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Zone of Capture Analysis for the A/M Area of the Savannah River Site (U)

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INTRODUCTION

The groundwater of the A/M Area of the Savannah River Site (SRS) is contaminated with trichloroethylene (TCE) and perchloroethylene (PCE) as the result of the past use and disposal of these solvents. For the purpose of remediating this contamination, the A/M Area of the Savannah River Site has been divided into three sectors termed the central, northern (or SRL), and southern sectors. The central portion of the A/M Area has had an active remediation system of eleven recovery wells since 1985 and its effectiveness has been evaluated through groundwater modeling (Haselow, 1991). Remediation will soon begin at the northern or SRL sector with a "pump and treat" system of six wells distributed at four different locations with total pumping of approximately 250 gallons per minute (gpm). The locations and effectiveness of the capture system for each sector has been estimated through groundwater modeling without full consideration of the central recovery system (Schreuder et al., 1990). This report will provide an estimate of the number of recovery wells required for the southern sector and also consider the effects of the current and planned recovery systems for the northern and central plumes.

The southern sector contamination (which is defined as the area south of the M-Area basin) has been initially characterized and one recovery well (RWM-16) has been installed, for which an aquifer test was performed (Hiergesell, personal communication, 1991). However, to date a recovery well system has not been designed for the southern sector nor has a comprehensive evaluation of the recovery systems for all three sectors been completed. The purpose of this groundwater modeling study is to: 1) determine the location and number of recovery wells necessary to contain or remediate the southern sector, based on currently available characterization information, and 2) complete an analysis of the combined central, northern and estimated southern sector remediation so that the interactions of the systems can be determined.

METHODOLOGY

A calibrated steady-state groundwater flow model for the A/M Area (Beaudoin et al., 1991) was used in conjunction with particle tracking to determine the effectiveness of the current and proposed recovery well networks. Particle tracking is an effective method to evaluate the performance of a recovery well system without completing a more-costly contaminant transport simulation. Particle tracking is completed by simulating the backward paths of a distribution of particles emanating from the circumference of a well. The mathematical conceptualization of this approach is piece-wise time integration of the negative of the velocity field. The particle tracking method allows one to determine the hydrologic control of a plume and estimate the region of water that is recovered by the network during a specific time period. For this study, the particle tracking method incorporated advection only and did not account for mechanical dispersion or retardation. However, equilibrium-type retardation can be included by dividing the zone of capture isochron by the equilibrium retardation coefficient. The effective porosity for this study was set equal to 30 percent, which is believed to be conservatively high.

An important point to consider with the zone of capture analysis is that it assumes that the contaminant is completely miscible in the aqueous phase, and therefore there is not a non-aqueous phase in the saturated portion of the subsurface. In the case of completely miscible flow the transport of an aqueous phase contaminant is given by the direction of groundwater flow, which is, as a first assumption, in the direction of the hydraulic gradient. For a dense non-aqueous phase (DNAPL), such as TCE, one must consider gravitational forces in addition to hydraulic forces, in which case the direction of flow is affected by the distribution and orientation of low permeability units. Thus in the DNAPL case, the zone of capture analysis may not adequately depict the control or recovery of the contaminants.

The MODFLOW code was used to simulate the steady-state groundwater flow system for the area (McDonald and Harbaugh, 1984). The MODFLOW code is a quasi three-dimensional groundwater flow computer code. That is, the vertical flow between aquifers is incorporated with a leakance coefficient, and the aquitards are therefore not discretized. The modeled system consists of four water bearing units. From top to bottom, these units have been informally named the water table, the Upper Congaree, the Lower Congaree, and the Black Creek. The Ellenton was not discretized as an aquifer because although it has zones of sand, it is mainly lenses of clay and as a whole does not have substantial water production capacity. It is recognized that these names do not adhere to the formal hydrostratigraphic nomenclature used for the SRS (Aadland and Bledsoe, 1991), but they were maintained to allow an easy comparison to the previous modeling effort.

Steady-state simulations of a coarse-grid model for the entire A/M Area were made to determine the hydrologic parameters for the system that adequately reproduced the observed average hydraulic heads (1Q89 to 1Q90) for the area (Beaudoin et al., 1991). The calibrated values of transmissivity, leakance coefficient, and recharge for the model domain are given in Appendix A. These parameters are within the range of those determined from aquifer tests and grain size analyses. The results from aquifer tests of RWM 1 through RWM-11 and RWM 16 were utilized to constrain the calibration. The coarse-grid model (Beaudoin et al., 1991) is used for the basis of the particle tracking, but the grid is refined throughout the contaminated region, so that wells could be placed at a node close to its true location, and to minimize numerical errors in the particle tracking used for the zone of capture analysis. The fine-grid model has 106 columns and 144 rows for a total of 61,056 nodes (Figure 1), and the grid spacing varies between 125 and 1000 feet.

The location and pumping rates used for the five existing production and eleven recovery wells in this model are listed in Table 1. The positions and pumping rates for the six proposed wells in the A-Area are listed on Table 2. The position and withdrawal rates for the existing wells in Table 1 and the proposed SRL wells in Table 2 are held constant for all particle tracking analyses.

RESULTS

Included herein are the results of five zone of capture analyses for proposed groundwater recovery systems for the southern sector of the A/M Area. In order to complete a comprehensive analysis of the A/M Area, the recovery systems for the southern sector were modeled assuming the existing recovery pumping in the M-Area, and the proposed remediation in the A-Area will proceed. Thus, the zone of capture analyses for all scenarios include the central and northern recovery systems. The design of the recovery well systems for the southern sector are based on capturing the contaminant plumes in the water table, Upper and Lower Congaree within the 100 parts per billion (ppb) contour. These five proposed pumping scenarios are identified as scenarios 1A, 1B, 1C, 2A and 2B. The scenario 1 systems (A, B, C) are based on contaminant contours as they appear in the Part B Post Closure Care Permit for the A/M Area (1Q, 1991). The scenario 2 systems (A, B) are based on alternate contaminant contours for the Lower Congaree that are given in the Appendix B of Beaudoin et al., 1991 and similar contours are in the Part B Application for the Metallurgical Basin (Sirrine, 1991). Estimates of the number of recovery wells required and the total pumping were made for both contours. The two estimates reveal the importance of obtaining additional characterization data for the southern sector.

Before the discussion of each the five scenarios, it is important to note that it is difficult to discern the Upper and Lower Congaree in the southern sector, and for all practical purposes they could be lumped as one unit. Additionally, the water table (unconfined aquifer) evidently pinches out in the vicinity of RWM-16, and in fact, a recent survey of MSB-40D (near RWM-16) indicates that this water table well is dry. This indicates that the first continuously saturated unit is most likely the "Upper Congaree" and probably exists as a partially-confined unit for most of the southern sector. Certainly though, the unconfined water table does exist in the portions of the southern sector south of MSB-40D because of varying topography and complex hydrogeology.

Scenario 1A

For Scenario 1A, we assume that the recovery wells will be screened across both the Upper and Lower Congaree and be capable of producing 30 gpm. With this assumption, twenty-seven (27) wells are necessary to control the plume. The well locations and the 5- 15- and 30-year groundwater capture zones for the Lower Congaree are shown on Figure 2. The TCE isoconcentration contours from the 1990 Part B Permit for the Lower Congaree are also included in Figure 2. The zone of capture for the southern sector is essentially complete. As was the situation reported in Haselow (1991), the zone of capture for the central A/M Area plume is incomplete. A portion of the plume to the east is not captured.

Likewise, the simulated capture zone for the proposed A-Area wells in the Lower Congaree is narrower than the capture zone reported in the Schreuder et al. (1990) analysis. This results from a recalibration of the coarse grid model to averaged 1989-1990 observed water levels, which lead to recalibration of aquifer parameters in selected areas. The sharp boundary on the northern part of the capture zone is caused by a one order-of-magnitude change in the leakage coefficient in Layer 3. Creating a more gradual transition zone between leakance values in the finely discretized model would produce a gradual transition in the capture zone in this area. Also in Figure 2, the results indicate that the contaminants are not being captured in the Lower Congaree in a strip of approximately 1500 feet between the SRL and Central sectors by the existing recovery well systems. Additional monitoring of this area may be necessary to evaluate the existing recovery well network and to better characterize the plume towards the east.

The groundwater capture zones for the Upper Congaree and Scenario 1A are shown in Figure 3. The contaminant plume within the 100 ppb contour in the southern sector is captured within 30 years. The capture area for the proposed A-Area wells is the same size as in the 1990 analysis (Schreuder et al., 1990). As in the Lower Congaree, the model predicts that the contaminant plume in the eastern A-Area is not completely captured. Again there is a region between the central and northern plumes that is not captured by the recovery systems, but this region is smaller than that for the Lower Congaree.

The capture zones for the water table and Scenario 1A are shown in Figure 4. The zone of capture is clipped at the southern limit of the modeled water table boundary. South of this boundary, contaminants would descend into the Upper Congaree. The relatively large vertical and downward gradient in the water table is exploited, and capture of contaminants in the water table at the 100 ppb level is essentially complete for the entire A/M Area.

