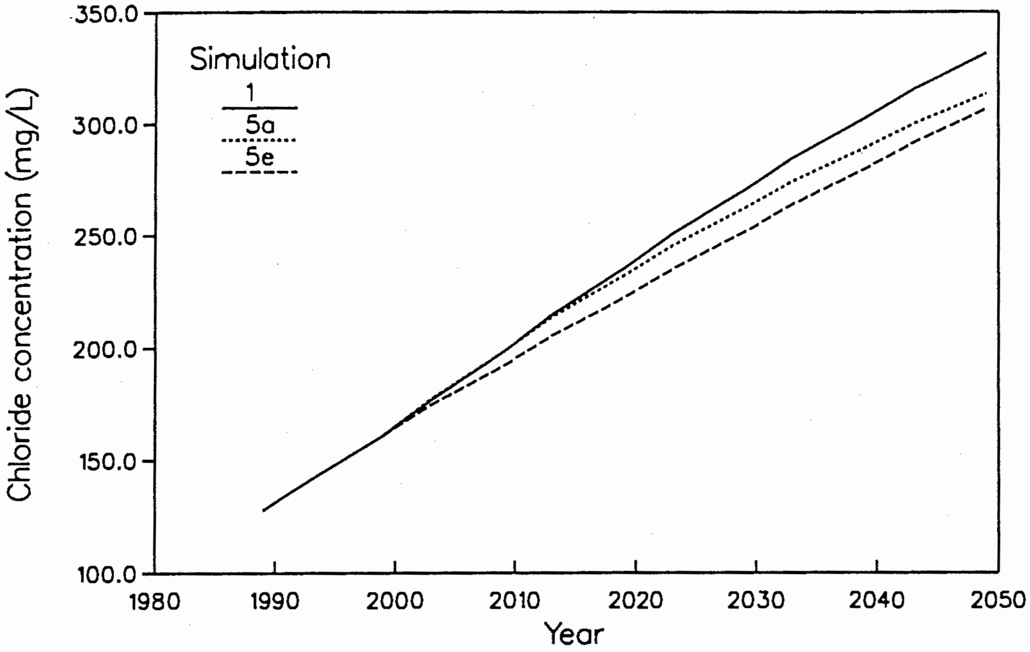


Figure A-41c.—Predicted average chloride concentration in the river zone for the lower model layer. Comparison of hydraulic barrier and reduced pumping.

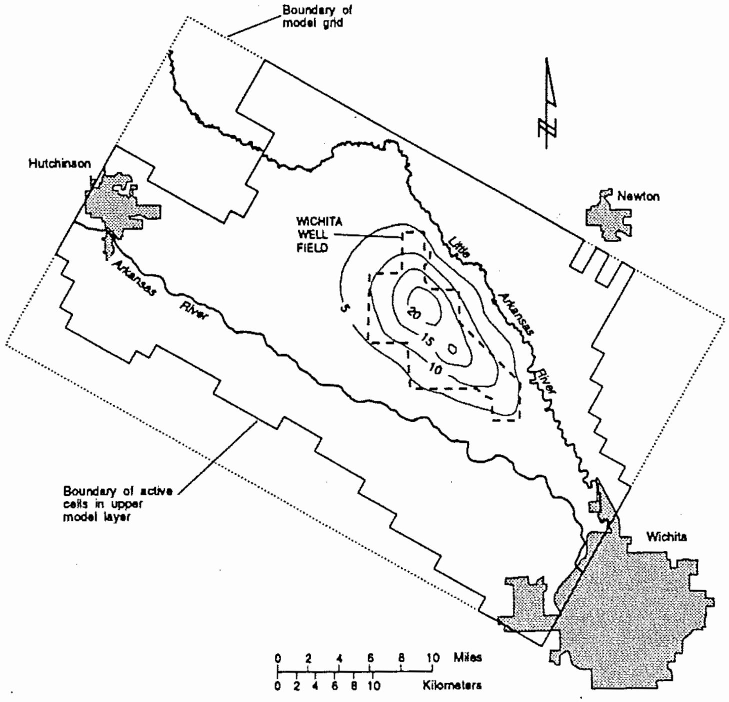


Figure A-42.—Predicted water table elevation difference from the base projection for reducing pumping by 22,400 acre-feet/year in the lower model layer.

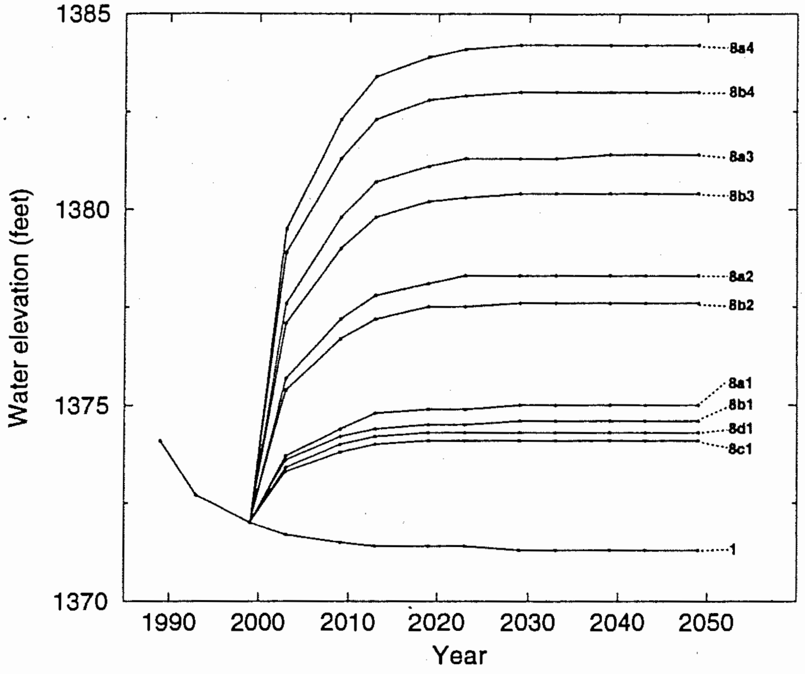


Figure A-43.—Predicted average water table elevation in the Wichita well field zone for reduction in pumpage simulations.

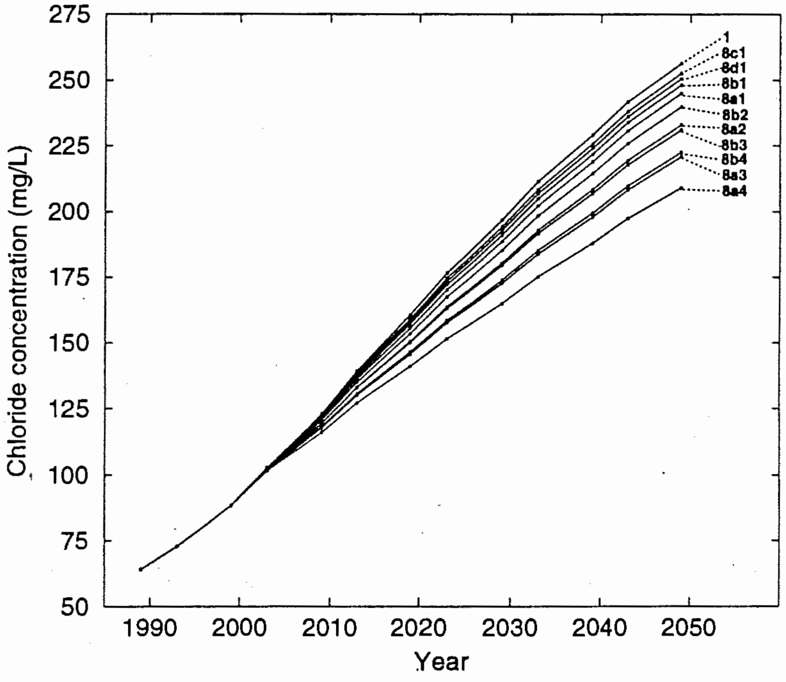


Figure A-44a.—Predicted average chloride concentration in the brine zone for reduction in pumpage simulations.

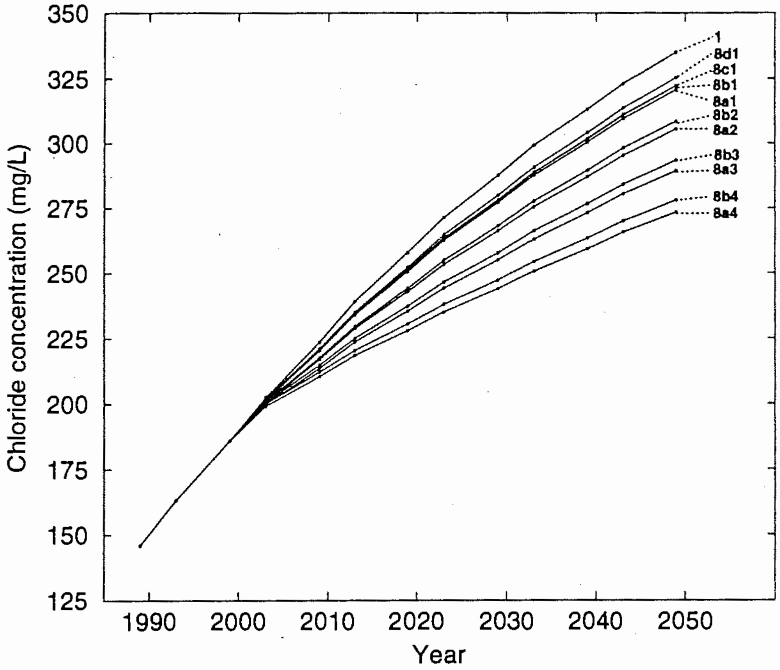
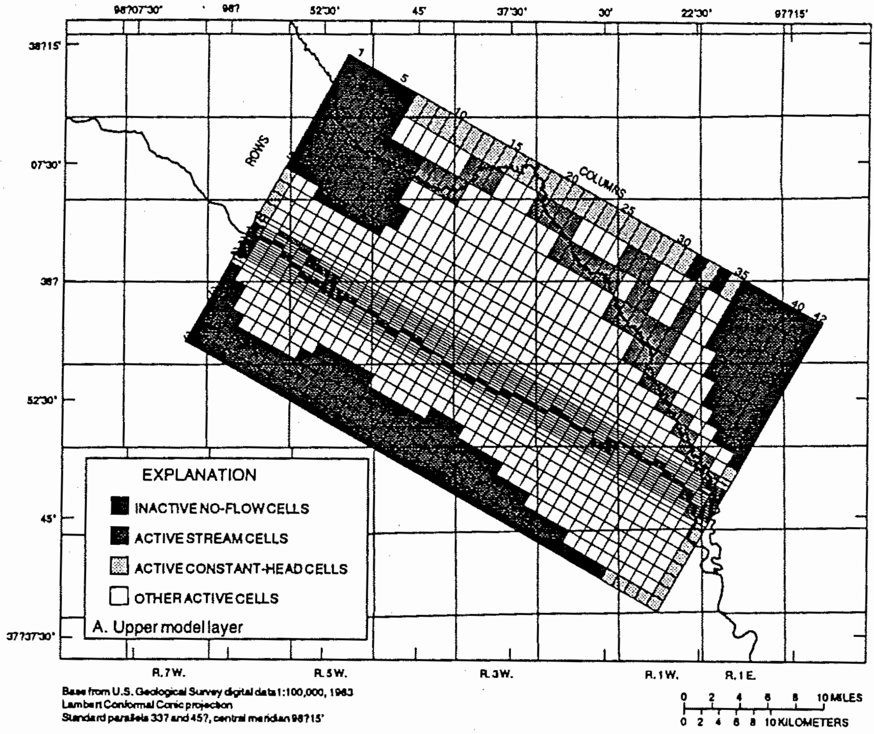


Figure A-44b.—Predicted average chloride concentration in the river zone for reduction in pumpage simulations.

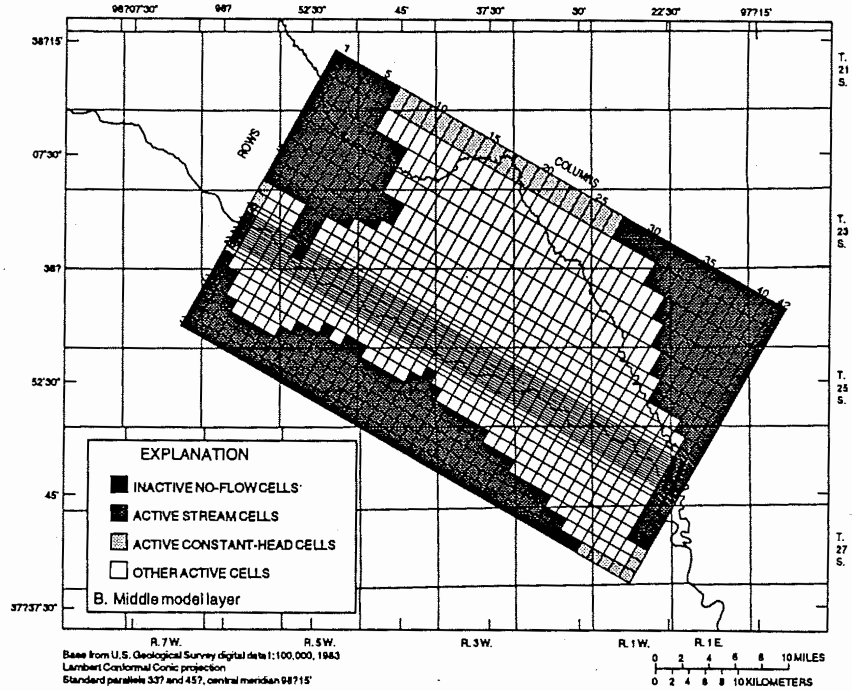
APPENDIX B

Maps Displaying Model Geometry, Boundary Conditions, Properties, and Stresses of USGS Flow Modeling (from Myers et al., in review)



Base from U.S. Geological Survey digital data 1:100,000, 1983
Lambert Conformal Conic projection
Standard parallels 33° and 45°, central meridian 98°15'

Figure B-1a.—Model grid and boundary conditions for the upper model layer of the USGS flow model (Myers et al., in review).



Base from U.S. Geological Survey digital data 1:100,000, 1983
Lambert Conformal Conic projection
Standard parallels 33° and 45°, central meridian 98°15'

Figure B-1b.—Model grid and boundary conditions for the middle model layer of the USGS flow model (Myers et al., in review).

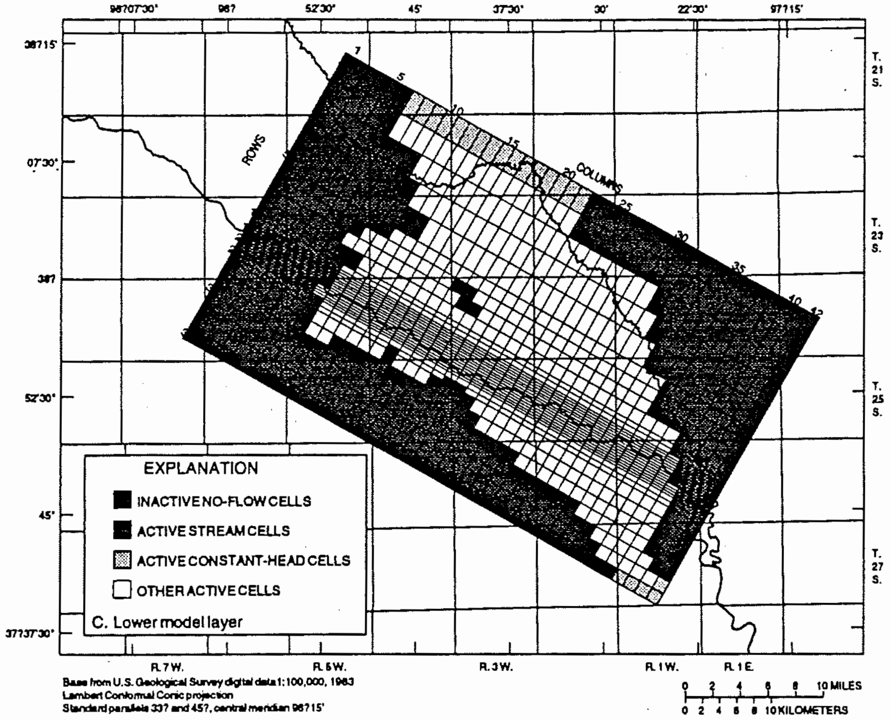


Figure B-1c.—Model grid and boundary conditions for the lower model layer of the USGS flow model (Myers et al., in review).