Scenario 1B

In Scenario 1B, we assume that all the proposed southern sector recovery wells are capable of producing 50 gpm. The southern tier of wells in the southern sector are screened only in the Lower Congaree (Figure 5) while the northern tier of wells and the existing recovery well RWM-16 are screened in both the Upper and Lower Congaree. Although in theory one may be able to delineate the Lower and Upper Congaree, in practice it may be quite difficult because the Upper and Lower Congaree are most likely not discernable in the area. However, one could screen the wells in the lower portion of the water bearing unit.

The well locations and groundwater capture zones for the Lower Congaree and Scenario 1B are shown on Figure 5. Proposed recovery wells screened in the Lower Congaree are represented by diamonds, and proposed recovery wells screened in both the Upper and Lower Congaree are represented by triangles. The 16 proposed recovery wells in the southern sector provide essentially complete capture of the Lower Congaree contaminant plume. As in Scenario 1A, capture of contaminated groundwater in the Lower Congaree appears to be incomplete between the central and northern sectors and to the east of the A/M Area.

The capture zones for the Upper Congaree and Scenario 1B are presented in Figure 6. It is clear from the results that although the wells are only pumping from the Lower Congaree in the down-gradient area, capture in the Upper Congaree seems to be complete in the southern sector. This is because there is very little hydrostratigraphic separation between the Upper and Lower Congaree in the southern sector. Again the capture is incomplete the central and northern sectors and to the east of the A/M Area.

The capture zones for the water table and Scenario 1B are shown in Figure 7. The zone of capture is clipped at the southern limit of the modeled water table boundary. South of this boundary, contaminants would descend into the Upper Congaree. The relatively large vertical and downward gradient in the water table is exploited, and capture of contaminants in the water table at the 100 ppb level is essentially complete for the entire A/M Area.

Scenario 1C

For Scenario 1C, we assume that the recovery wells are capable of producing 50 gpm and that they are screened across both the Upper and Lower Congaree. In this case, seventeen recovery wells are needed to contain the southern sector plume.

The Lower Congaree capture zones for Scenario 1C are shown in Figure 8. The contaminant plume is captured within the 100 ppb TCE concentration contour in the southern sector. Again, as in Scenarios 1A and 1B, capture of contaminated groundwater in the Lower Congaree appears to be incomplete between the central and northern sectors and to the east of the A/M Area.

The Upper Congaree groundwater capture zones for Scenario 1C are shown in Figure 9. Coverage of the contaminant plume is complete within the 100 ppb contour, and the zone of capture is more extensive than in Scenario 1B because of the additional withdrawal in the Upper Congaree.

The groundwater capture zones for the water table are shown on Figure 10. Again, the water table boundary is clipped, and there is good capture of the contaminant plume within the 100 ppb contour because of the relatively strong downward gradient.

Scenario 2 (General)

As with all of the Scenario 1 simulations, there is a region between the central and northern sector plumes that is not captured in the Upper and Lower Congaree. This zone does not exist for the water table because the contaminant contour does not extend this far. Also, in Scenario 1, there is an extensive region of groundwater contamination to the east that is not captured. However, in the Scenario 2 analyses this zone is not present because of the reinterpretation of previous contaminant contours.

Scenario 2A

In Scenario 2A, the recovery well network is designed to capture the Lower Congaree contaminant plume within 100 ppb contour of the alternative contaminant contour map for the southern sector. Eighteen recovery wells pumping 30 gpm from the Upper and Lower Congaree are used in this scenario (Figure 11). Coverage within the alternative contaminant plume is reasonable, with only a few small gaps along the northern boundary of the southern sector.

The zone of captures for Scenario 2A are shown in Figures 12 and 13 for the Upper Congaree and water table, respectively. The zone of capture for the Upper Congaree would be nearly complete for contaminants as depicted in Sirrine (1991), but they would not be complete for the plumes as depicted in the 1Q 90 Post Closure Care Permit. The zone of capture for the water table would be sufficient for the water table.

Scenario 2B

The groundwater capture zones for the Lower Congaree and the alternative TCE concentration contours are presented in Figure 14. Ten wells pumping 50 gpm are used in this scenario; six of the wells are screened in the Lower Congaree, and four are screened in both the Upper and Lower Congaree. There is good coverage of the contaminant plume within the 100 ppb contour.

The zone of captures for Scenario 2A are shown in Figures 15 and 16 for the Upper Congaree and water table, respectively. The zone of capture for the Upper Congaree would be nearly complete for contaminants as depicted in Sirrine (1991), but they would not be complete for the plumes as depicted in the 1Q 90 Post Closure Care Permit. The zone of capture for the water table would be sufficient.

DISCUSSION

Two Scenarios which are based on different contaminant contours were considered for estimating the number of recovery wells required to control the southern sector plume. Table 3 summarizes the pumping rate, screen interval and total number of proposed wells in the southern sector for each of the five recovery simulations. The number of wells includes recovery well RWM-16, which has already been installed in the southern sector.

For Scenario 1, the total estimated pumping rate varies by approximately 5 percent, between 810 and 850 gpm. However, the number of wells that are required is 16, 17, or 27 wells depending on the pumpage rate and screen zones (Table 3). There is only a difference of one well (16 vs. 17) between screening the wells in the entire Congaree versus the Lower Congaree, when withdrawing water at 50 gpm. Therefore, it is prudent to screen the wells across the entire Congaree so that the problems with well screen placement are minimized and so that additional well capacity is achieved. The Congaree should be capable of transmitting 50 gpm in this area, because RWM-16 yielded approximately 38 gpm during a recent aquifer test, despite having a well efficiency of approximately 20 percent, which was based on a distance-drawdown analysis (Hiergesell, personal communication). (This should not present a problem to the regulators for screening the wells across more than one unit because the two units are not differentiable in this area.)

For Scenario 2, the total estimated pumping rates were 540 or 500 gpm for 18 and 10 wells, respectively. There is a significant difference between the number of wells owing to the 30 gpm and 50 gpm rates for the two cases, but the difference in pumping is less than ten percent.

Based on both Scenarios 1 and 2, the volumetric rate of groundwater removal to control the contamination is most sensitive to the extent of the contamination (as expected). However, the volumetric rate is rather insensitive to the number of wells and the production rate of the wells. Therefore, the most important aspect for effectively developing a remediation strategy for the southern sector is to improve the characterization of the extent of the contamination. This has the greatest potential for saving funds, and is exemplified in the comparison of Scenarios 1 and 2, by the approximately 60% difference in groundwater removal that is required for the two contaminant contours.

A second important area for characterization is the area to the east of the Metallurgical Laboratory Basins. There is a significant difference in contours that have been developed for this area and before additional funds are expended for improving control of the contamination in this area, it is again important to determine the proper contaminant contours.

A third consideration is that the number of wells required to remediate the area is fairly insensitive to whether the wells are screened in the entire Congaree or just in the Lower Congaree. Therefore, it is best just to install the wells screened across the entire Congaree in this area, because it is not clear that the Upper and Lower Congaree are differentiable in this area.

In summary, this report should not be considered a final design for the southern sector remediation. Additional characterization is required for the southern sector, and thereafter the recovery system design issue should be updated with consideration to the information in this report. The report does provide the first comprehensive analysis of A/M Area remediation program, and should allow for planning of future remediation activities.

ACKNOWLEDGEMENTS

Schreuder & Davis Inc. completed all of the groundwater modeling and drafting for this project under the guidance of John Haselow. The final report was written by John Haselow.

Table 1. Location of Wells and Pumping Rates of Existing Wells in the A/M Area.

Well No.	North SRS (ft)	East SRS (ft)	Total Pumping Rate (gpm)	Pumpage From Model Layer (gpm)*			
				1	2	3	4
PW-53A	105011	50757	350				116.7
PW-20A	104000	50615	350				116.7
PW-82A	103330	51100	900				300
PW-67B	86693	42622	75				25
PW-68A	106266	50266	30				10
RWM-1	102608	48581	28	1.4	17.7	8.8	
RWM-2	104434	49206	24	1.2	15	7.8	
RWM-3	104730	49680	57	2.9	36.1	18	
RWM-4	103719	48948	42	2.1	26.6	13.3	
RWM-5	103502	49628	43	2.2	27.2	13.5	
RWM-6	102002	50107	50	2.5	31.7	15.8	
RWM-7	101905	49450	40	2.0	25.3	12.6	
RWM-8	101948	47353	43	2.2	27.3	13.5	
RWM-9	104100	50400	45	2.3	28.5	14.2	
RWM-10	102001	48244	60	3	38	19	
RWM-11	104875	50400	65	3.3	41.2	20.5	

*Production wells in layer 4 are also pumping from the lower portion of Aquifer System I, which is not simulated in this model. Discharge is proportional to transmissivity.

Table 2. Location of Wells and Pumping Rates of Proposed A-Area Recovery Wells.

Well No.	North SRS(ft)	East SRS (ft)	Total Pumping Rate (gpm)	Pumpage From Model Layer (gpm)			
				1	2	3	4
1	106900	52475	60		60		
2	105550	53550	95		60	35	
3	106350	53050	70		35	35	
4	107450	53850	35		35		

Table 3. Summary of Proposed Southern Sector Wells for the Remediation Scenarios Evaluated.

Scenario	Pumping Rate (gpm)	No. of Wells Screened in Lower Congaree	No. of Wells Screened in Upper & Lower Congaree	Total No. of Proposed Wells	Total Pumpage (gpm)
1A	30	-	27	27	810
1B	50	10	6	16	800
1C	50	-	17	17	850
2A	30	-	18	18	540
2B	50	6	4	10	500

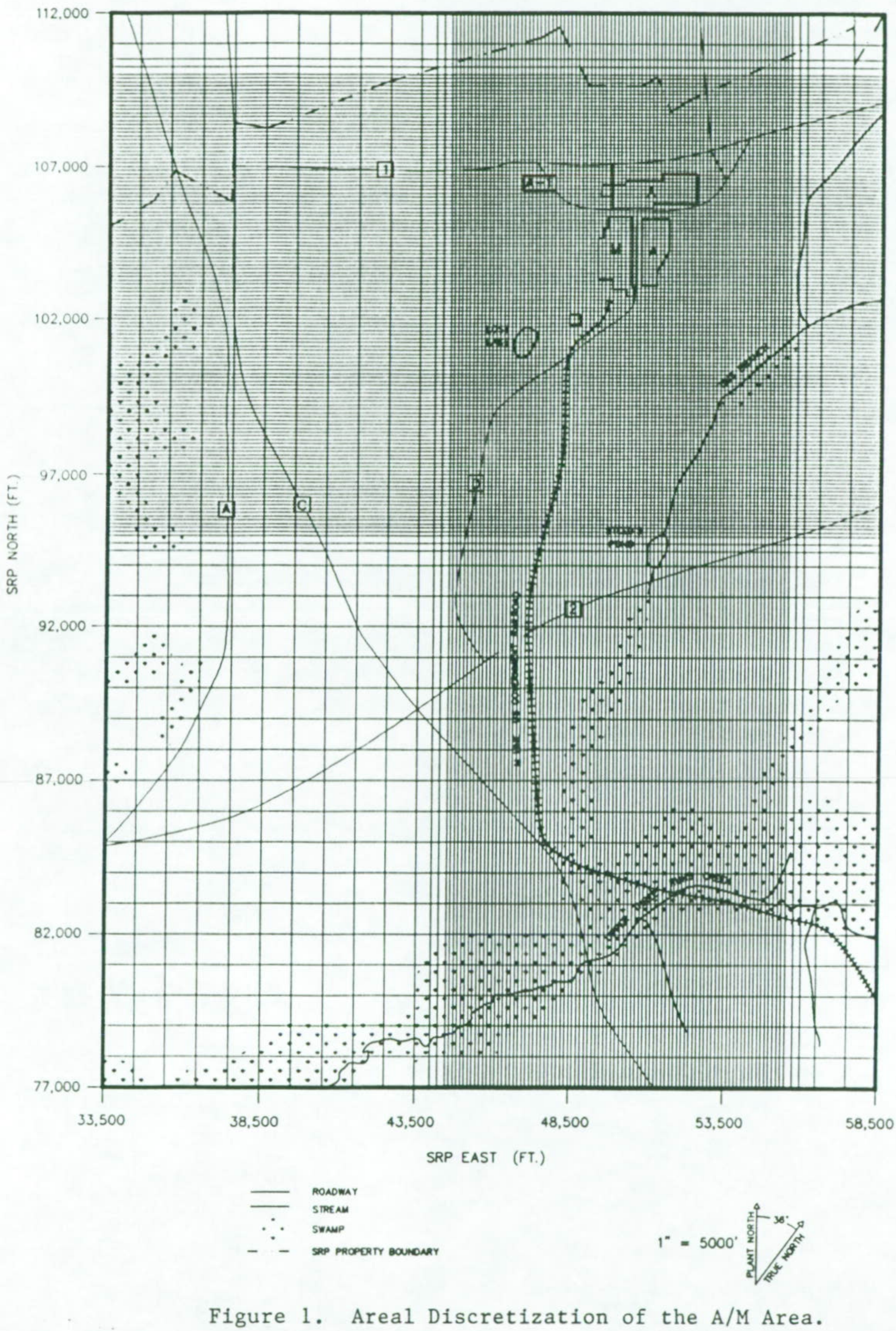

Figure 1. Areal Discretization of the A/M Area.

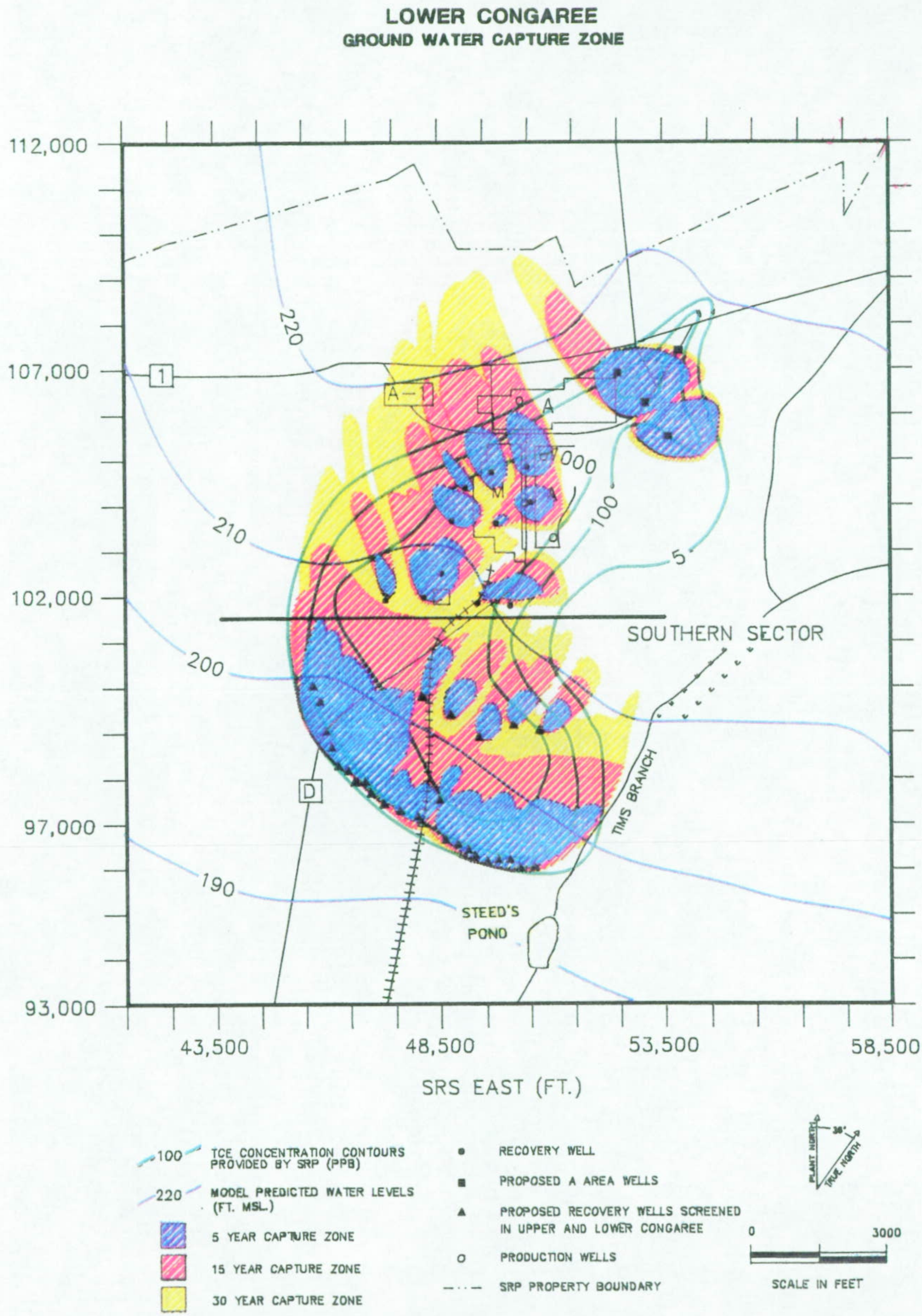

Figure 2. **Scenario 1A: Proposed Southern Sector Recovery Wells Pumping 30 GPM from Upper and Lower Congaree.**