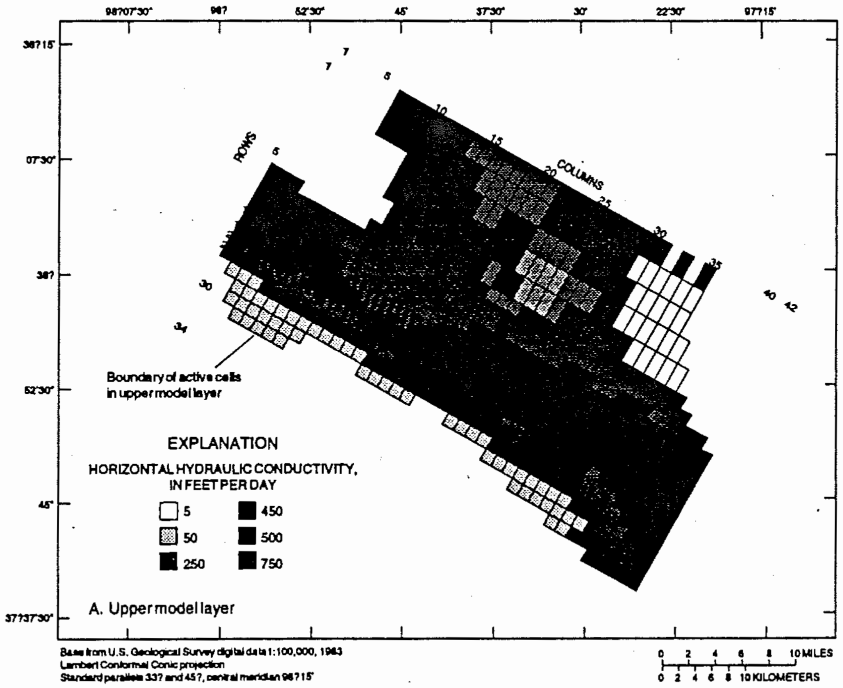
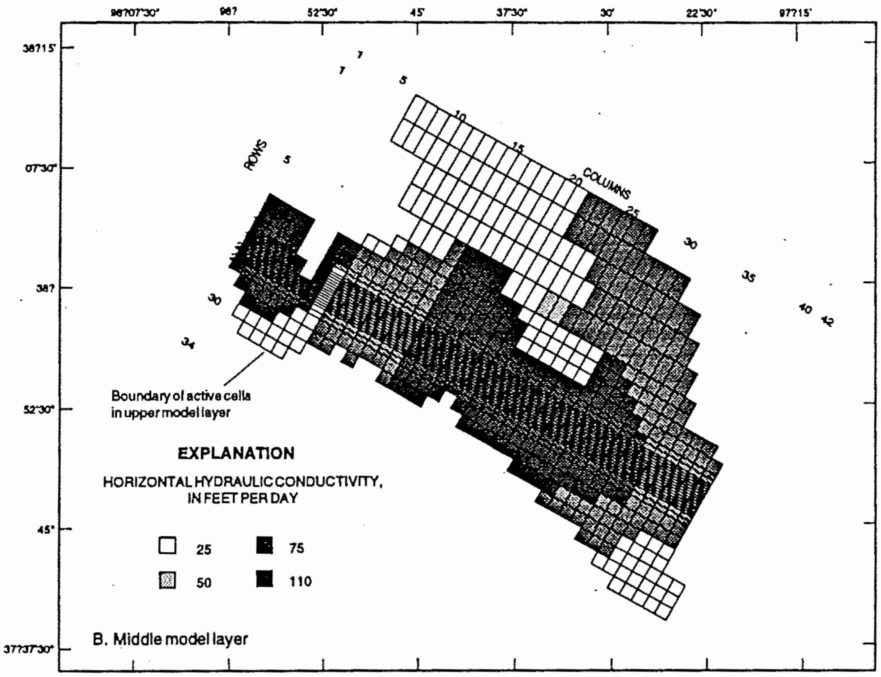
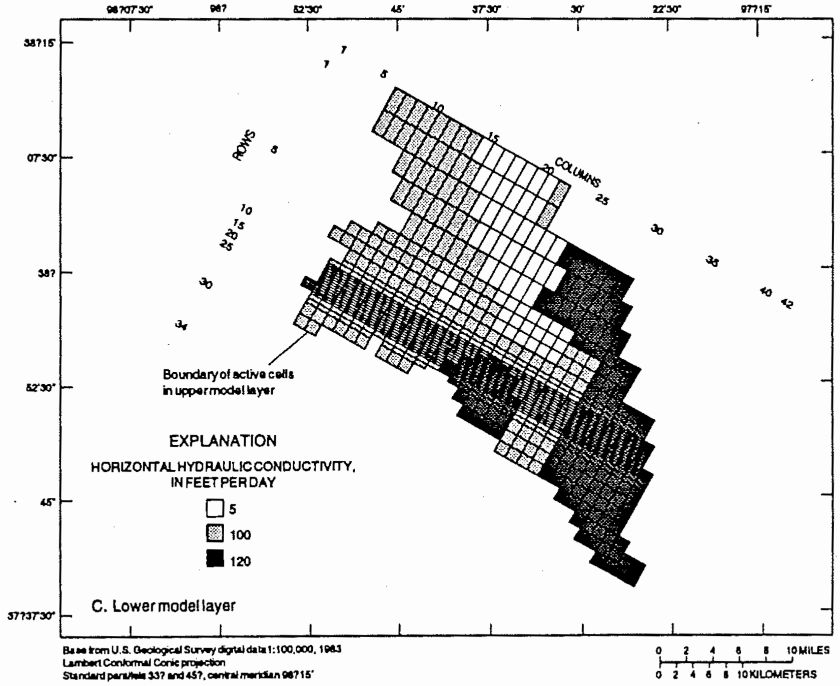


Figure B-2a.—Distribution of horizontal hydraulic conductivity in the upper model layer of the USGS flow model (Myers et al., in review).



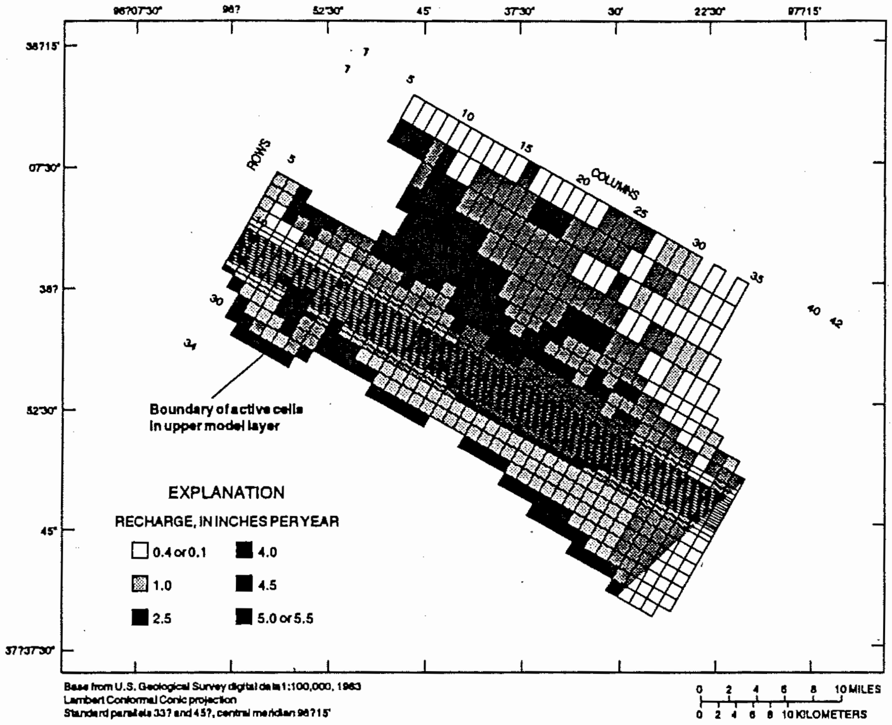
Base from U.S. Geological Survey digital data 1:100,000, 1983
Lambert Conformal Conic projection
Standard parallels 33° and 45°, central meridian 96°15'

Figure B-2b.—Distribution of horizontal hydraulic conductivity in the middle model layer of the USGS flow model (Myers et al., in review).



Base from U.S. Geological Survey digital data 1:100,000, 1983
Lambert Conformal Conic projection
Standard parallels 33° and 45°, central meridian 96°15'

Figure B-2c.—Distribution of horizontal hydraulic conductivity in the lower model layer of the USGS flow model (Myers et al., in review).

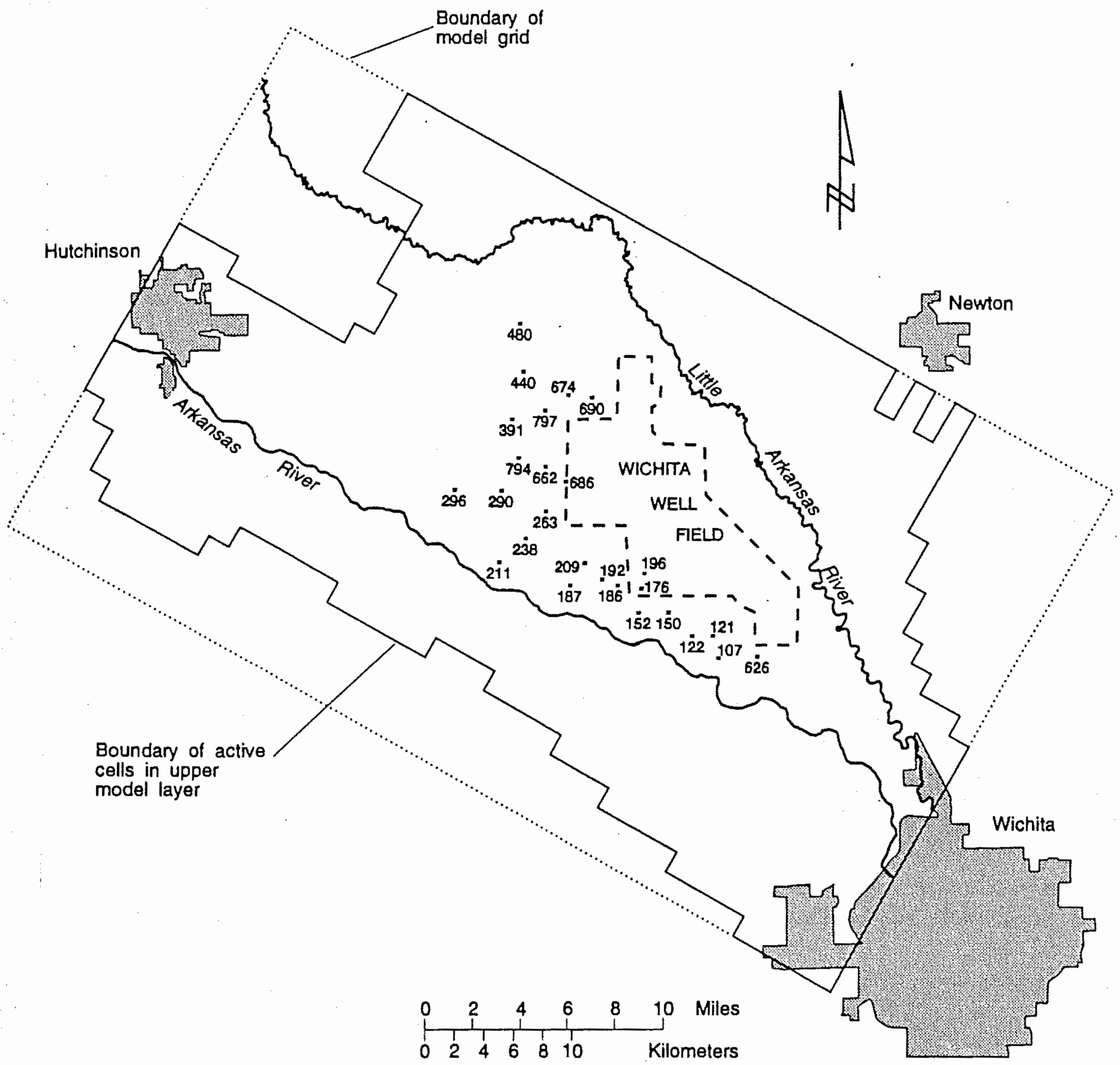


Base from U.S. Geological Survey digital data 1:100,000, 1983
Lambert Conformal Conic projection
Standard parallels 33? and 45?, central meridian 98?15'

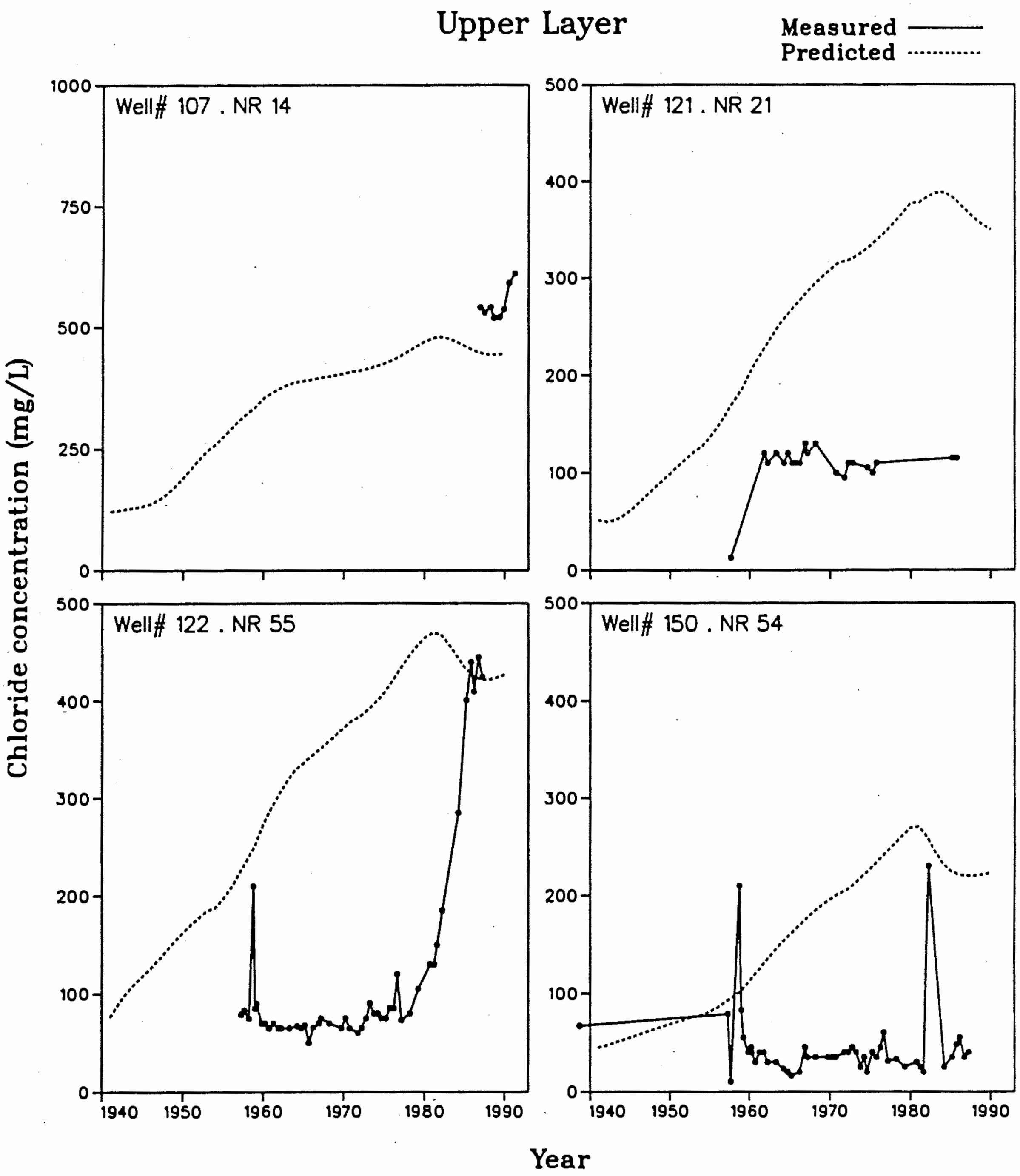
Figure B-3.—Ground-water recharge rates of the USGS steady-state flow model (Myers et al., in review).