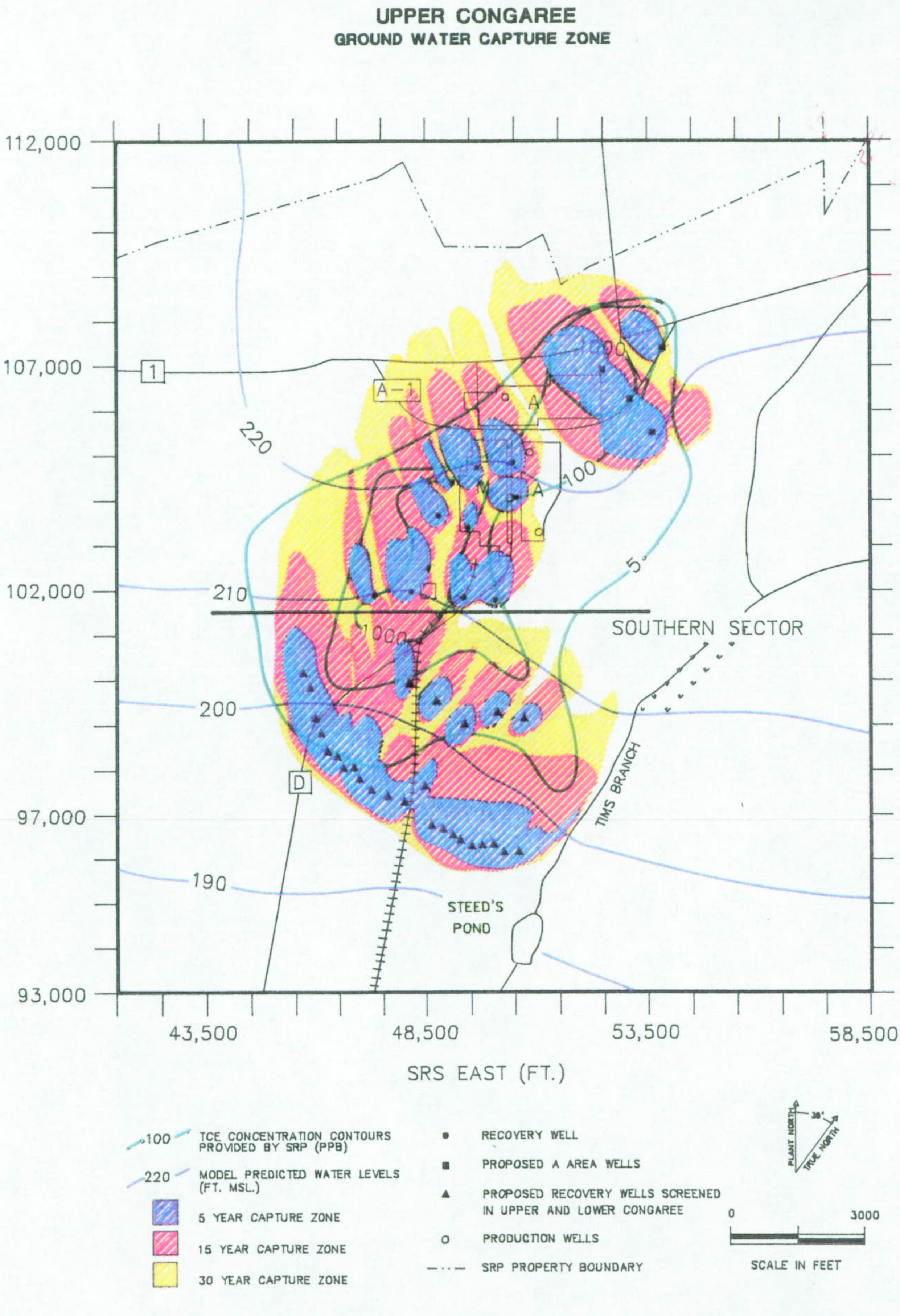

Figure 3. **Scenario 1A: Proposed Southern Sector Recovery Wells Pumping 30 GPM from Upper and Lower Congaree.**

WATER TABLE
GROUND WATER CAPTURE ZONE

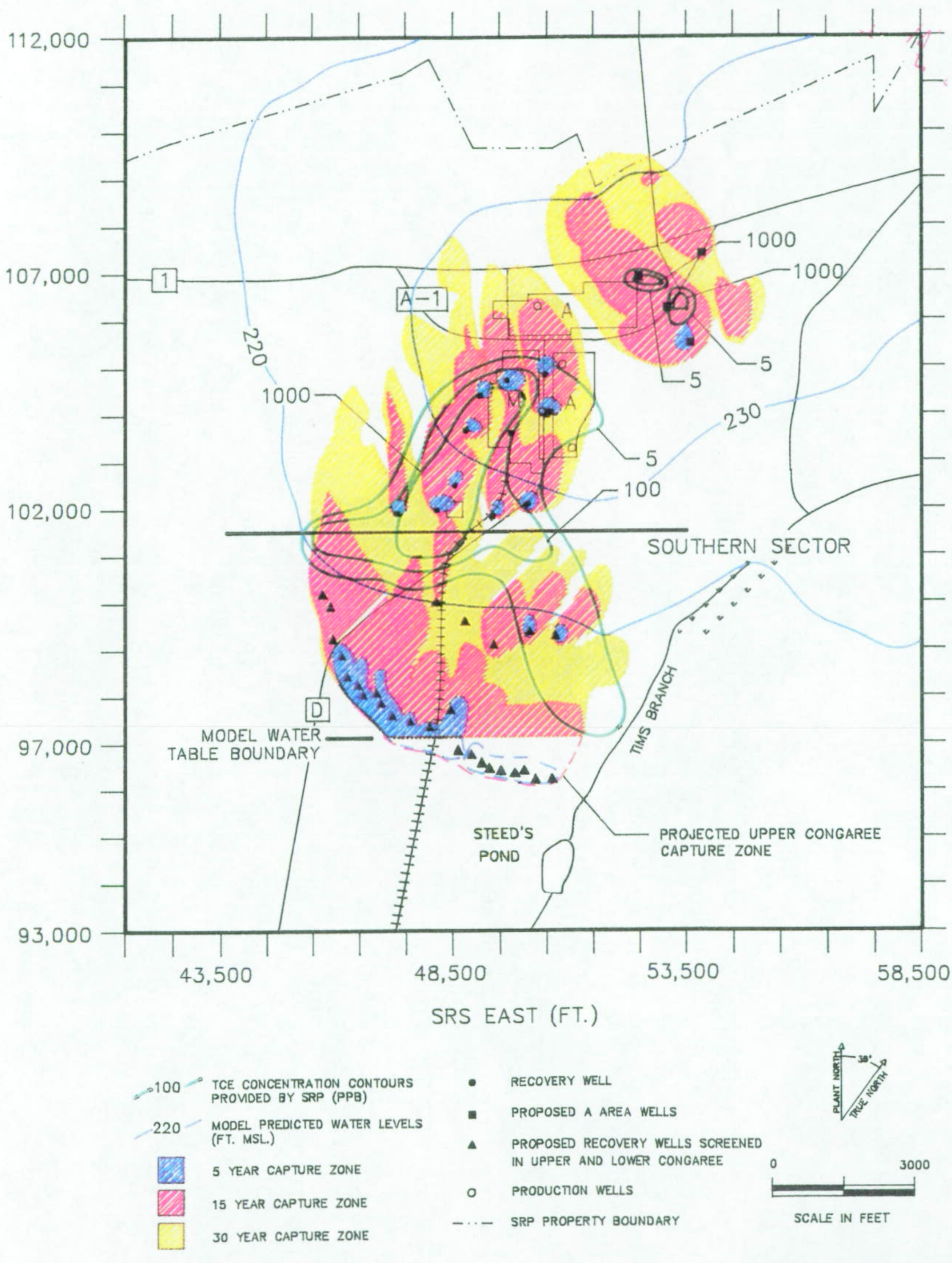

Figure 4. Scenario 1A: Proposed Southern Sector Recovery Wells Pumping 30 GPM from Upper and Lower Congaree.

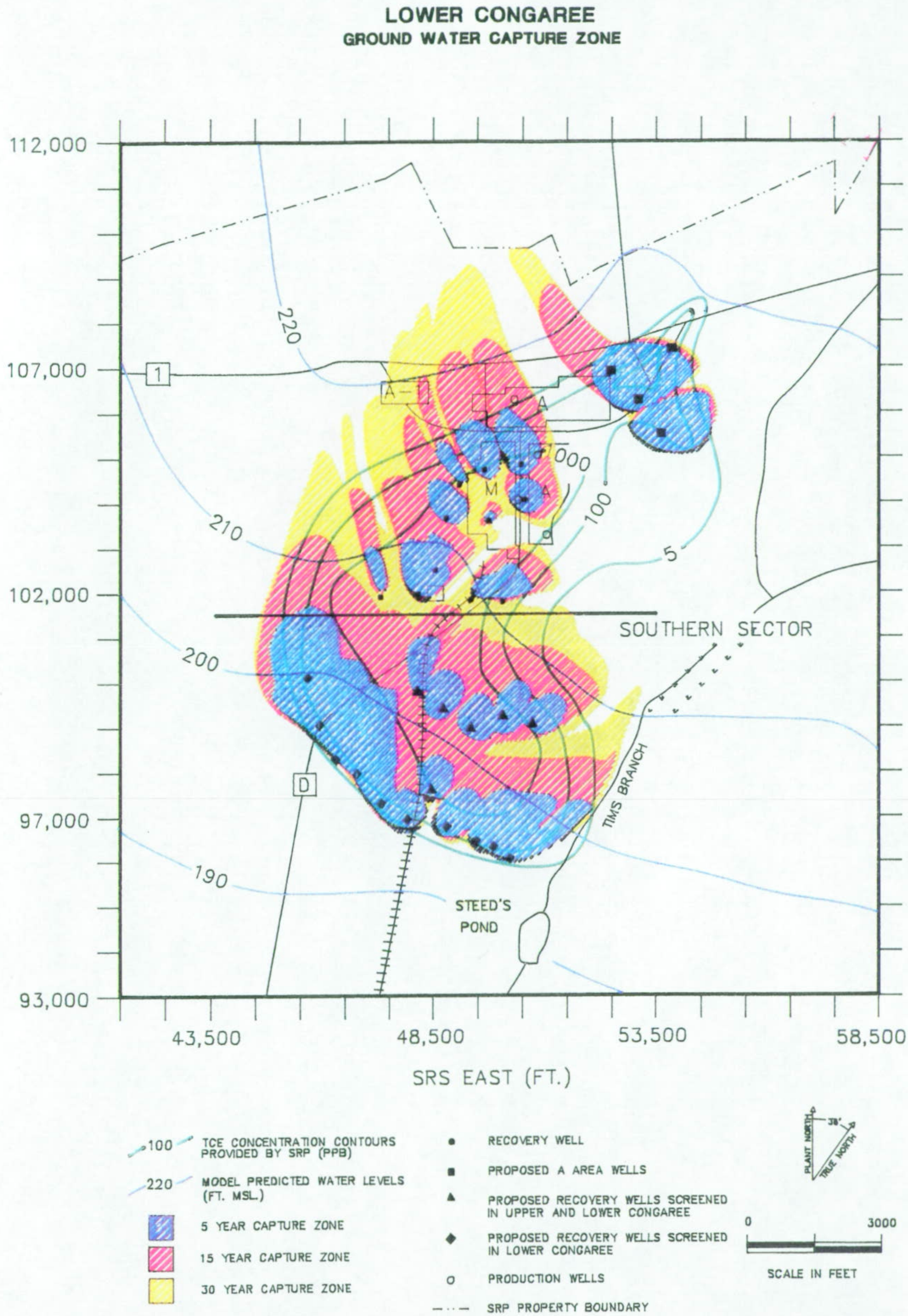

Figure 5. **Scenario 1B: Proposed Southern Sector Recovery Wells Pumping 50 GPM. Downgradient Wells Pumping from Lower Congaree Only.**

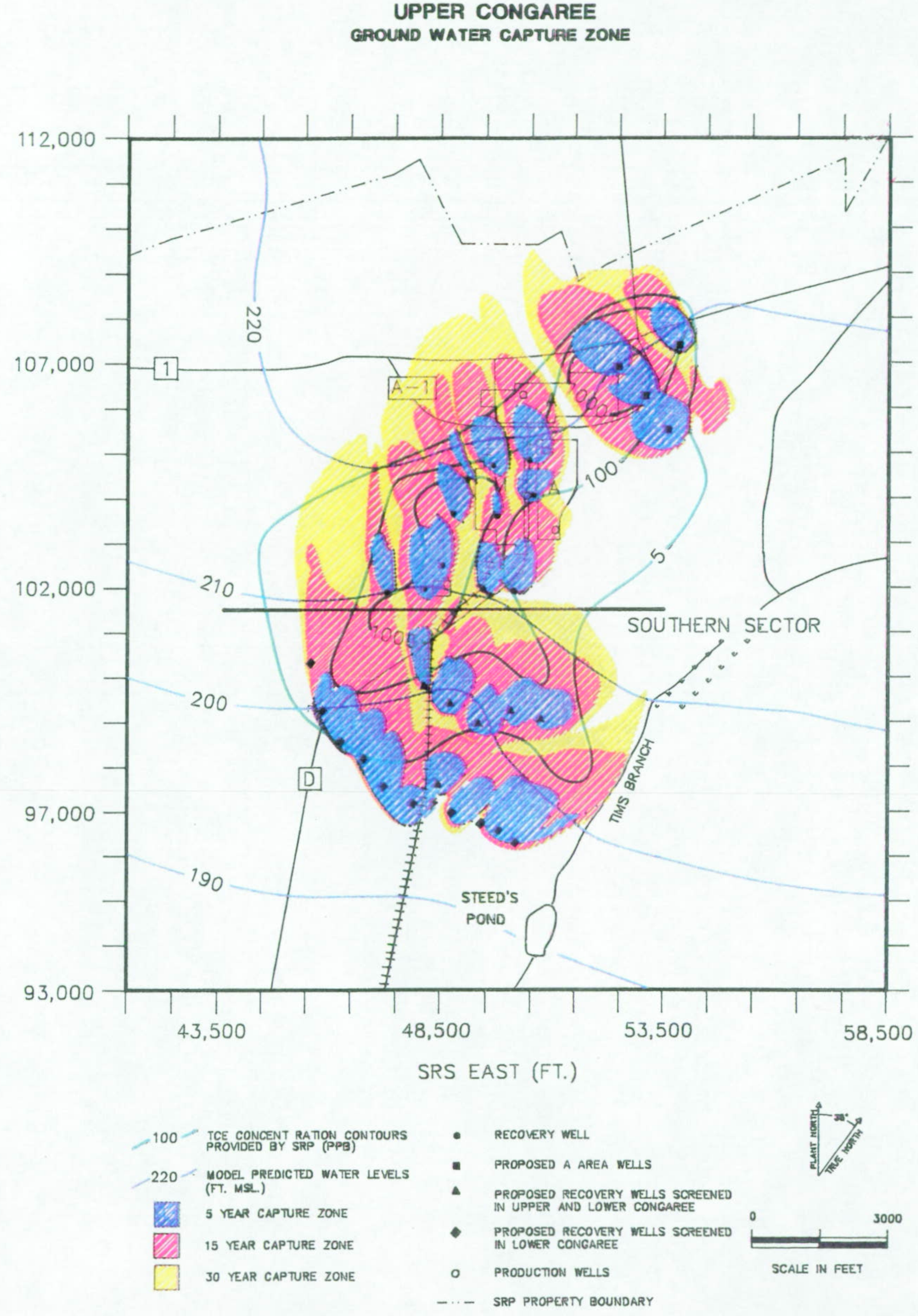

Figure 6. **Scenario 1B: Proposed Southern Sector Recovery Wells Pumping 50 GPM. Downgradient Wells Pumping from Lower Congaree Only.**

WATER TABLE
GROUND WATER CAPTURE ZONE

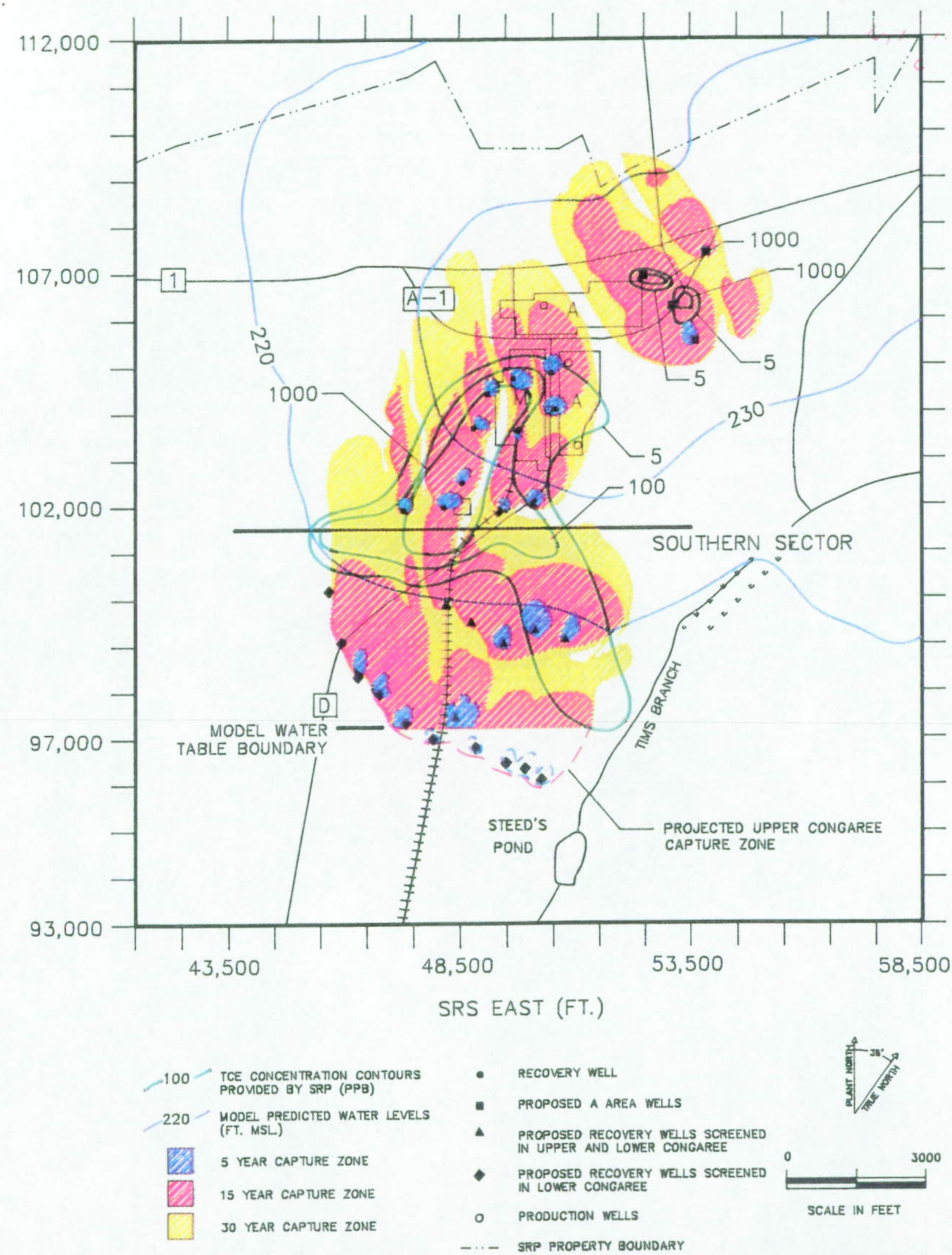

Figure 7. **Scenario 1B: Proposed Southern Sector Recovery Wells Pumping 50 GPM. Downgradient Wells Pumping from Lower Congaree Only.**