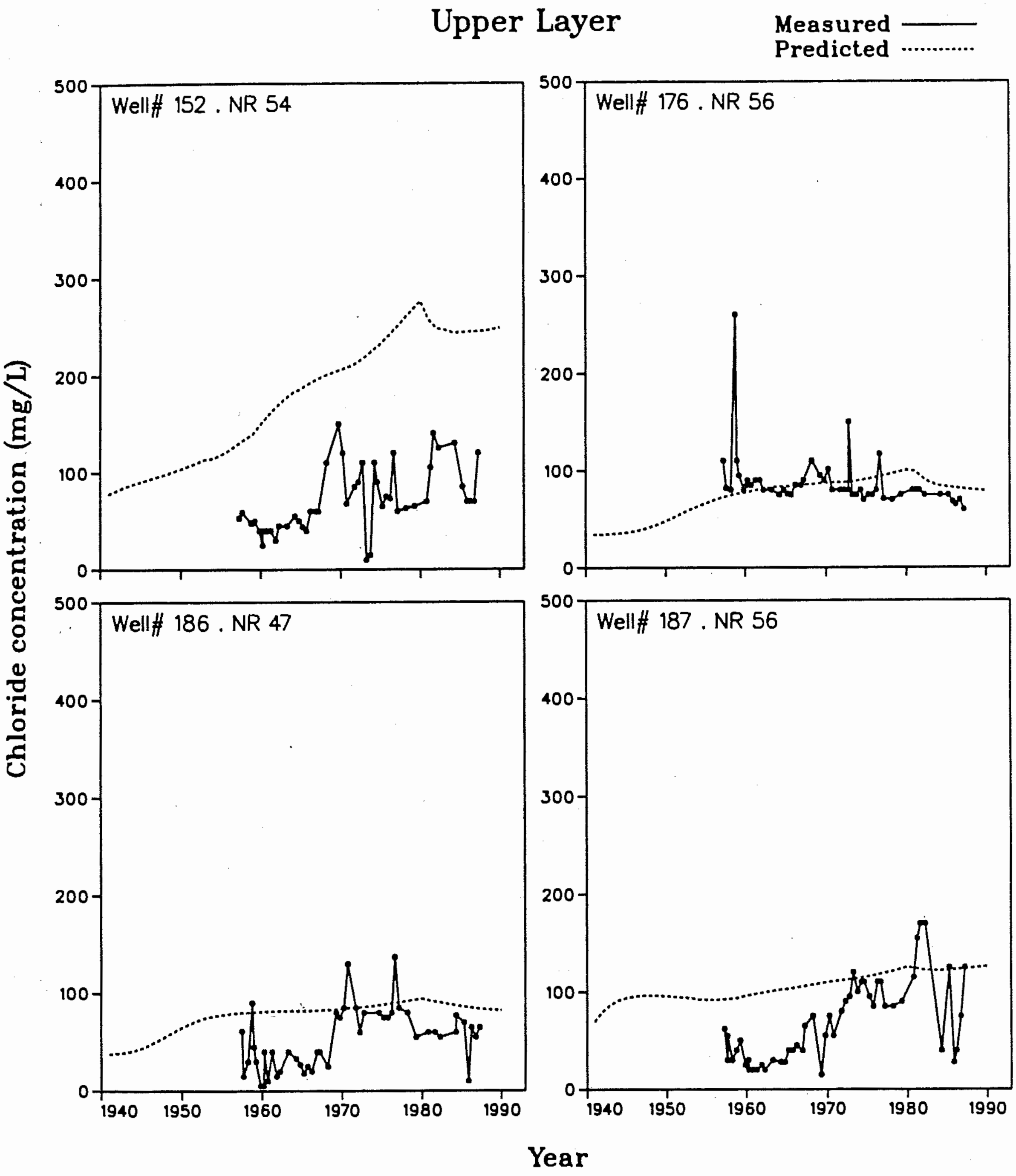
APPENDIX C

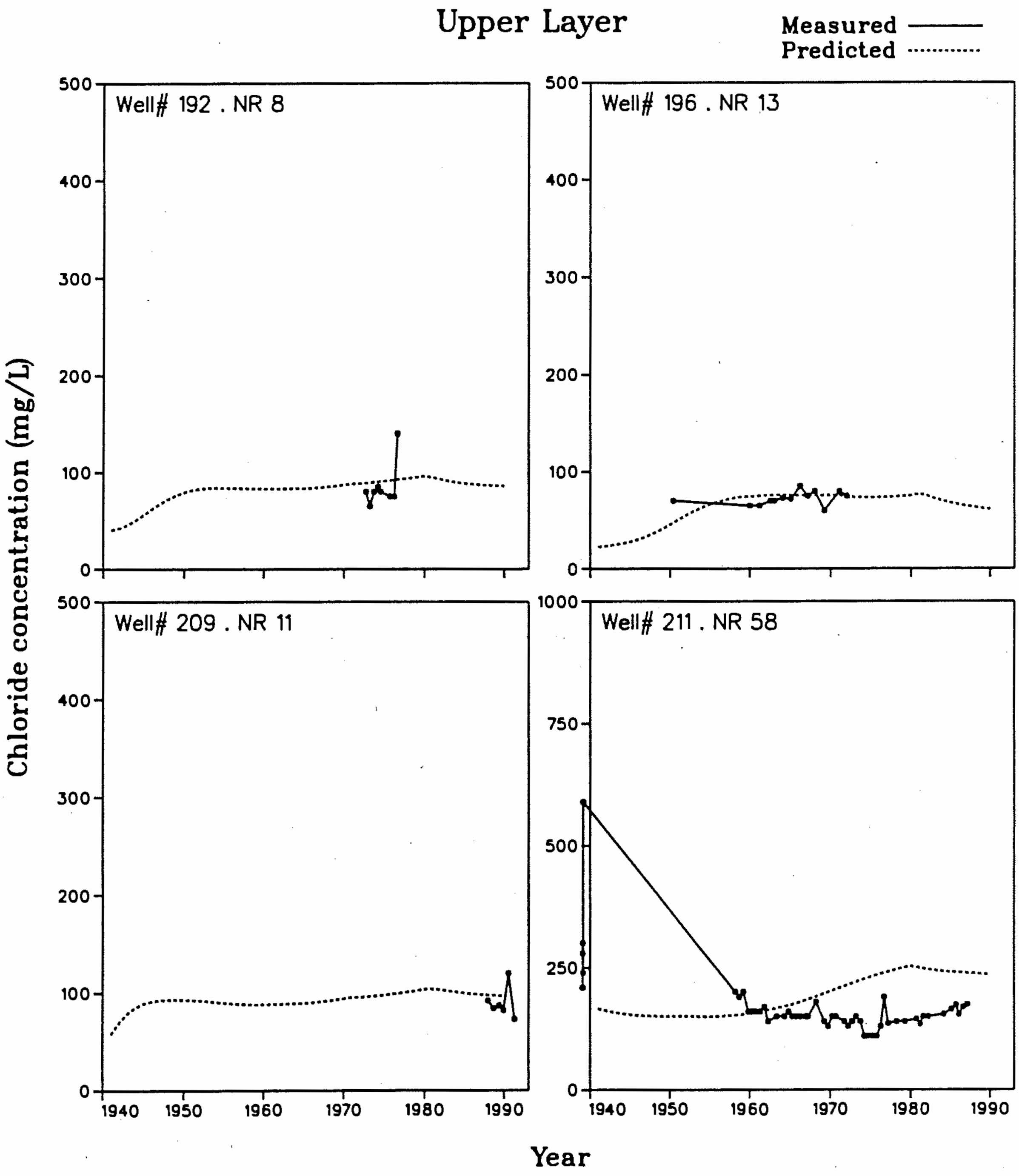
Graphs of Measured and Predicted Chloride Concentration Used in the Model Calibration

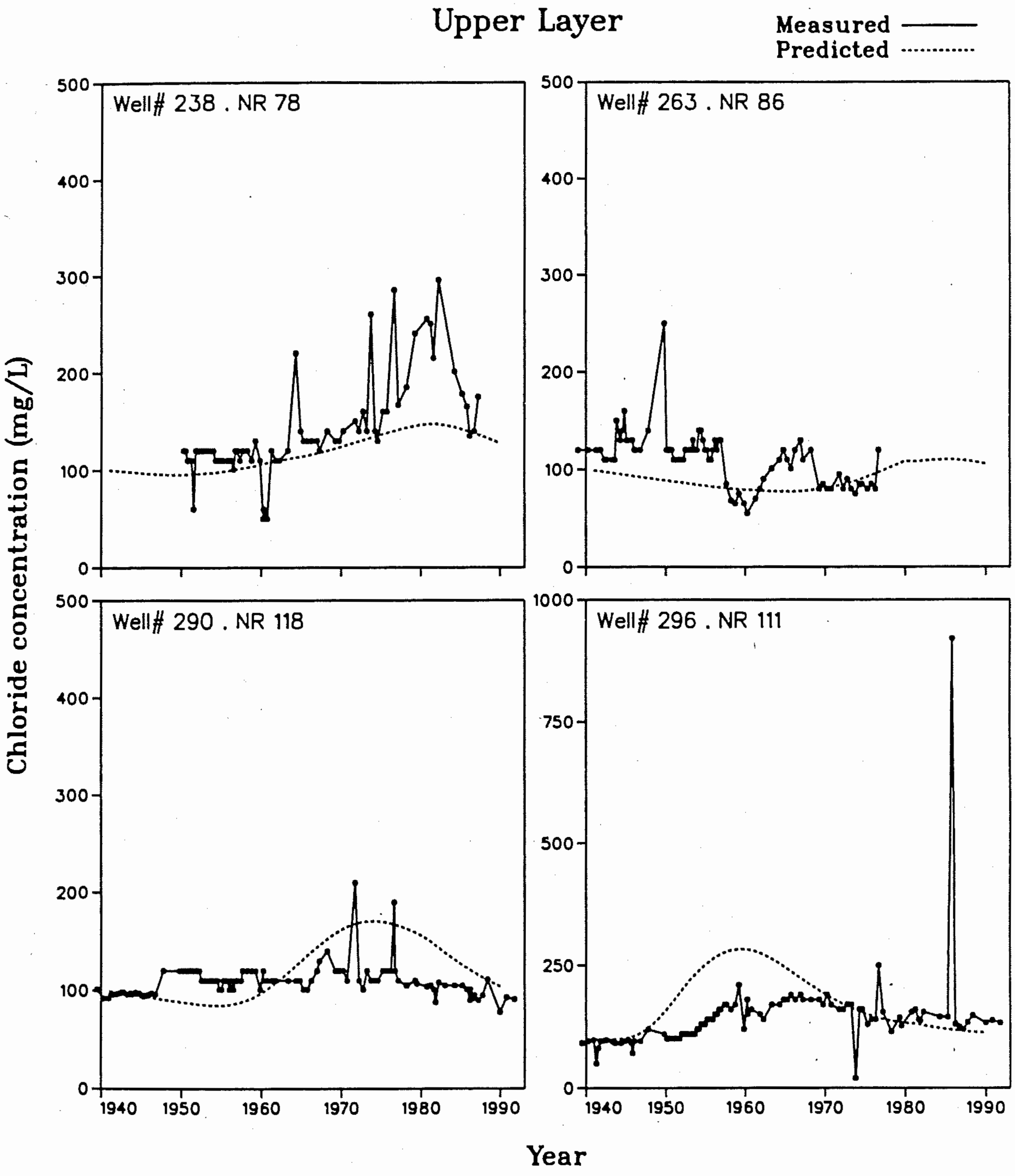


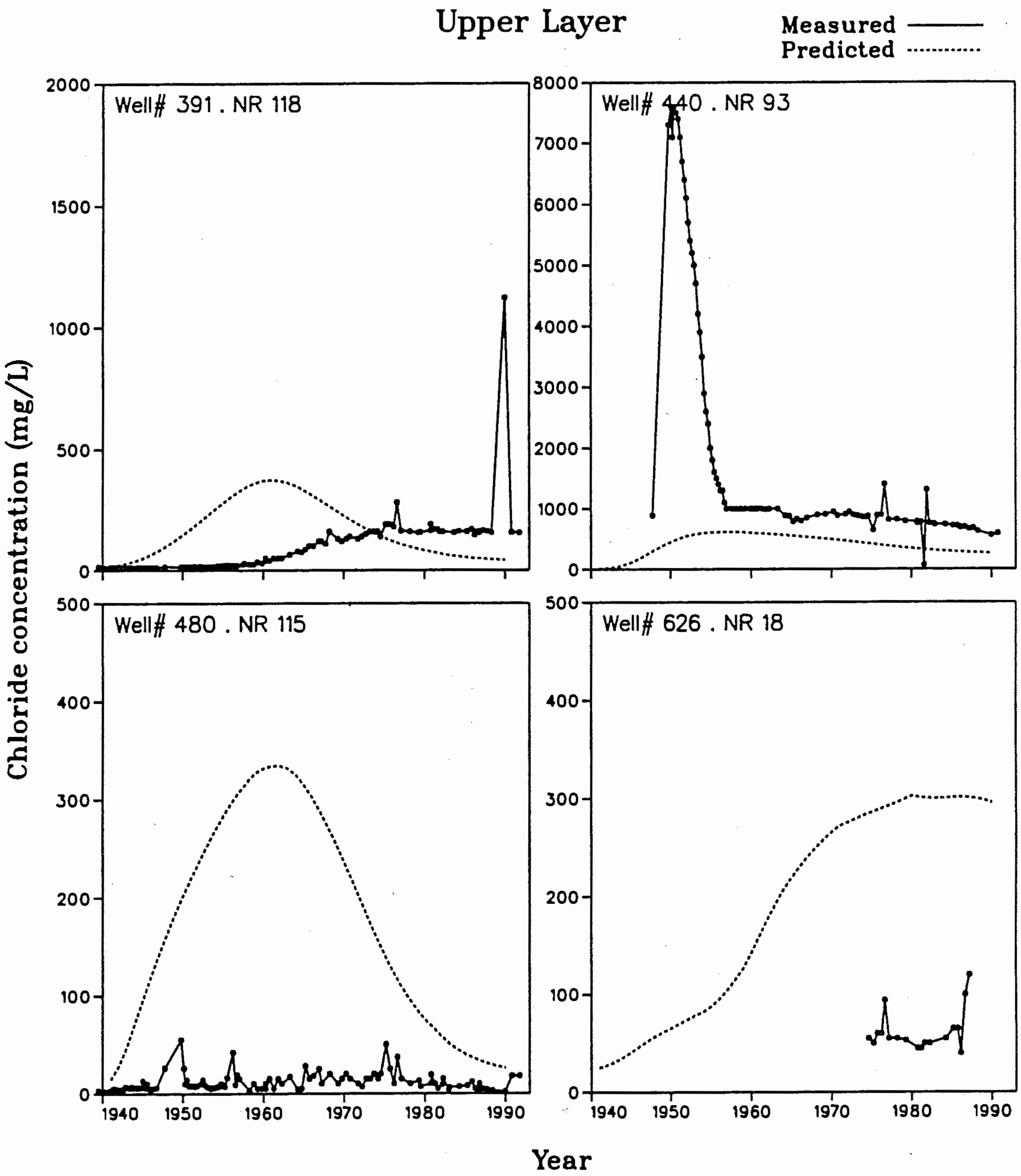
Locations having well data used in the model calibrations for the upper model layer. Graphs of measured and predicted chloride concentration for each well, referenced by number, follow.

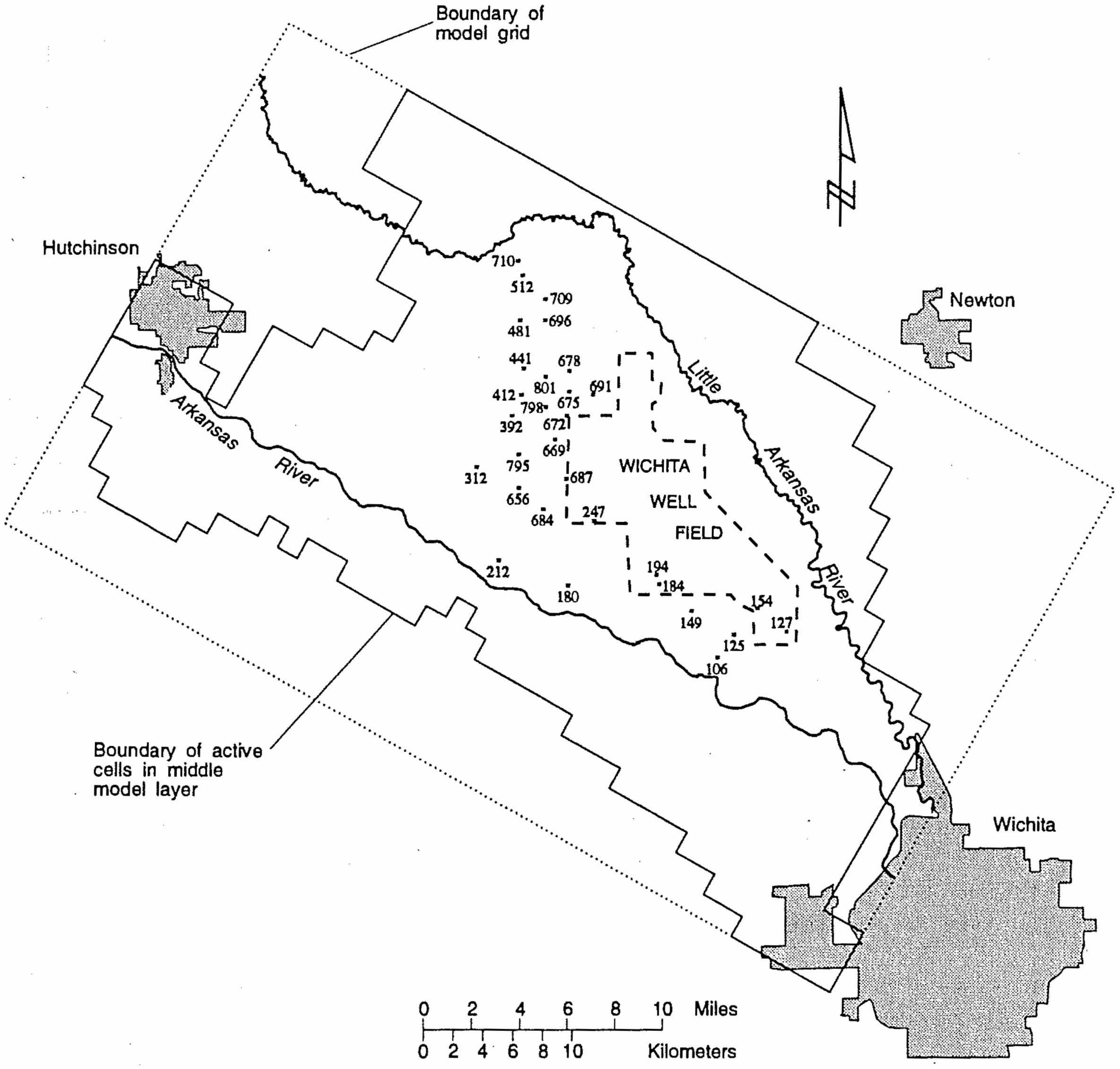

Upper Layer
Measured
Predicted
Chloride concentration (mg/L)
Year
Well# 107 . NR 14
1000
750
500
250
0
Well# 121 . NR 21
500
400
300
200
100
0
Well# 122 . NR 55
500
400
300
200
100
0
Well# 150 . NR 54
500
400
300
200
100
0
1940
1950
1960
1970
1980
1990