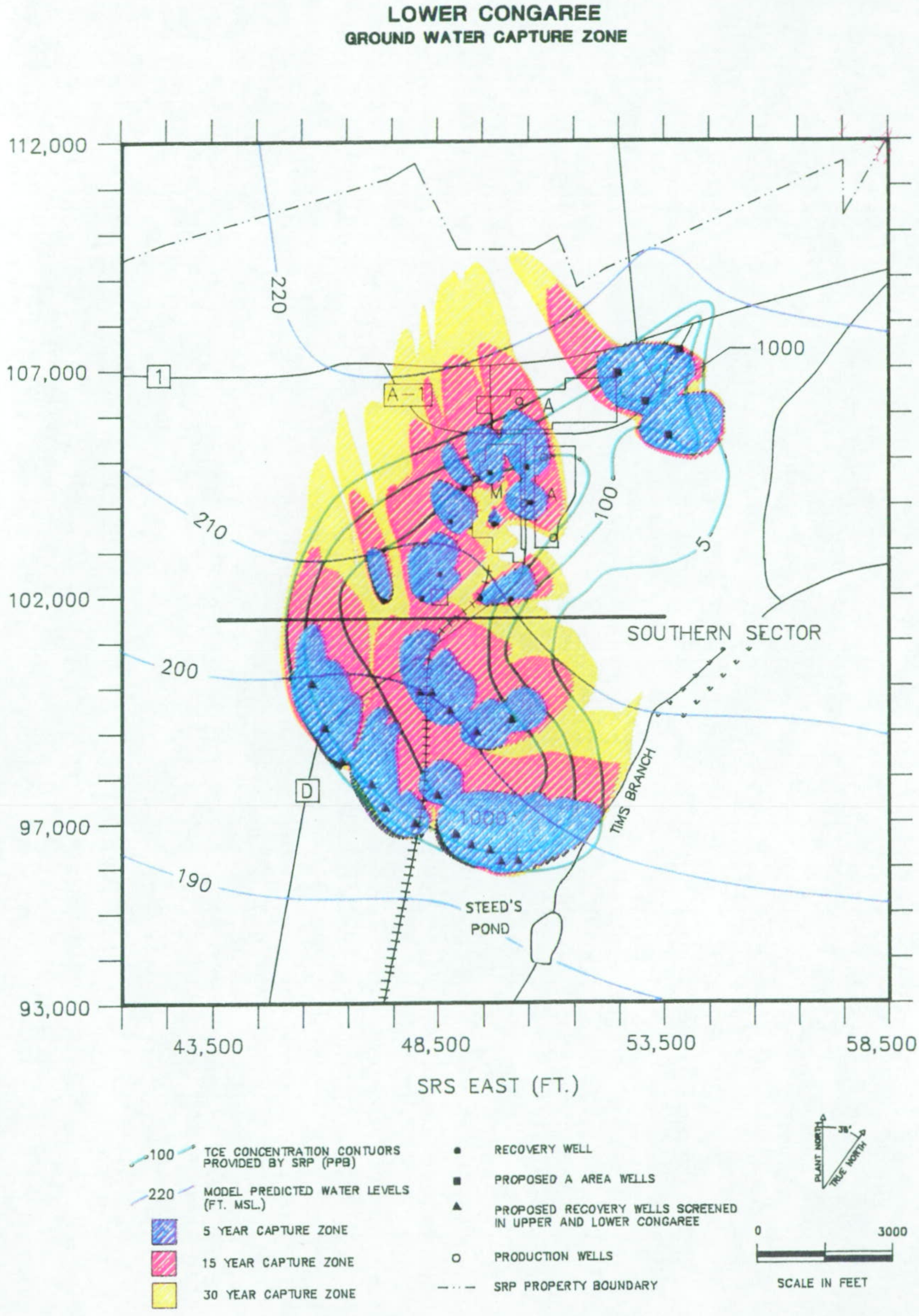

Figure 8. Scenario 1C: Proposed Southern Sector Recovery Wells Pumping 50 GPM from Upper and Lower Congaree.

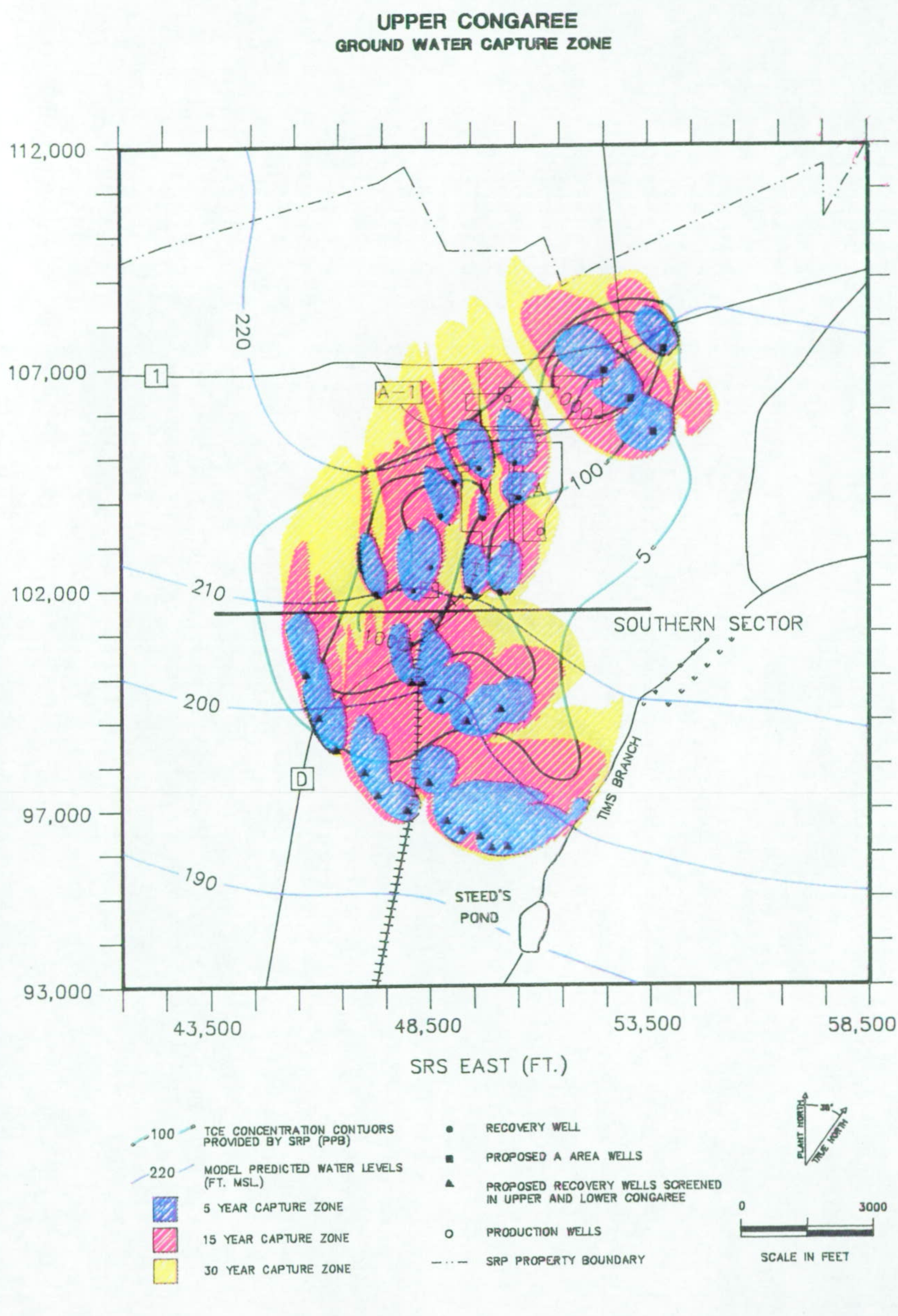

Figure 9. **Scenario 1C: Proposed Southern Sector Recovery Wells Pumping 50 GPM from Upper and Lower Congaree.**