Upper Layer
Measured
Predicted
Well# 152 . NR 54
Well# 176 . NR 56
Well# 186 . NR 47
Well# 187 . NR 56
Chloride concentration (mg/L)
0
100
200
300
400
500
1940
1950
1960
1970
1980
1990
Year

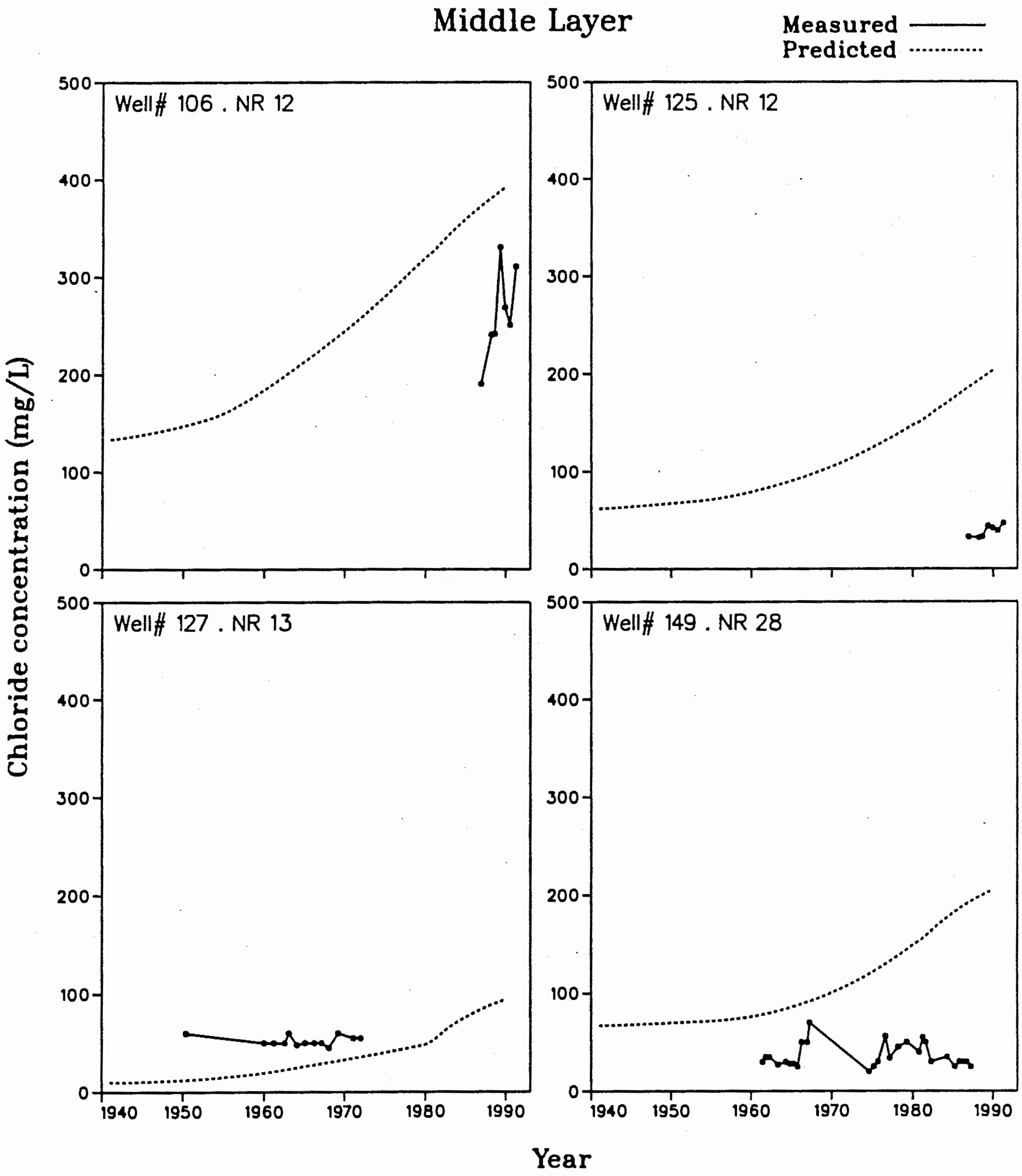

Upper Layer
Measured
Predicted
Well# 192 . NR 8
Well# 196 . NR 13
Well# 209 . NR 11
Well# 211 . NR 58
Chloride concentration (mg/L)
0
100
200
300
400
500
250
750
1000
1940
1950
1960
1970
1980
1990
Year

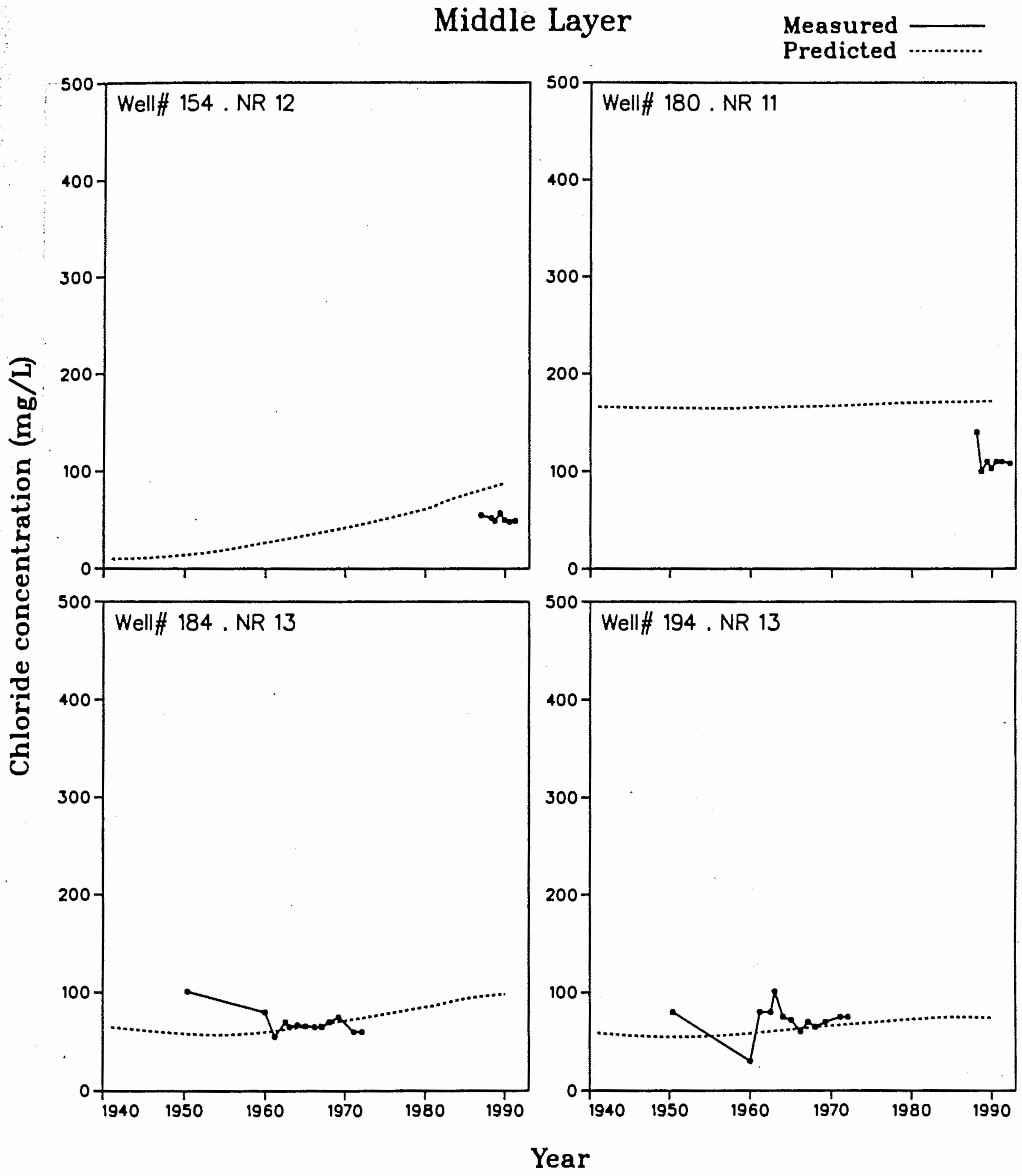

Upper Layer
Measured
Predicted
Well# 238 . NR 78
Well# 263 . NR 86
Well# 290 . NR 118
Well# 296 . NR 111
Chloride concentration (mg/L)
0
100
200
300
400
500
250
750
1000
1940
1950
1960
1970
1980
1990
Year

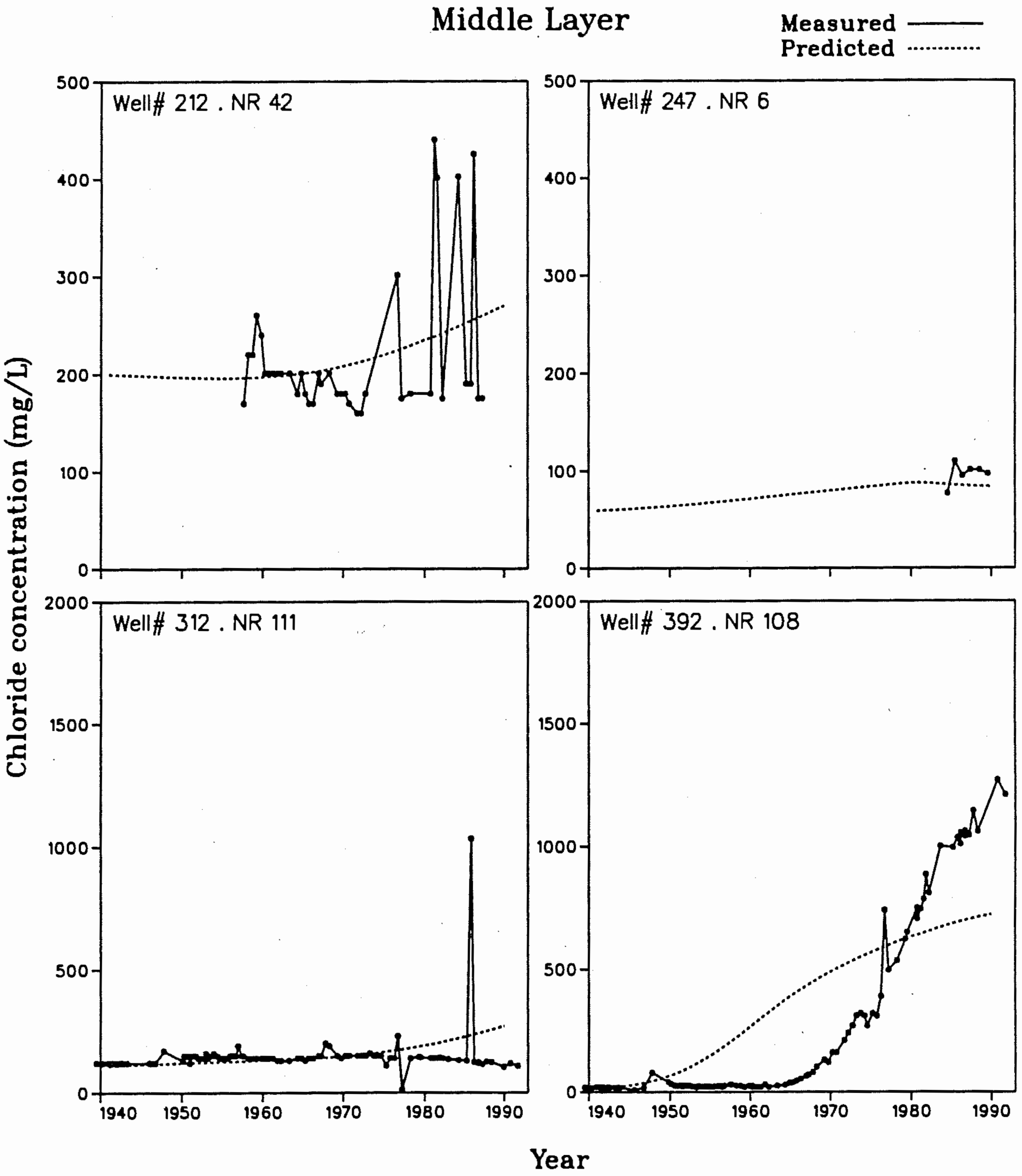

Upper Layer
Measured
Predicted
Well# 391 . NR 118
Well# 440 . NR 93
Well# 480 . NR 115
Well# 626 . NR 18
Chloride concentration (mg/L)
0
500
1000
1500
2000
0
1000
2000
3000
4000
5000
6000
7000
8000
0
100
200
300
400
500
1940
1950
1960
1970
1980
1990
Year