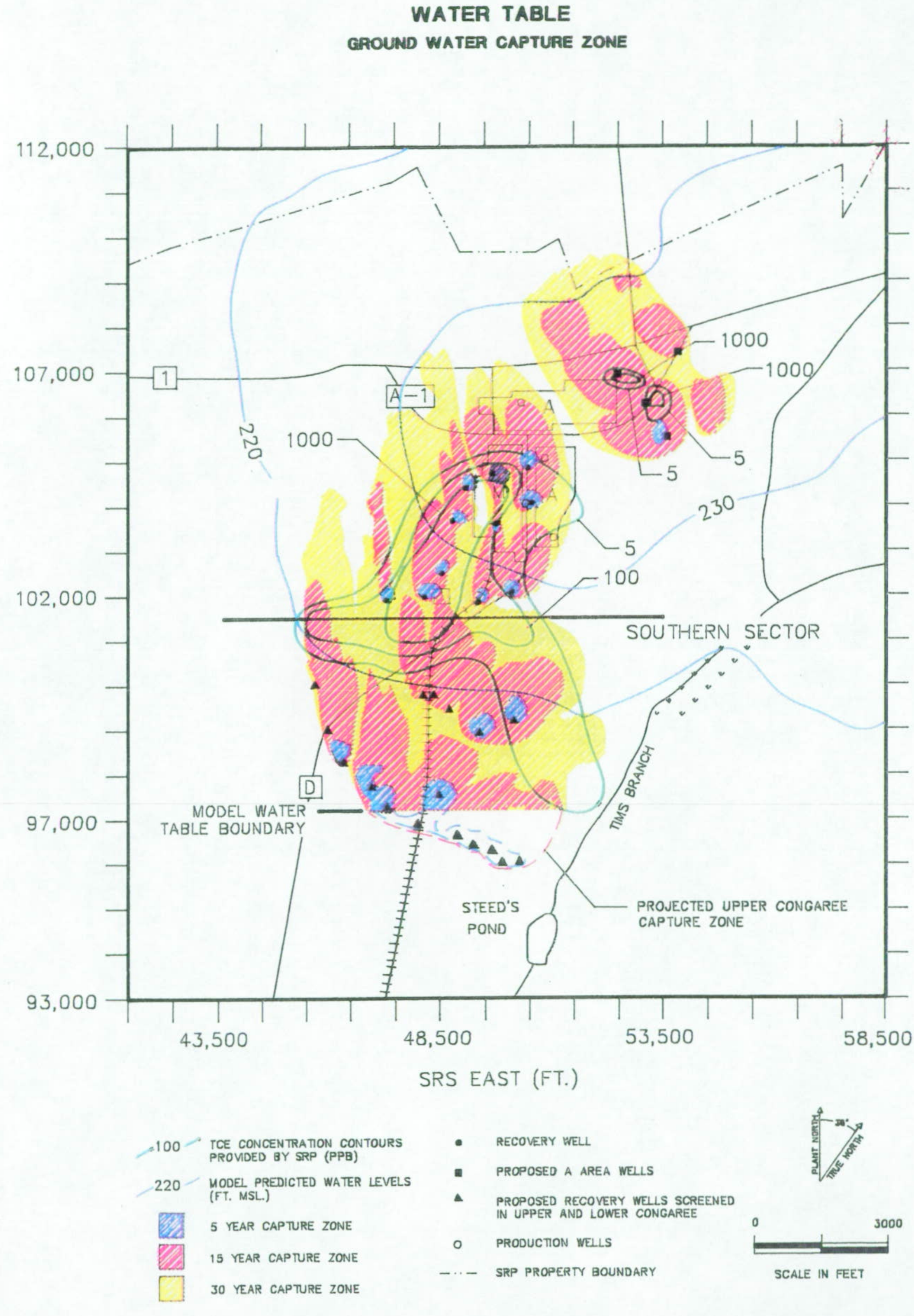

Figure 10. **Scenario 1C: Proposed Southern Sector Recovery Wells Pumping 50 GPM from Upper and Lower Congaree.**

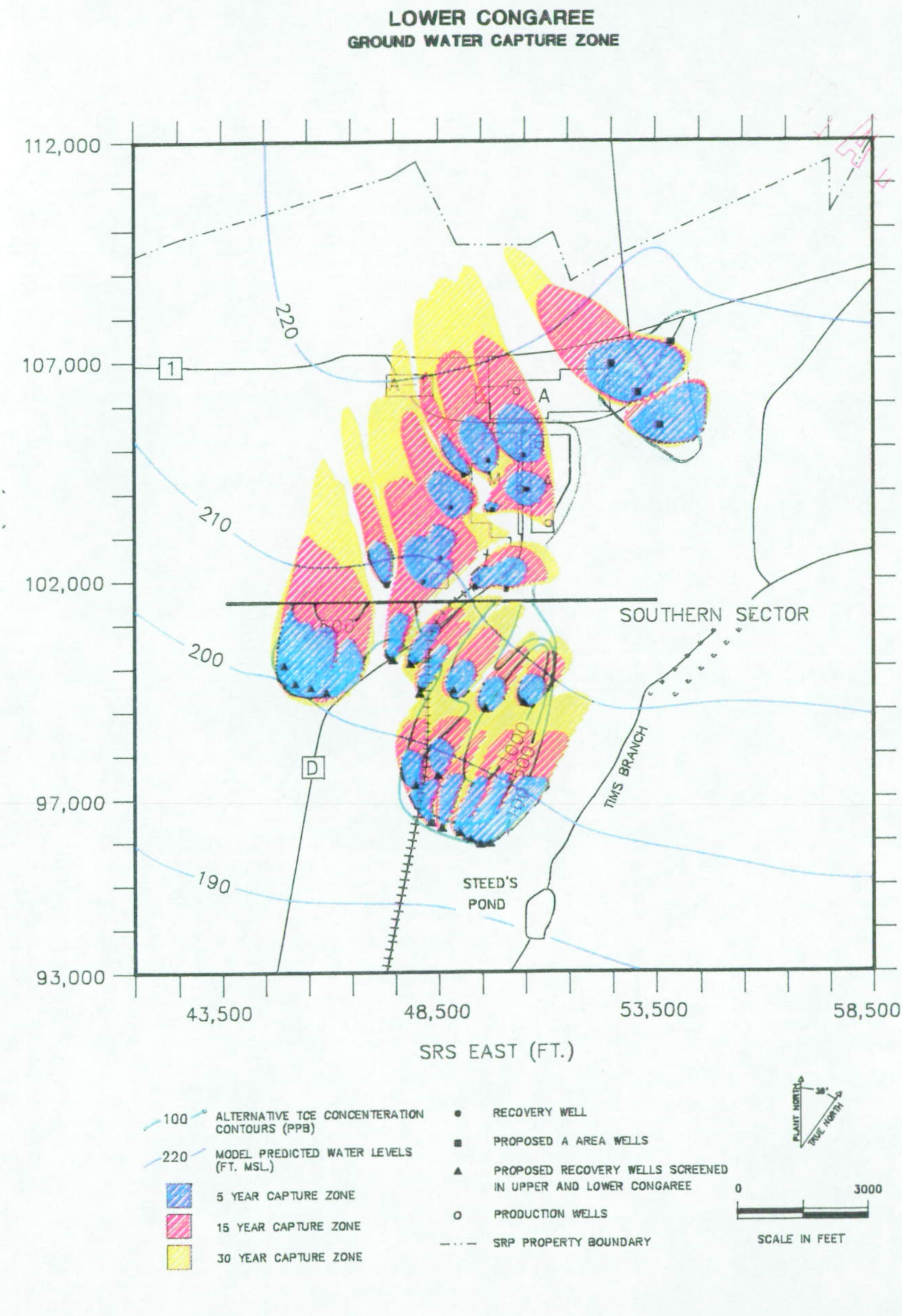

Figure 11. Scenario 2A: Proposed Southern Sector Recovery Wells Pumping 30 GPM from Upper and Lower Congaree. Alternative TCE Concentration Contours for the Lower Congaree.

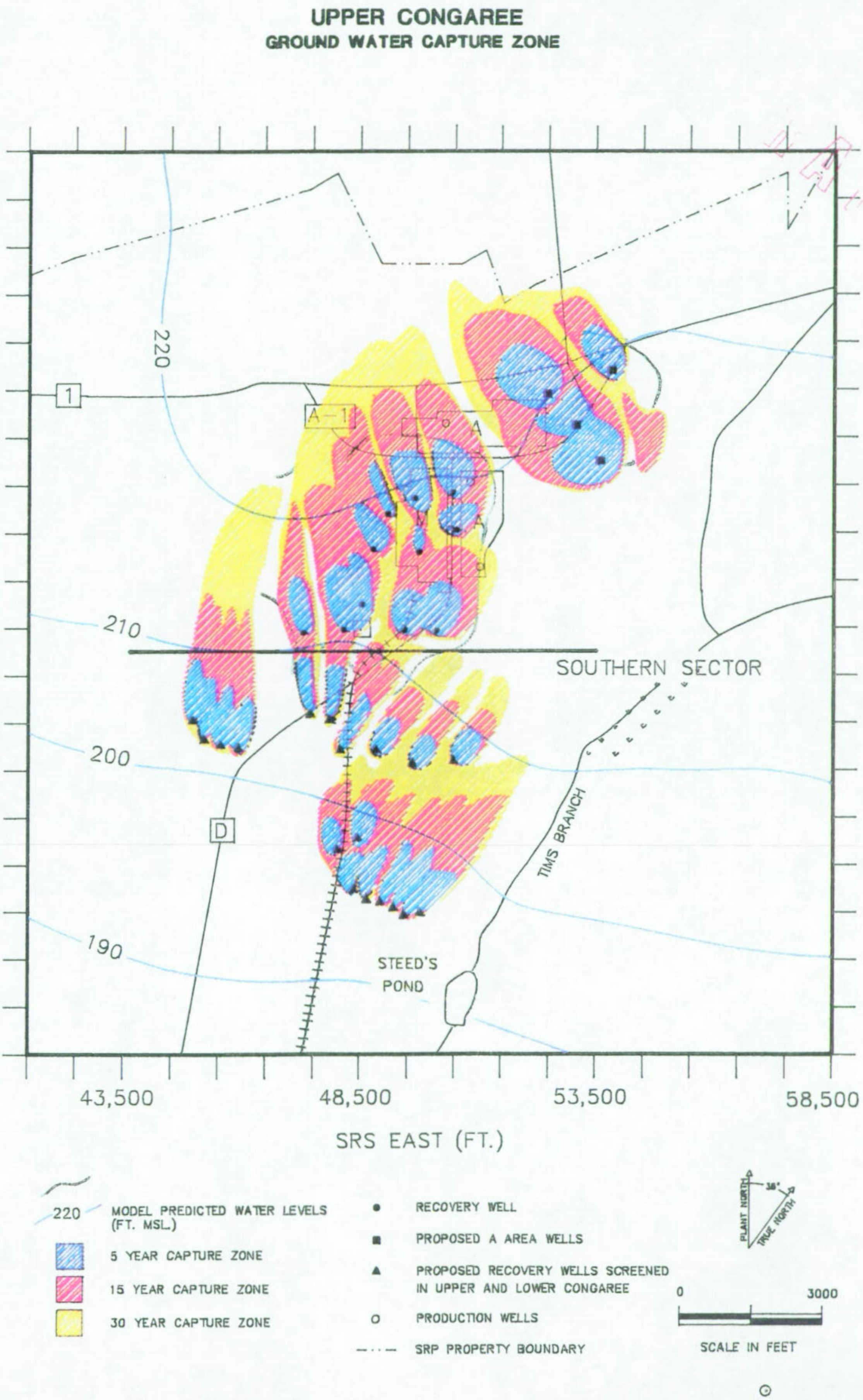

Figure 12. **Scenario 2A: Proposed Southern Sector Recovery Wells Pumping 30 GPM from Upper and Lower Congaree.**