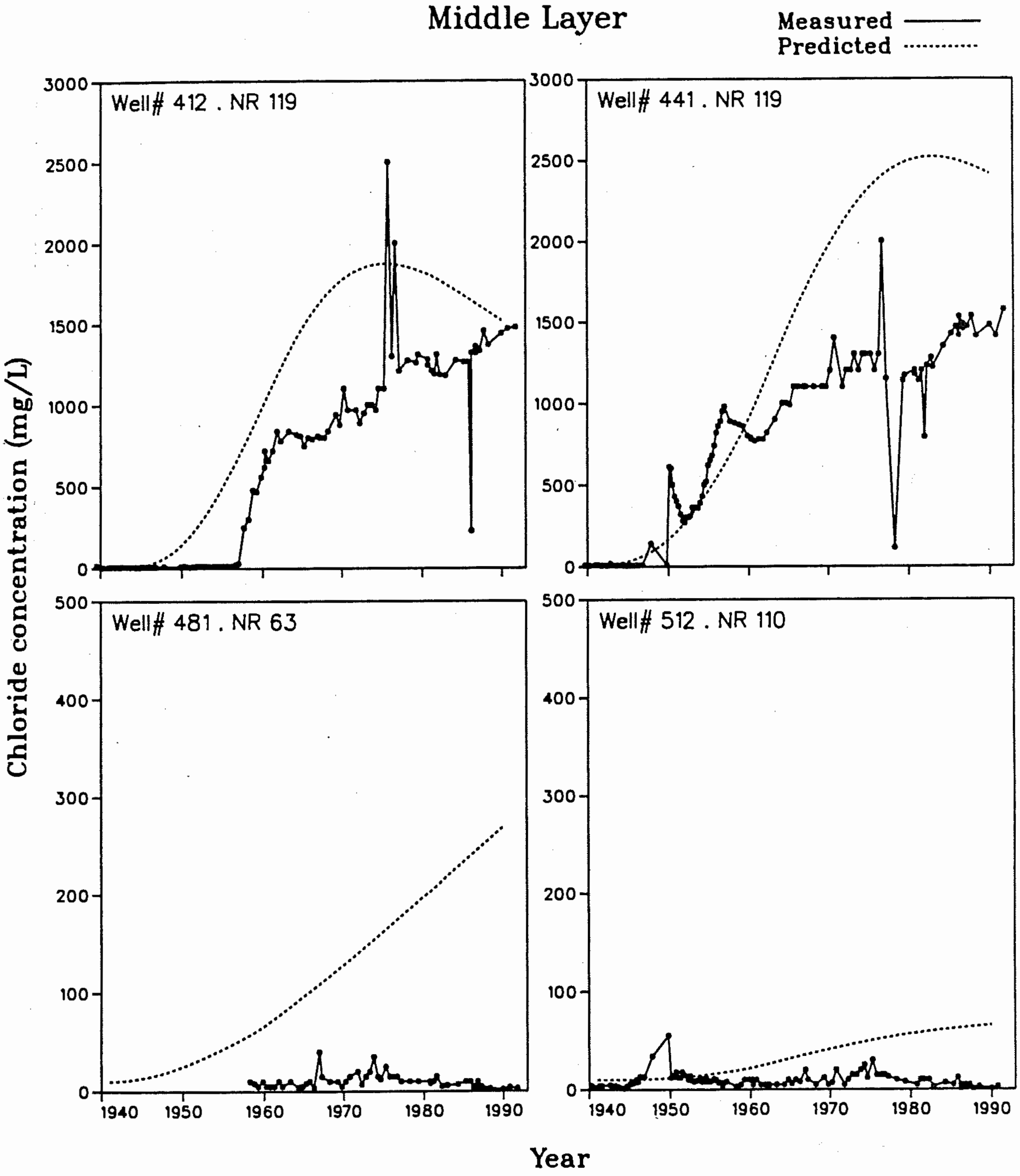


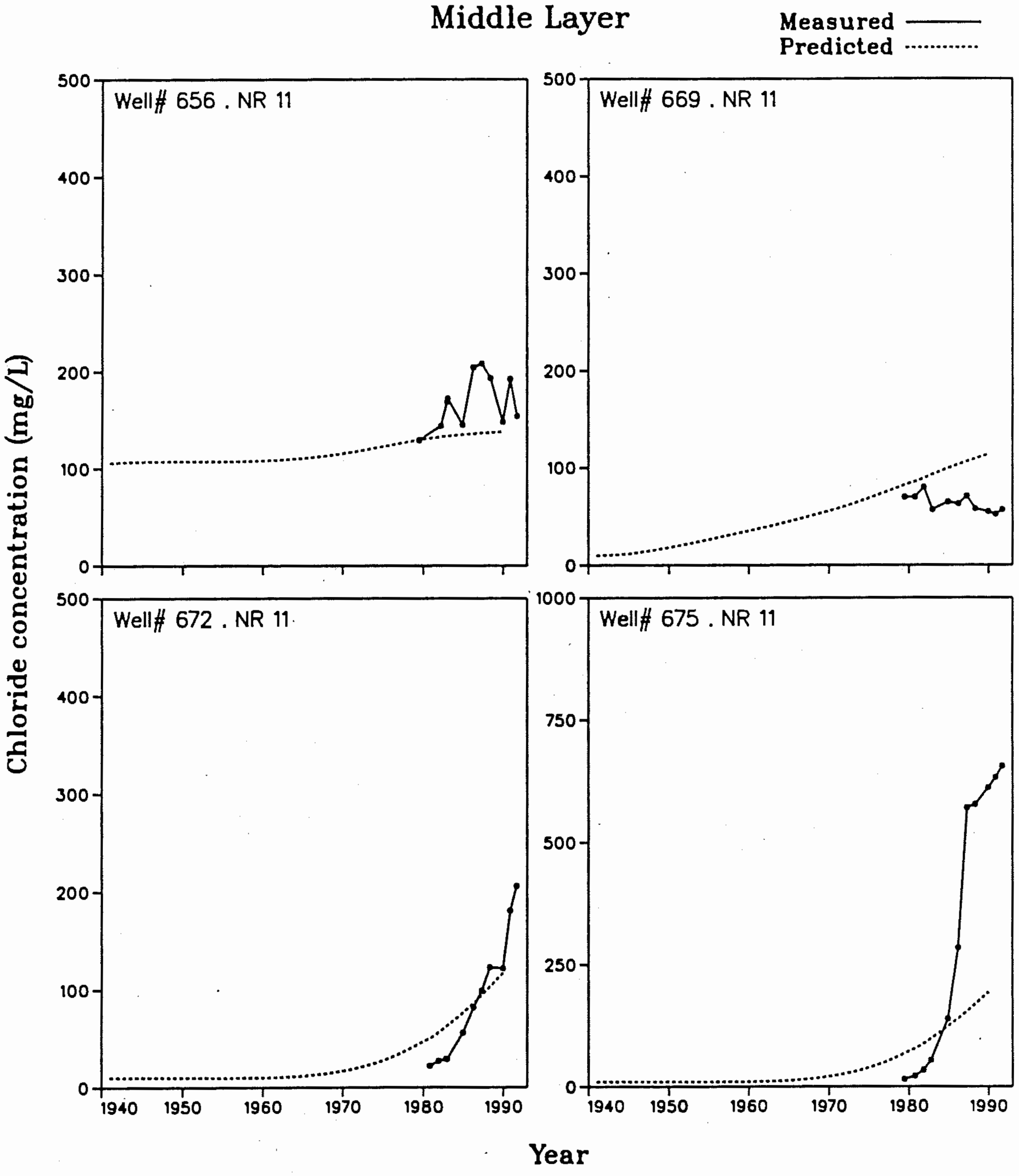
Locations having well data used in the model calibrations for the middle model layer. Graphs of measured and predicted chloride concentration for each well, referenced by number, follow.

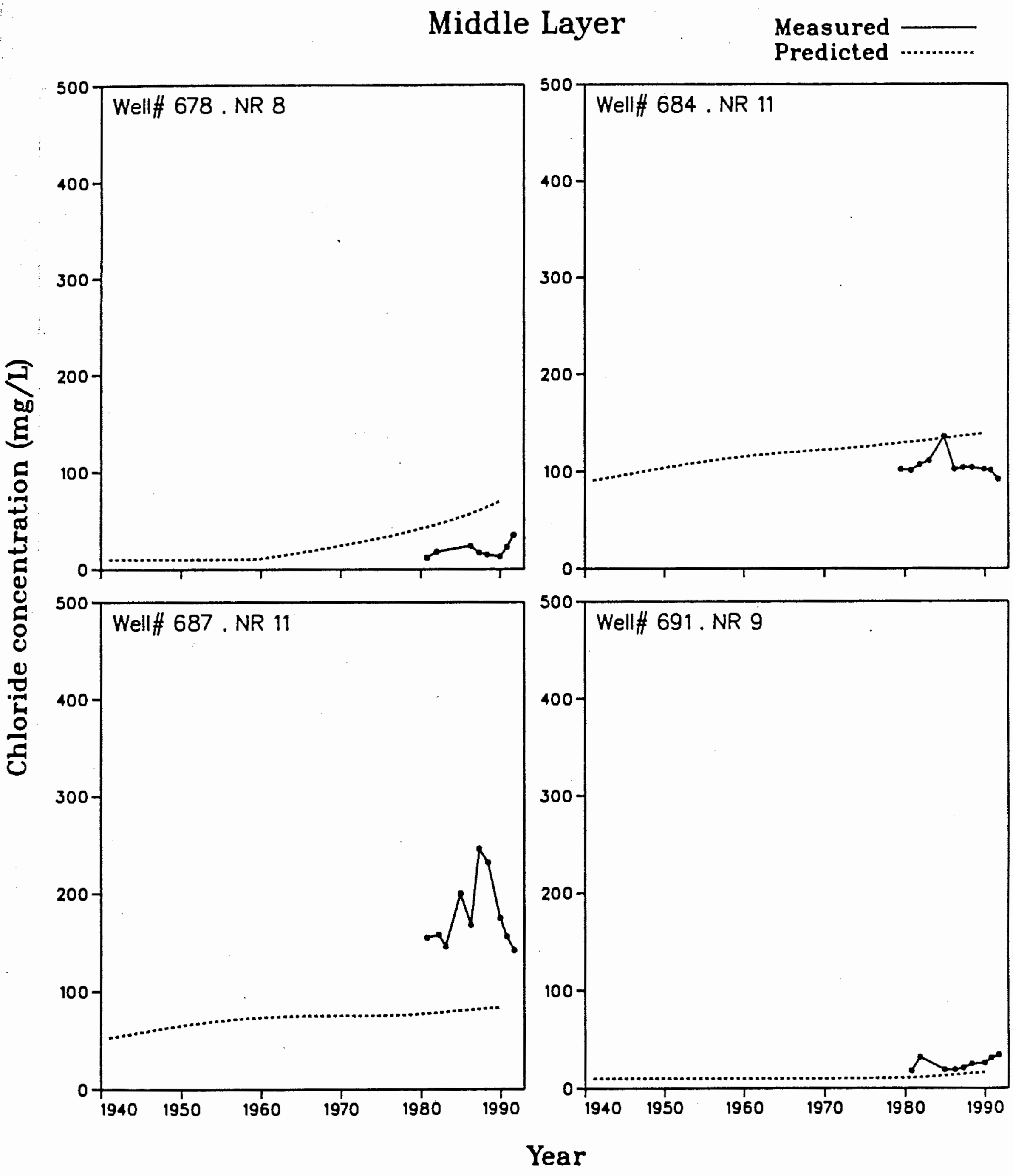

Middle Layer
Measured
Predicted
Chloride concentration (mg/L)
Year
Well# 106 . NR 12
Well# 125 . NR 12
Well# 127 . NR 13
Well# 149 . NR 28
0
100
200
300
400
500
1940
1950
1960
1970
1980
1990

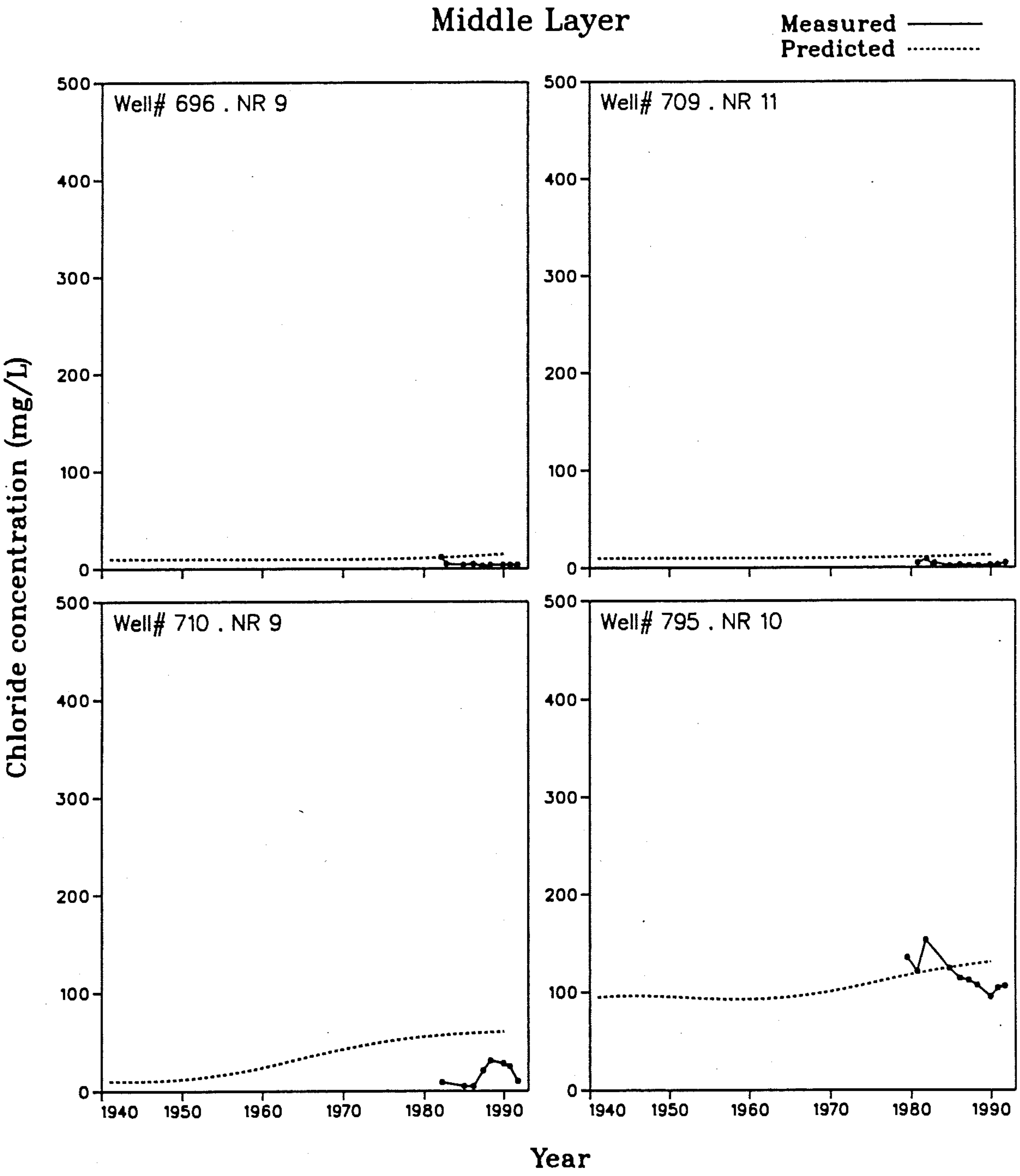

Middle Layer
Measured
Predicted
Well# 154 . NR 12
Well# 180 . NR 11
Well# 184 . NR 13
Well# 194 . NR 13
Chloride concentration (mg/L)
0
100
200
300
400
500
1940
1950
1960
1970
1980
1990
Year

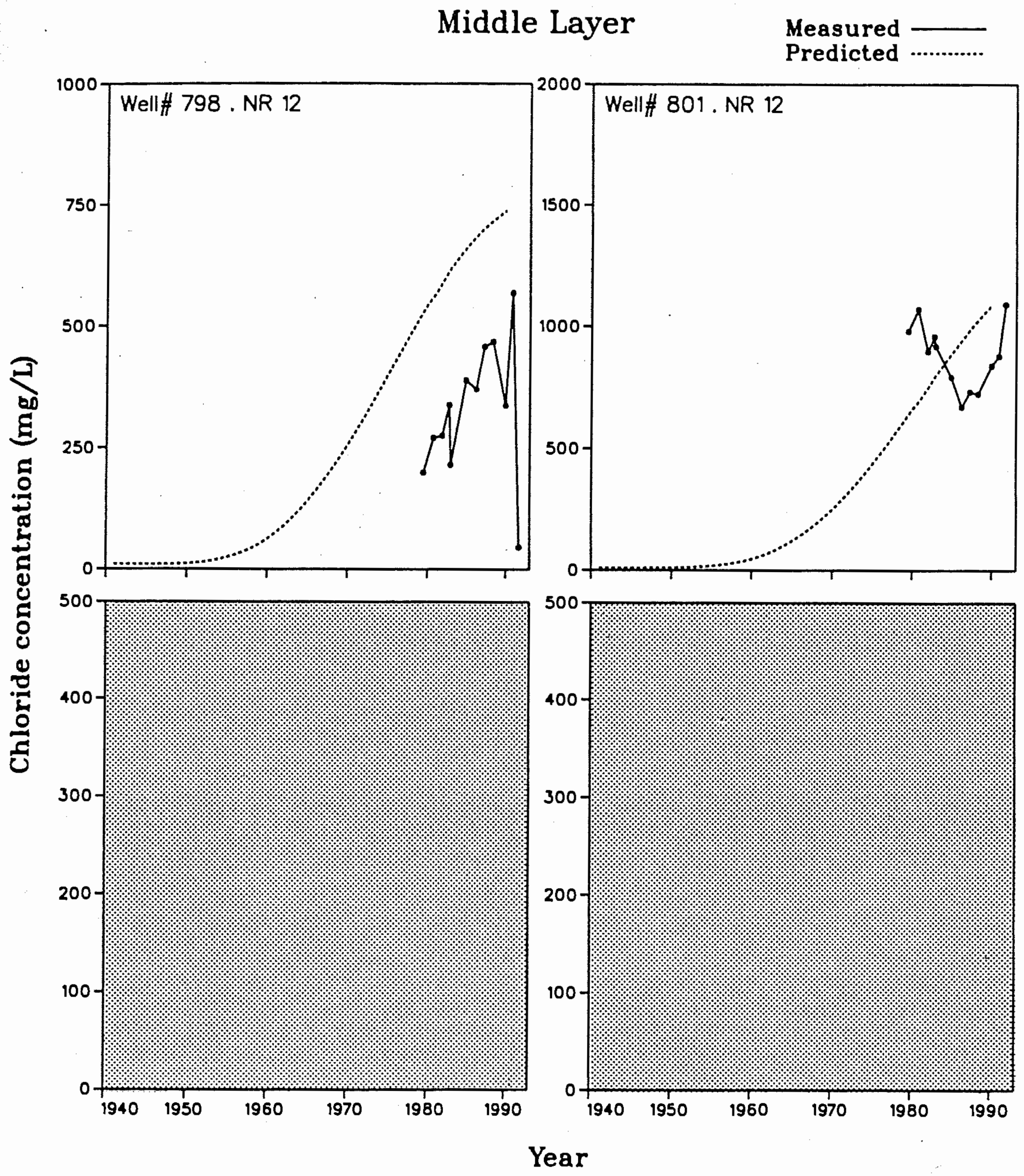

Middle Layer
Measured
Predicted
Chloride concentration (mg/L)
Year
Well# 212 . NR 42
Well# 247 . NR 6
Well# 312 . NR 111
Well# 392 . NR 108
500
400
300
200
100
0
2000
1500
1000
500
1940
1950
1960
1970
1980
1990

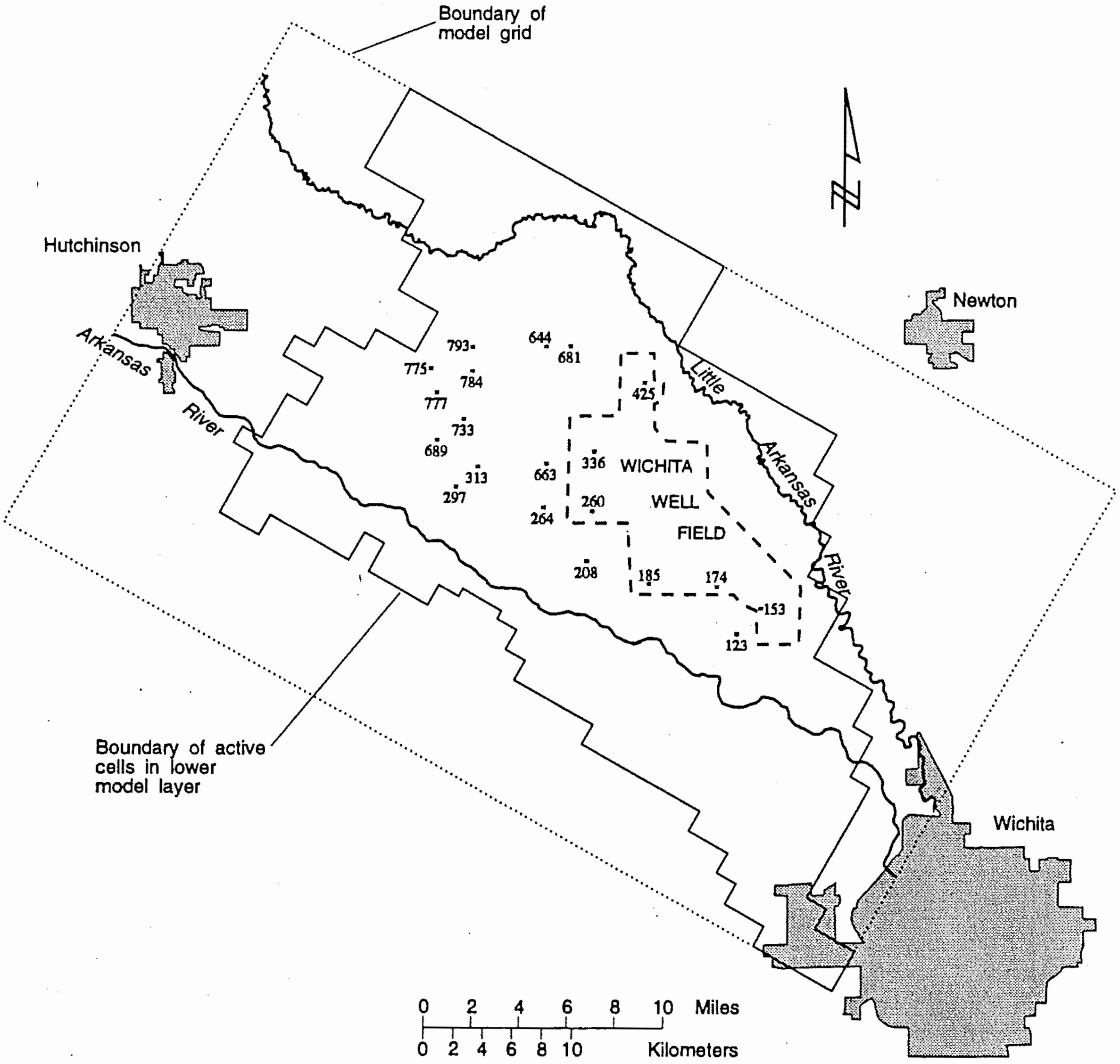

Middle Layer
Measured
Predicted
Well# 412 . NR 119
Well# 441 . NR 119
Well# 481 . NR 63
Well# 512 . NR 110
Chloride concentration (mg/L)
0
500
1000
1500
2000
2500
3000
100
200
300
400
1940
1950
1960
1970
1980
1990
Year


Middle Layer
Measured
Predicted
Chloride concentration (mg/L)
Well# 656 . NR 11
Well# 669 . NR 11
Well# 672 . NR 11
Well# 675 . NR 11
0
100
200
300
400
500
250
750
1000
1940
1950
1960
1970
1980
1990
Year

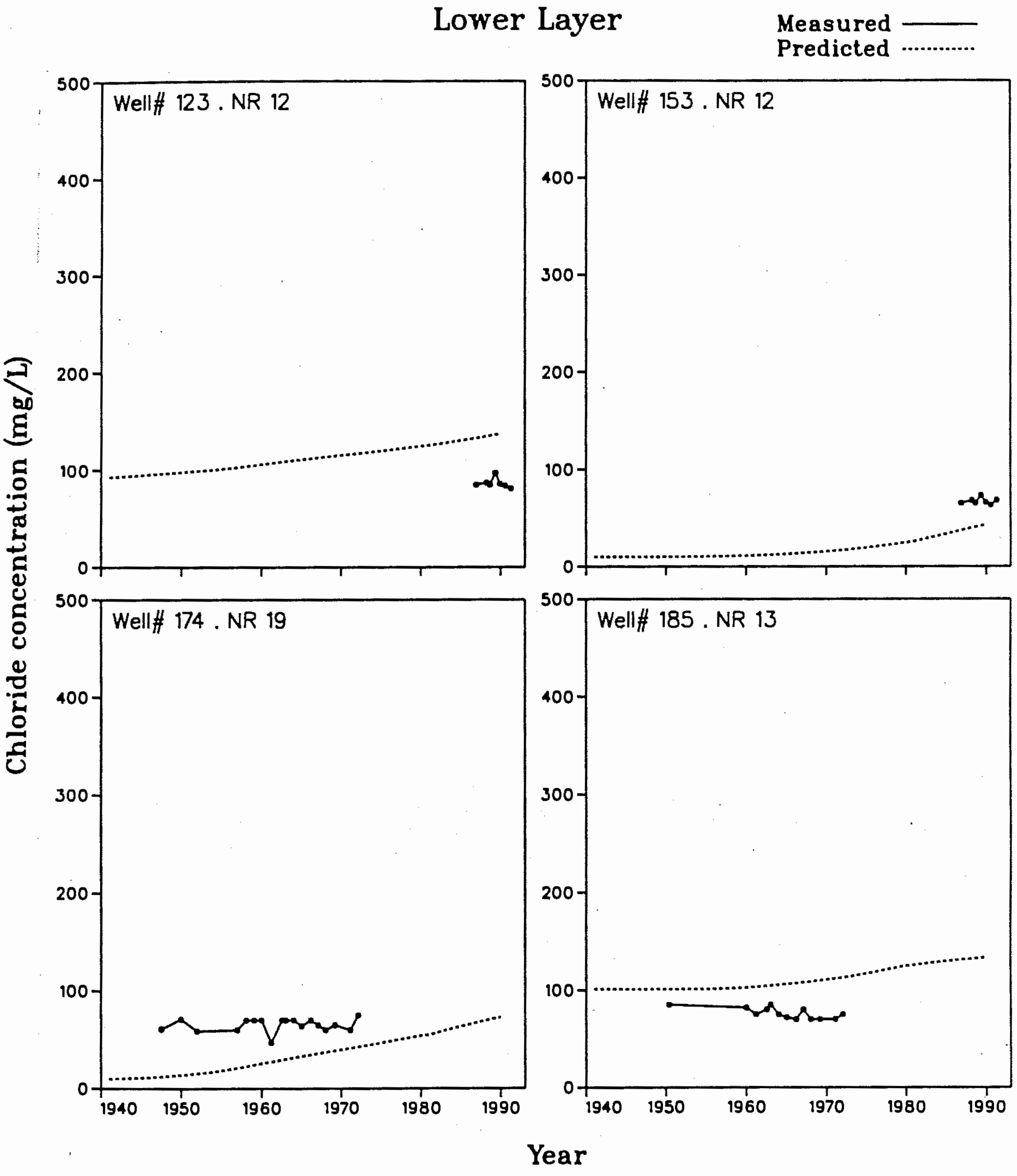

Middle Layer
Measured
Predicted
Chloride concentration (mg/L)
Well# 678 . NR 8
Well# 684 . NR 11
Well# 687 . NR 11
Well# 691 . NR 9
0
100
200
300
400
500
1940
1950
1960
1970
1980
1990
Year


Middle Layer
Measured
Predicted
Chloride concentration (mg/L)
Well# 696 . NR 9
Well# 709 . NR 11
Well# 710 . NR 9
Well# 795 . NR 10
500
400
300
200
100
0
1940
1950
1960
1970
1980
1990
Year

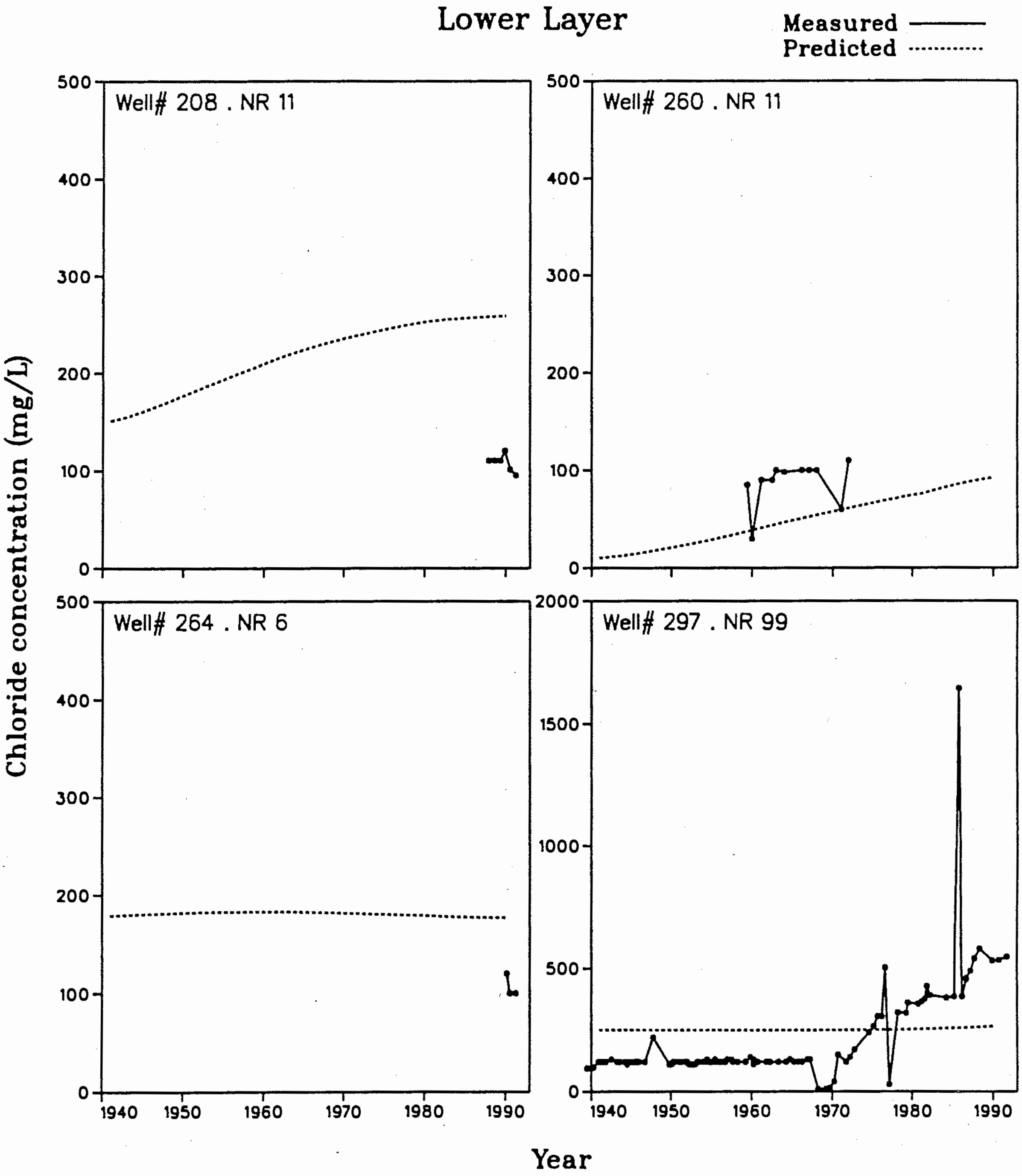

Middle Layer
Measured
Predicted
Well# 798 . NR 12
Well# 801 . NR 12
1000
750
500
250
0
2000
1500
1000
500
0
500
400
300
200
100
0
Chloride concentration (mg/L)
1940
1950
1960
1970
1980
1990
Year

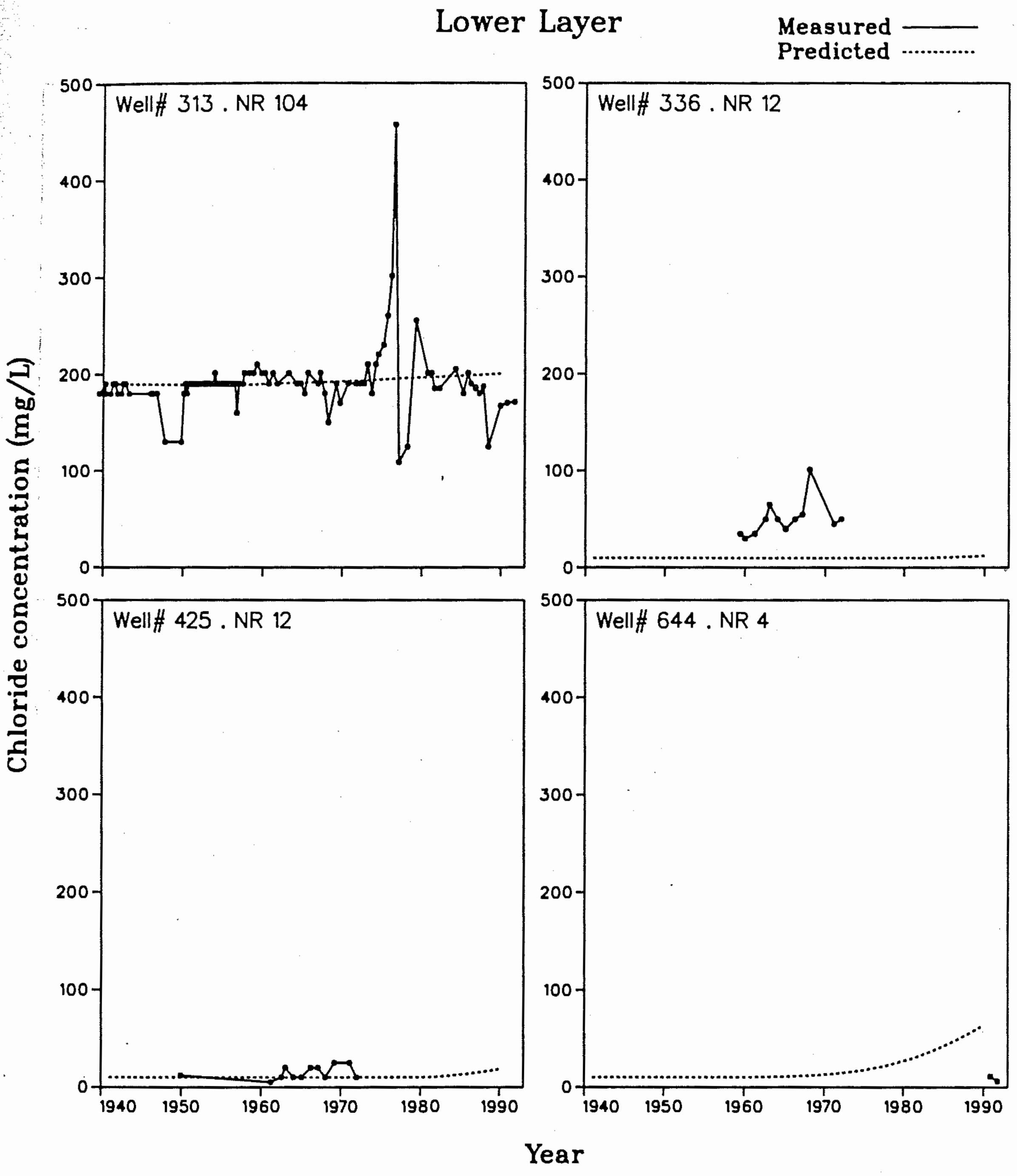


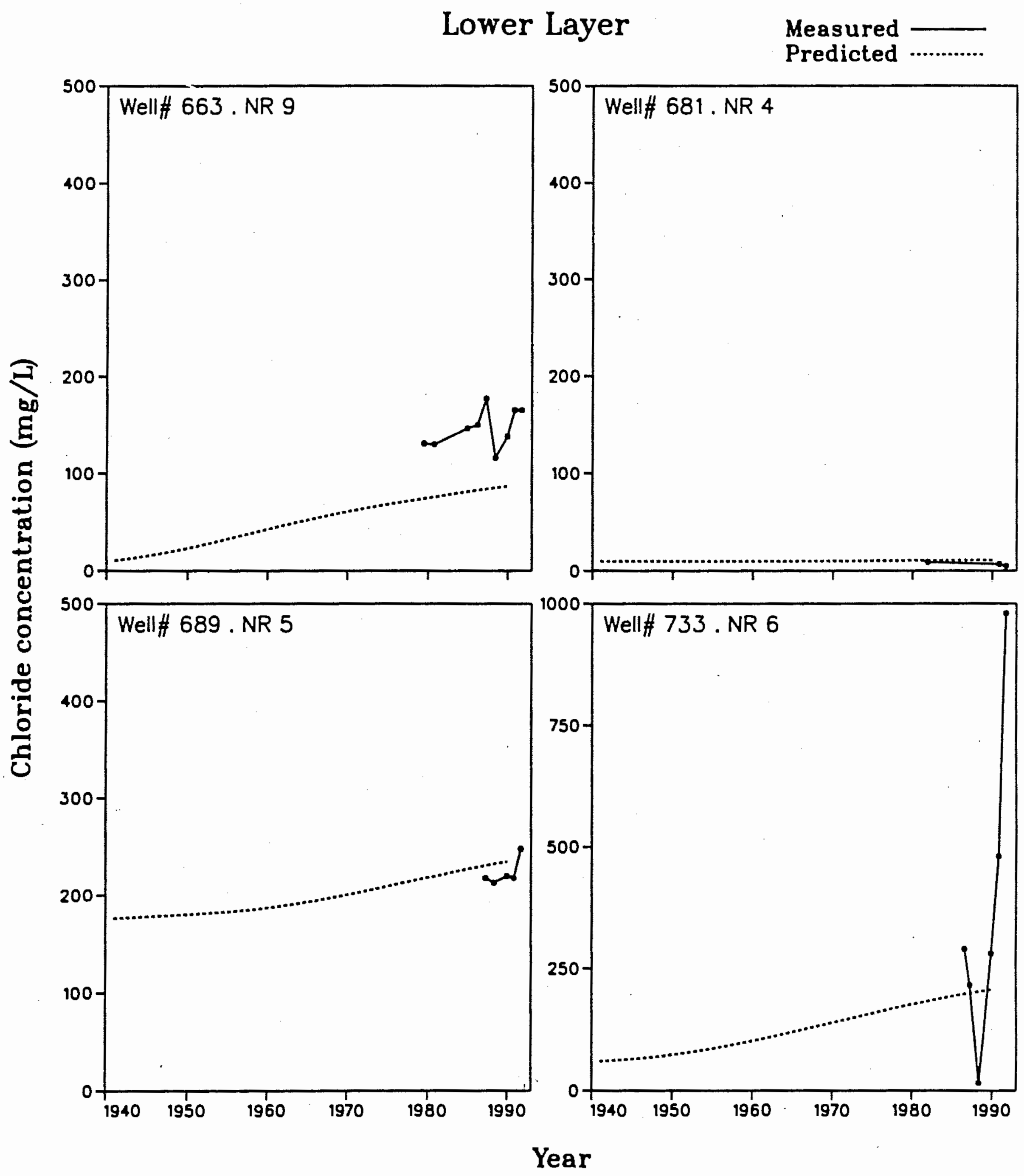
Locations having well data used in the model calibrations for the lower model layer. Graphs of measured and predicted chloride concentration for each well, referenced by number, follow.

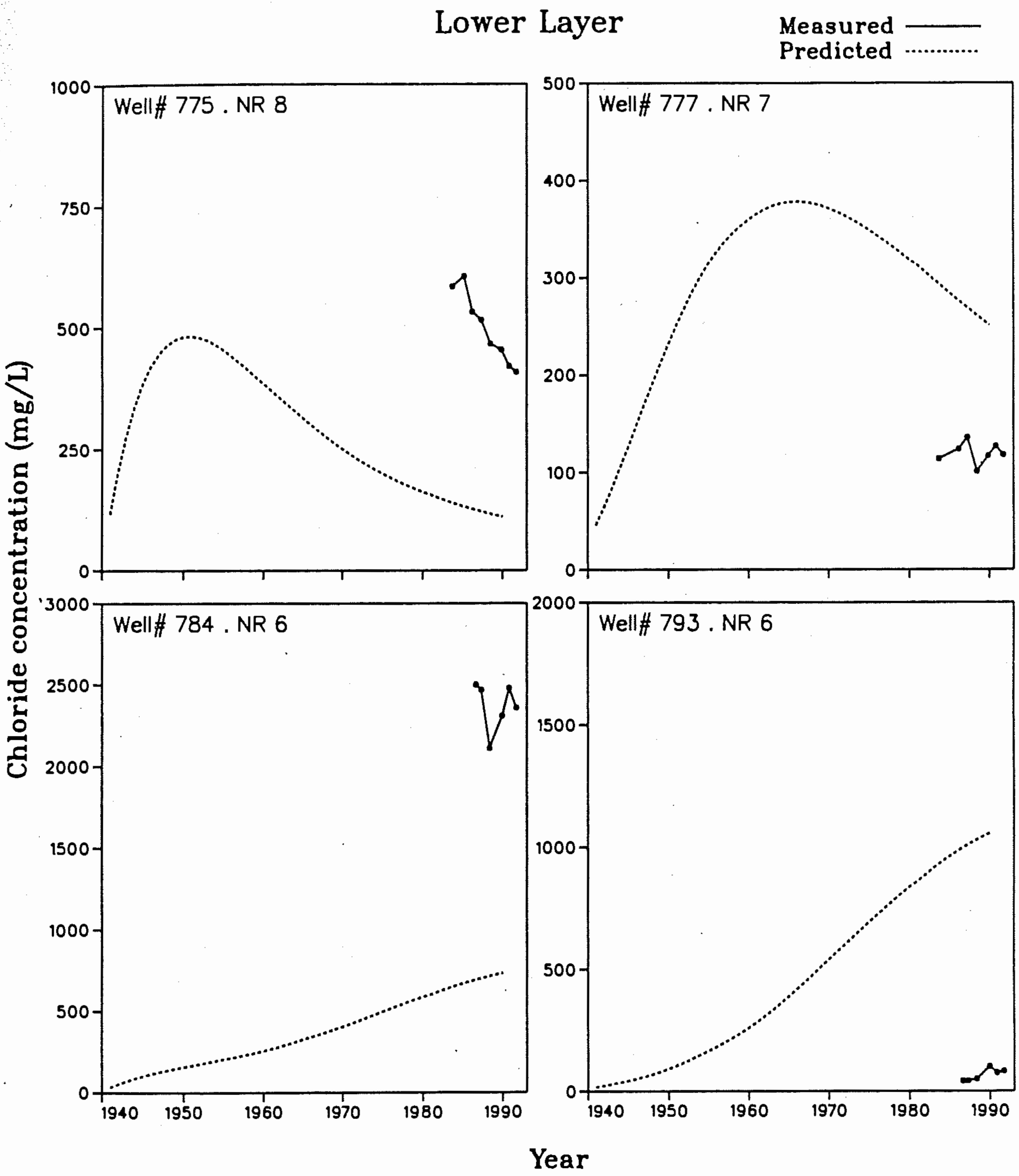


Lower Layer
Measured
Predicted
Well# 123 . NR 12
Well# 153 . NR 12
Well# 174 . NR 19
Well# 185 . NR 13
Chloride concentration (mg/L)
0
100
200
300
400
500
1940
1950
1960
1970
1980
1990
Year


Lower Layer
Measured
Predicted
Chloride concentration (mg/L)
Well# 208 . NR 11
Well# 260 . NR 11
Well# 264 . NR 6
Well# 297 . NR 99
0
100
200
300
400
500
1000
1500
2000
1940
1950
1960
1970
1980
1990
Year


Lower Layer
Measured
Predicted
Well# 313 . NR 104
Well# 336 . NR 12
Well# 425 . NR 12
Well# 644 . NR 4
Chloride concentration (mg/L)
0
100
200
300
400
500
1940
1950
1960
1970
1980
1990
Year


Lower Layer
Measured
Predicted
Chloride concentration (mg/L)
Well# 663 . NR 9
Well# 681 . NR 4
Well# 689 . NR 5
Well# 733 . NR 6
0
100
200
300
400
500
250
750
1000
1940
1950
1960
1970
1980
1990
Year


Lower Layer
Measured
Predicted
Chloride concentration (mg/L)
Year
Well# 775 . NR 8
1000
750
500
250
0
Well# 777 . NR 7
500
400
300
200
100
0
Well# 784 . NR 6
3000
2500
2000
1500
1000
500
0
Well# 793 . NR 6
2000
1500
1000
500
0
1940
1950
1960
1970
1980
1990
1940
1950
1960
1970
1980
1990

APPENDIX D

Water Quality

Water Quality Data

Introduction

The complete set of water quality data collected during the period 1988 through 1990 was reviewed. Several tasks were undertaken in the data analysis. The initial task involved the development of a spreadsheet that was used for statistical analysis and comparison of observed values with water quality standards. Of the data available in the data set, there are standards for chloride (Cl), sulfate (SO_4), (NO_3), fluoride (F), iron (Fe), and manganese (Mn).

Specific conductance, which is also known as electrical conductivity (EC), is a measure of the total dissolved solids (TDS) in water. There is a standard for TDS, but not for EC. A gross estimate of the TDS in water is often made using a factor of 0.7, which is multiplied times the EC. Frequently the dominant ions in water are also highly correlated with EC as well. Because the major concern of the Arkansas River Water Management Improvement Study (ARWMIS) is Cl, possible correlations of Cl on EC were investigated.

Regressions of chloride on specific conductance were derived for the complete data set and for several subsets of the data collected throughout the sampling period of 1986 through 1990. The regression were derived using a LOTUS 123, Version 3.1+ spreadsheet. A regression of sodium (Na) on chloride (Cl) was also calculated to evaluate whether the components of salt were behaving similarly or differently.

Comparison to Water Quality Standards

The comparison to water quality standards is summarized in Table 1. It should be noted that all of the standards shown are secondary drinking water standards and do not represent a level of the substances shown that relate to public health. The standards are based on levels that are related to the acceptability of the water by the public, primarily based on taste or undesirable effects on various domestic uses.

Table 1: Comparison of Water Quality Data for 1988 through 1990 from Well in Groundwater Management District Number 2 to Drinking Water Standards

	Cl	SO_4	NO_3	F	Fe	Mn
Standard (mg/L)	250	250	10	2	0.3	0.05
% > standard	40.8	8.9	2.6	0	85.4	76.8

There are a total of 574 well samples were analyzed for chloride, which is the most of any of the dissolved solids shown. The fewest are for Fe and Mn, which were analyzed only in 1988 and 1989 and have a total of 328 analyses. Because of the varying number of samples, the comparisons are based on percentages.

The standards that are most frequently exceeded are those for the metals Fe and Mn. Fe gives the water a rusty flavor. Mn gives water a somewhat metallic taste, but of more concern is that at a concentration only slightly greater than the standard, it will stain laundered fabrics black or dark brown. Fe is easily removed from most waters by simple settling; Mn is difficult to treat and is most often removed by in-line adsorption on activated charcoal. The standard that is exceeded next most often is Cl, which is the major subject being addressed in the ARWMIS. The only way to remove Cl is to evaporate (distill) the water.

Regression Relationships

The EC-Cl regressions are summarized in Table 2. All of the regressions appear to be quite useable based on their R^2 values (Table 2). However, when predicted values are generated using the regression equations, the results are not very satisfactory. As can be seen from the b_0 values shown in the table, all are negative and for the most part relatively large, *i.e.* near 200. Since most of the b_1 coefficients are on the order of 0.3, conductivities less than 600 yield negative chloride estimates. At lower conductivities and chloride concentrations, the addition of the standard error to the final estimate yields a much more usable value; at higher chlorides, such an adjustment makes little difference in the final estimate. For estimating purposes this procedure could be used.

Table 2: Parameters of Regressions of Chloride (mg/L) on Specific Conductance (µS/cm) by Cross-Section and Depth Interval

Data Set	R^2	Std. Err. of Y-Est.	b_1	b_0
All Data	0.981	94.1	0.310	-194.3
Cross-section:				
Hutchinson	0.994	39.0	0.308	-162.9
Haven	0.987	122.8	0.324	-219.6
Mt. Hope	0.962	94.9	0.289	-176.7
Bentley	0.908	73.1	0.221	-85.2
Maize	0.986	38.3	0.318	-192.5
Depth:				
A-Wells	0.958	76.7	0.310	-190.2
B-Wells	0.990	64.6	0.331	-211.9
C-Wells	0.982	119.4	0.305	-196.4

The slopes of the regression lines for 4 of the 5 cross-sections are around 3. The b_1 value for the Bentley cross-section is nearer to 2 than to 3. The associated R^2 values show the same relationship as the b_1 values, as would be expected since the 2 are calculated from similar data. The decrease in the b_1 values indicates that chloride accounts for a decreasing amount of the variation in the EC. However, the Bentley cross-section has the smallest b_1 value, but sits somewhat in the center of the set of cross-sections. Dilution by water lower in chloride is indicated, but the pattern is not entirely consistent with the pattern of ground water flow.

The regression of Cl on Na is also very highly significant. The r^2 is 0.93, indicating that 93 % of the variation in Na is reflected in that of Cl. The slope of the regression line is 1.7. If the Na and Cl were completely related the slope would be 1.5. The slope of 1.7 indicates that there is some reduction of Na relative to the Cl concentration, but any loss is relatively small. Na undergoes ion exchange reactions, but like Cl it behaves conservatively for the most part.

Chloride Data

Attached is a set of plots of all of the chloride data for the major cross-sections broken down by individual well. The sections are arranged from west to east in the general direction of the Arkansas River. Each plot shows the northern end of the cross-section on the left and the south end to the right. The main three layers are shown on each plot.

Figure 1 shows the Cl concentrations in the Hutchinson cross-section wells. The highest Cl concentrations are from wells in the north-central part of the cross-section. The northernmost well (EB228) shows little Cl at any depth. Immediately to the south, well EB229 shows the greatest Cl of any well in the cross-section in the C-well, with Cl decreasing in the B-well and at its lowest in the A-well. Continuing to the south, EB230 shows the greatest Cl in the B-well; the A-well has Cl concentrations nearly the same as the B-well. In both cases the Cl are at approximately the same concentration as the EB229, B-well. The greatest Cl in both EB231 and EB232 decrease with decreasing depth. EB232 is slightly lower in Cl in the C-well and B-well than the more northerly EB231 and much lower in the A-well. EB233, EB234, and EB235 are relatively low in Cl at all depths.

The peak Cl in the Haven cross-section is in the C-well near the center of the cross-section (Figure 2). The highest concentration in the shallow wells is in well 216, which is located immediately adjacent to the Arkansas River. The peak Cl in the B-wells in the cross-section occur near the C-well peak.

Figures 3 through 5 show similar information for the remaining cross-sections. Each section shows a peak in the Cl concentration at the approximate location of the river in the cross-section. In the Mt. Hope section (Figure 3), the peak Cl is in the EB210 C-well; there is a smaller peak in the A- and B-wells also in EB210. In the Bentley cross-section (Figure 4), the peak is also in the C-well (EB205), which is also located adjacent to the river. Smaller peak are present in the shallow (A-wells) at EB203 and EB204. The Cl in the Bentley cross-section appears more complicated than that in the other sections. The Cl in the Maize cross-section is very similar to that in the Mt. Hope cross-section. The peak at all depths is in the well near the river, with the maximum Cl in the C-well.

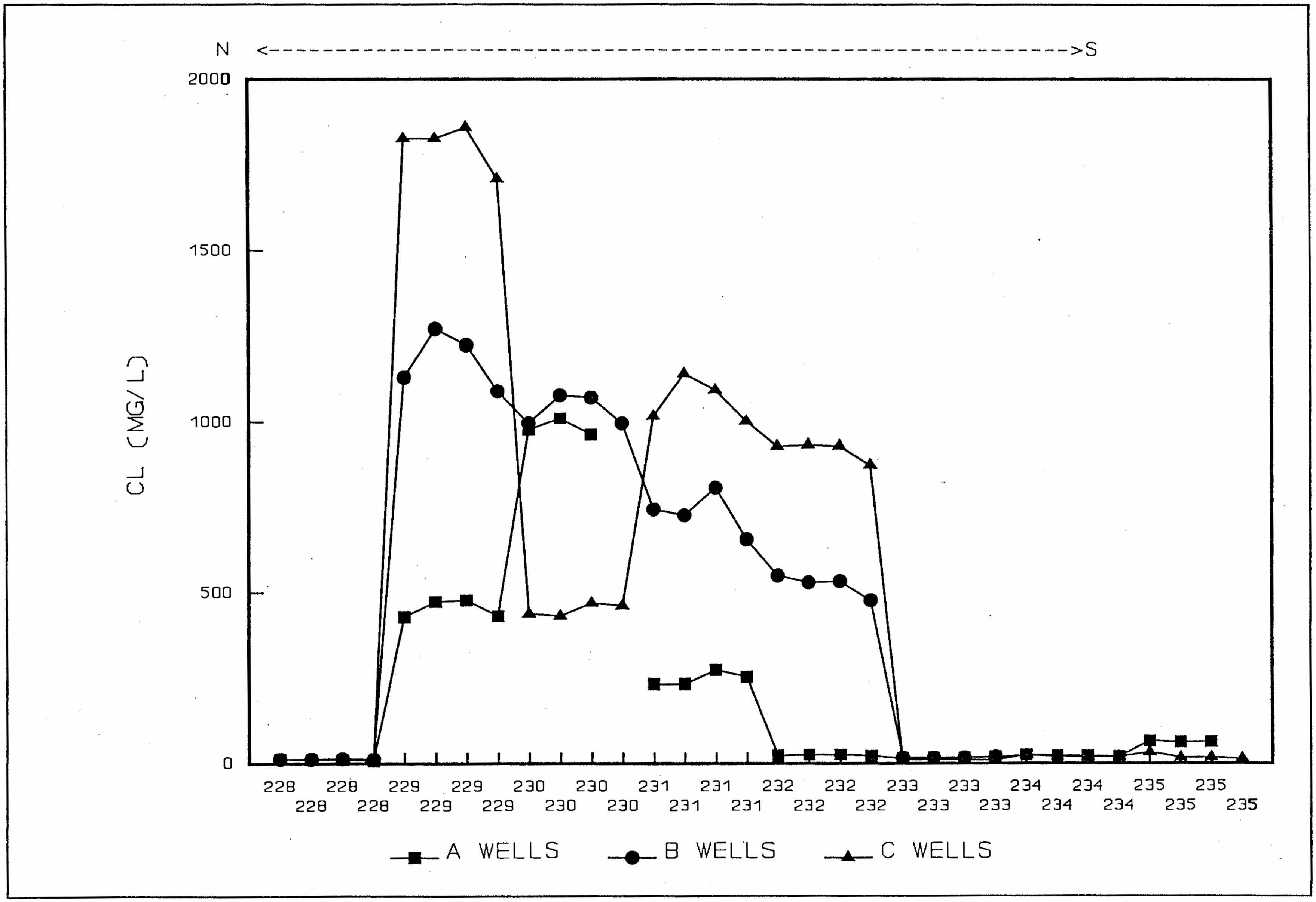


Figure 1: Chloride Concentrations by Layer in the Hutchinson Cross-Section Wells

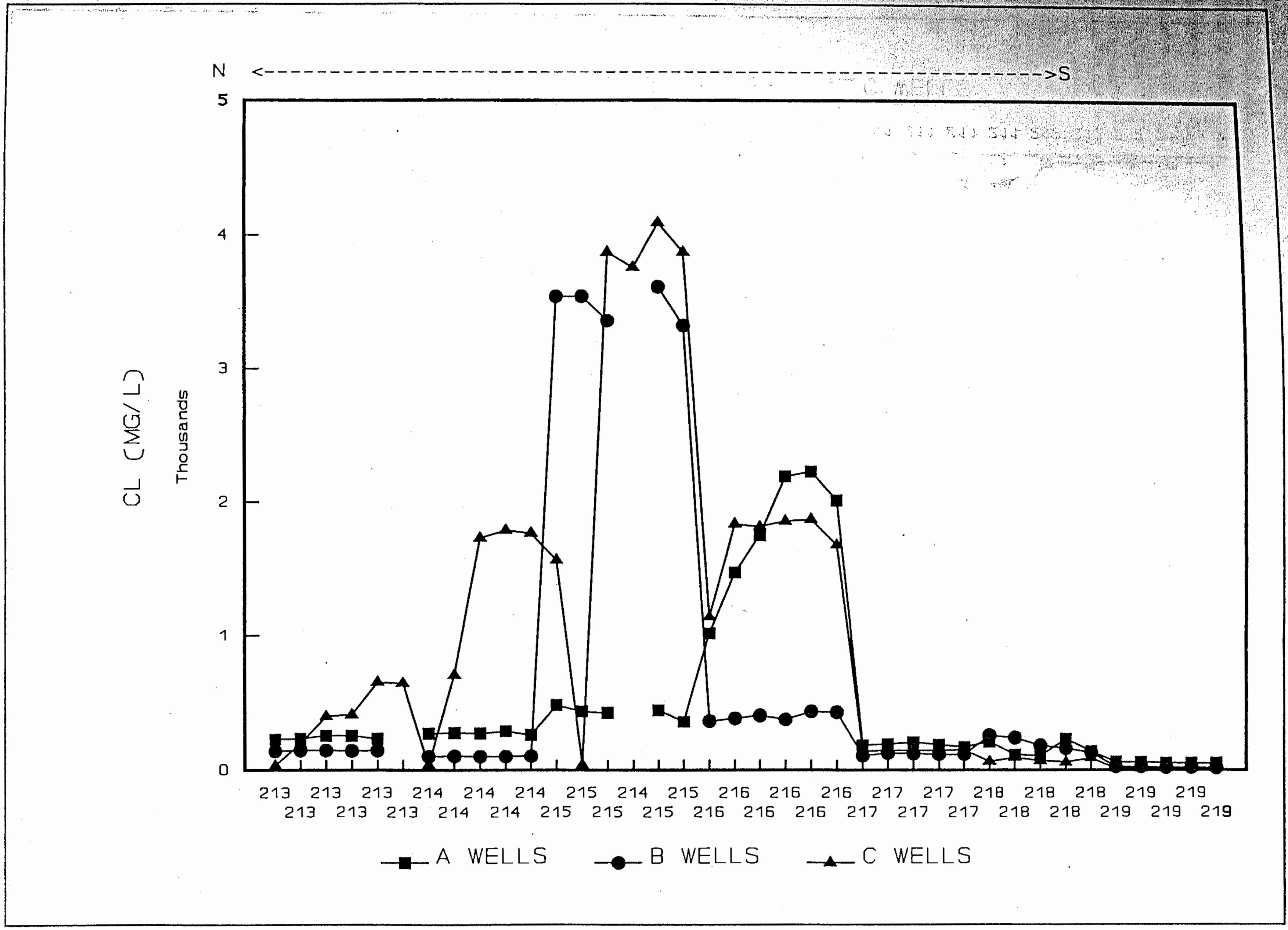


Figure 2: Chloride Concentrations by Layer in the Haven Cross-Section Wells

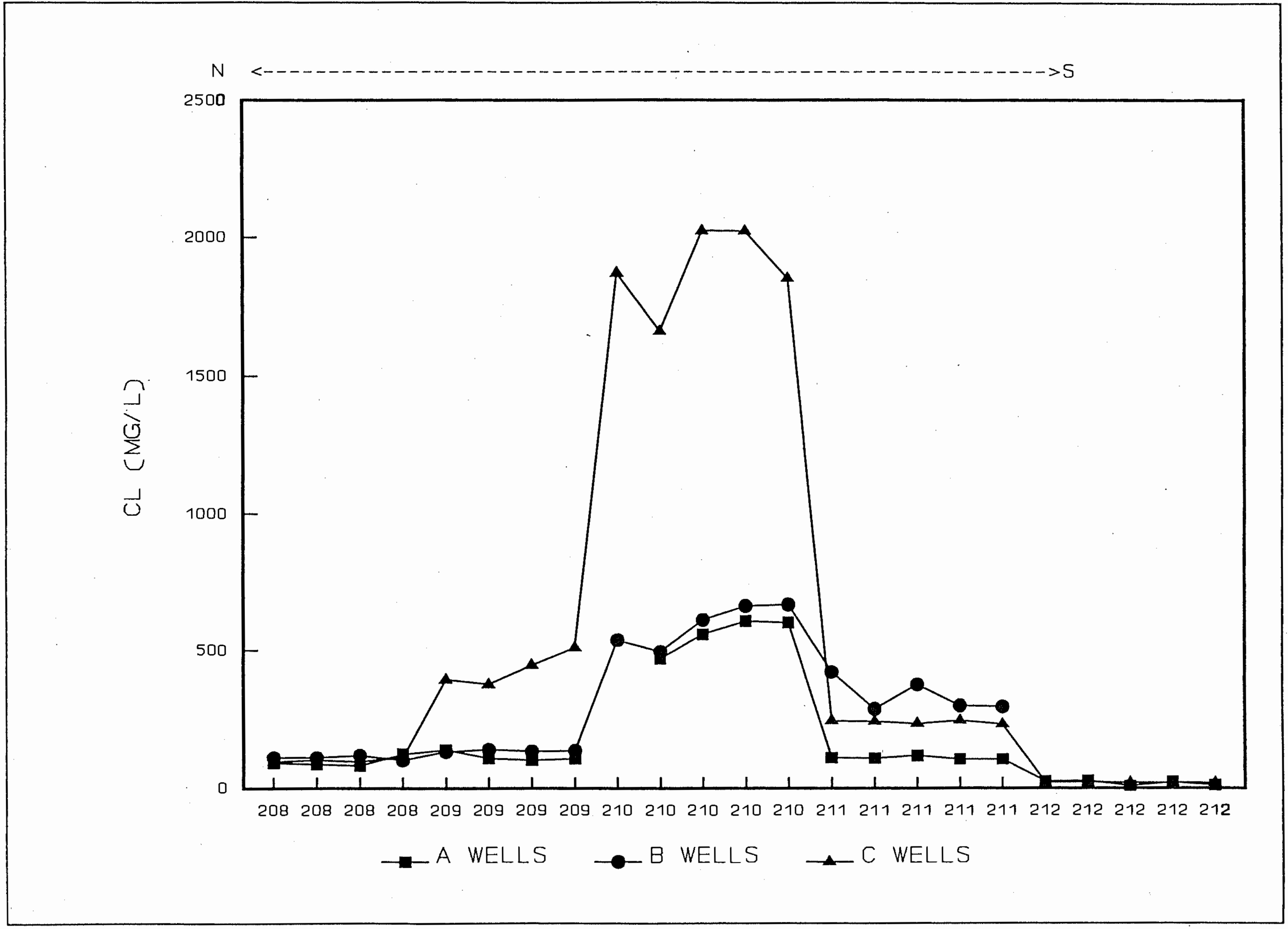


Figure 3: Chloride Concentrations by Layer in the Mt. Hope Cross-Section Wells

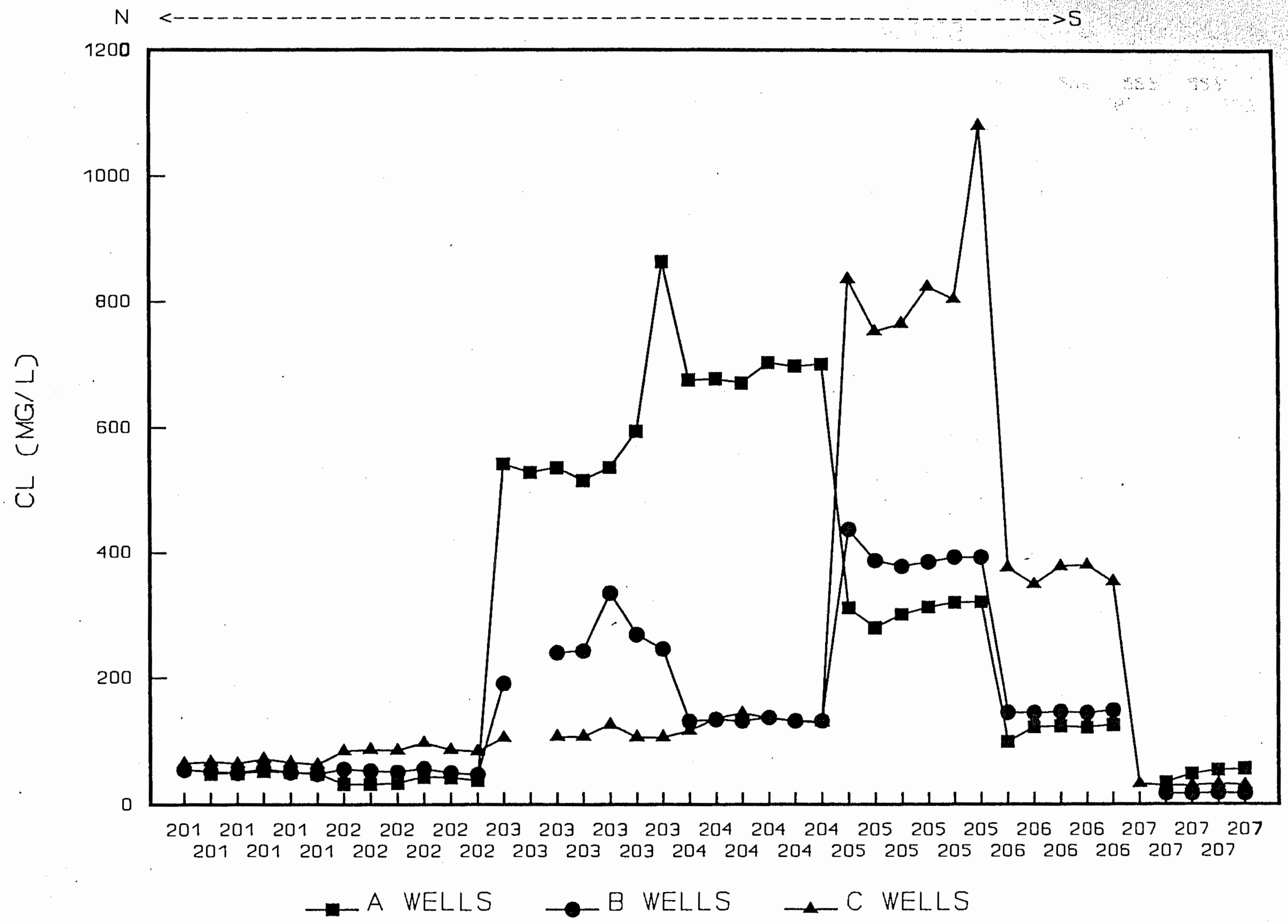


Figure 4: Chloride Concentrations by Layer in the Bentley Cross-Section Wells

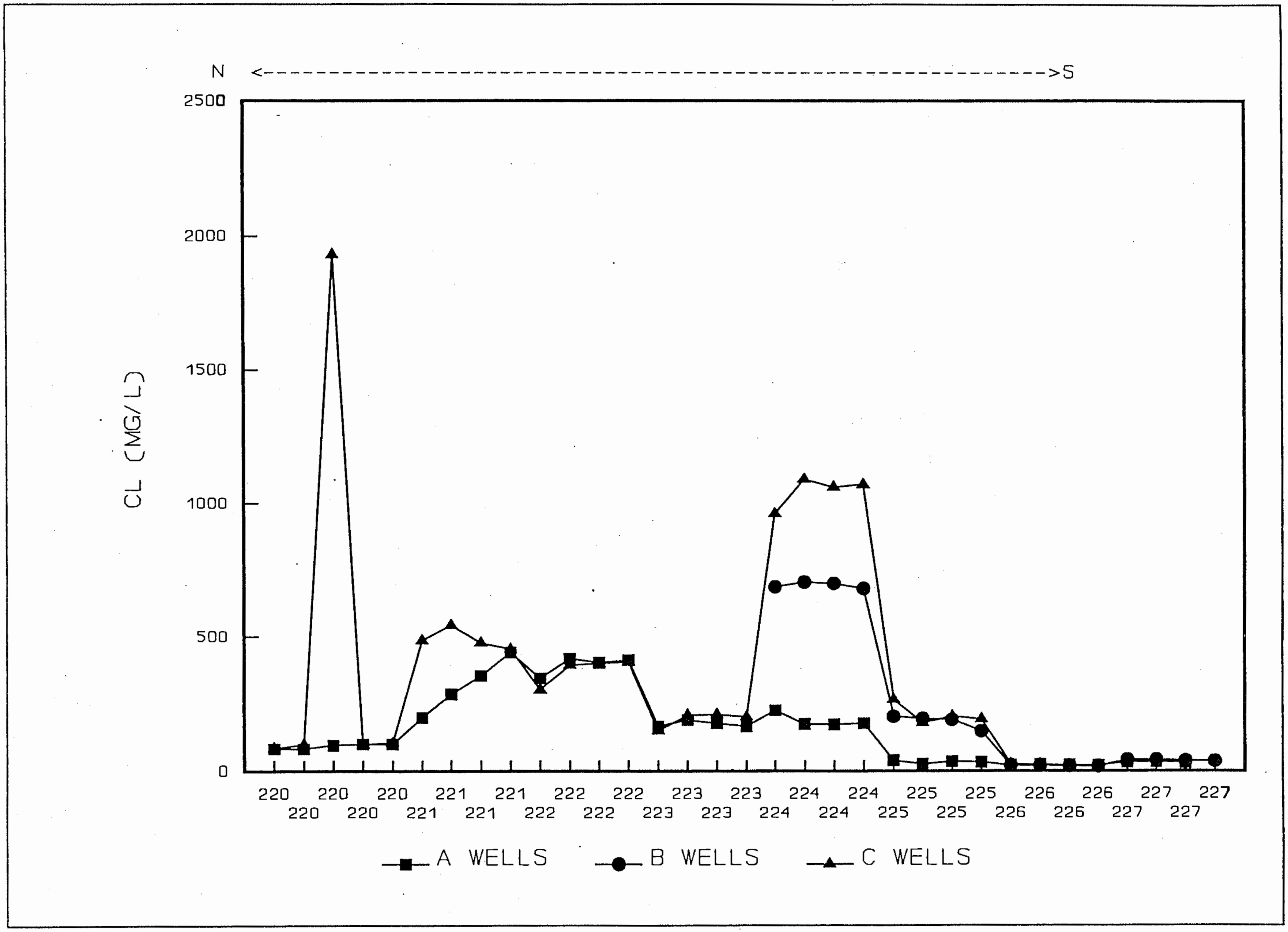


Figure 5: Chloride Concentrations by Layer in the Maize Cross-Section Wells