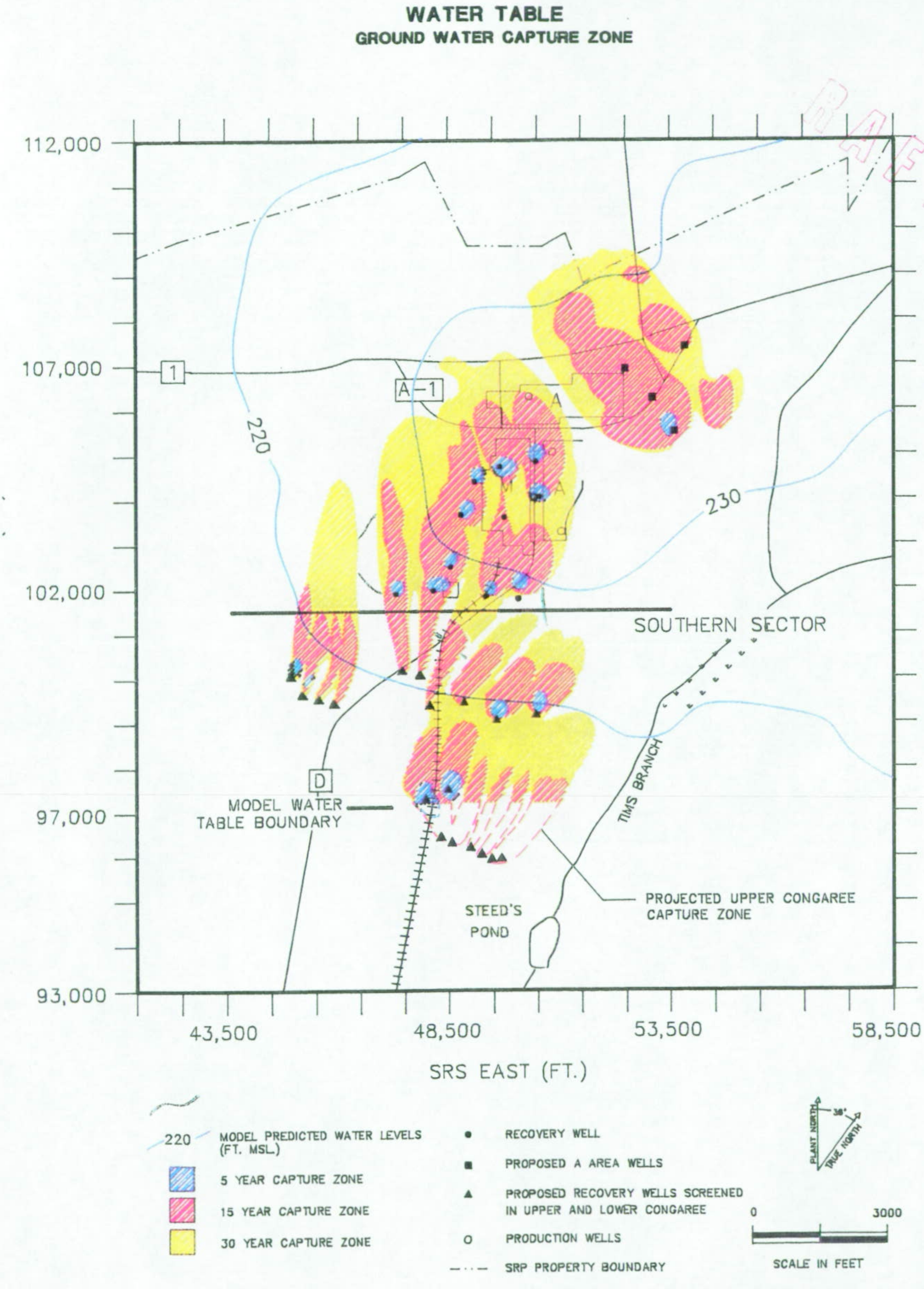

Figure 13. **Scenario 2A: Proposed Southern Sector Recovery Wells Pumping 30 GPM from Upper and Lower Congaree.**

LOWER CONGAREE
GROUND WATER CAPTURE ZONE

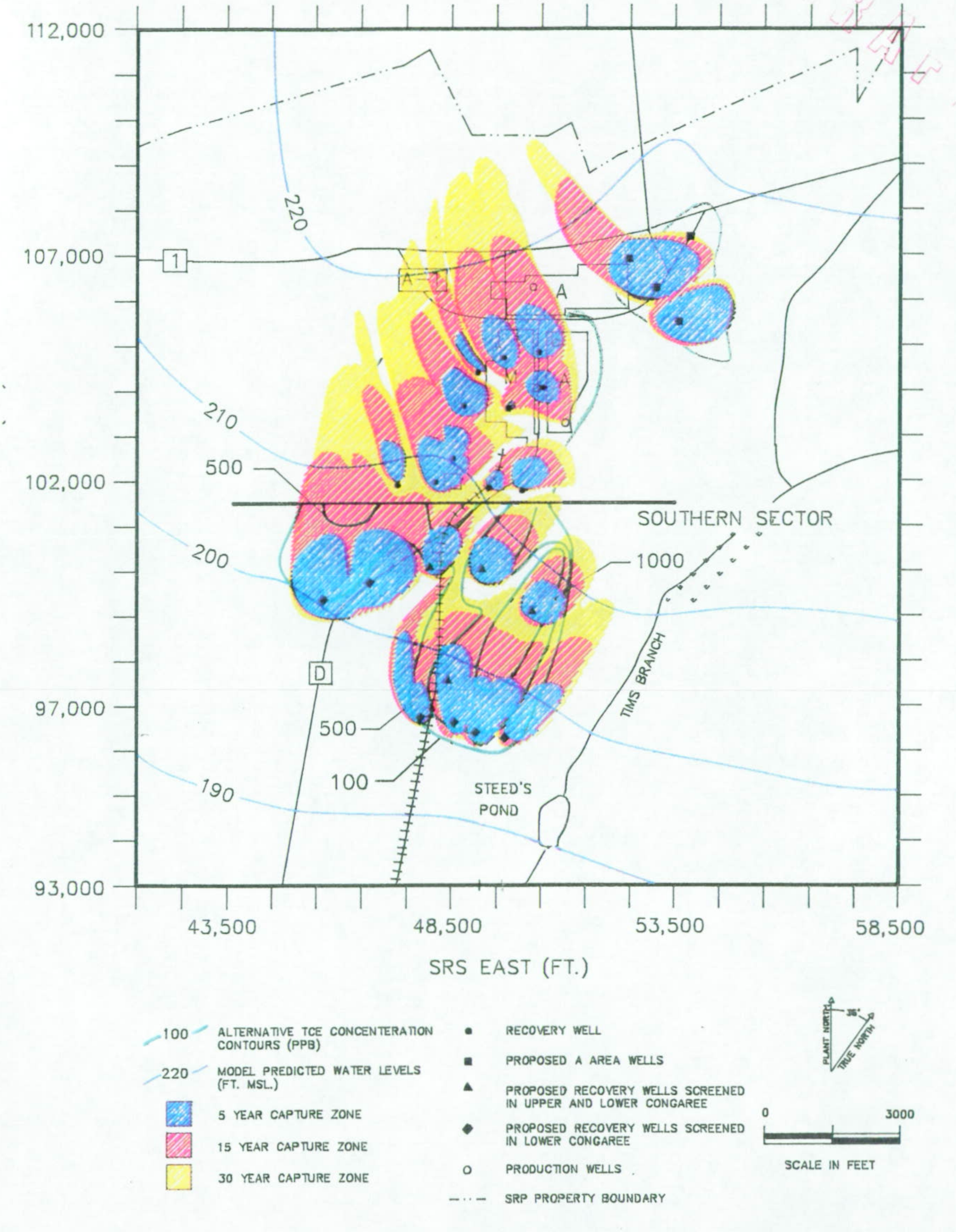

Figure 14. **Scenario 2B: Proposed Southern Sector Recovery Wells Pumping 50 GPM. Downgradient Wells Pumping from Lower Congaree Only. Alternative TCE Concentration Contours for Lower Congaree.**

UPPER CONGAREE
GROUND WATER CAPTURE ZONE

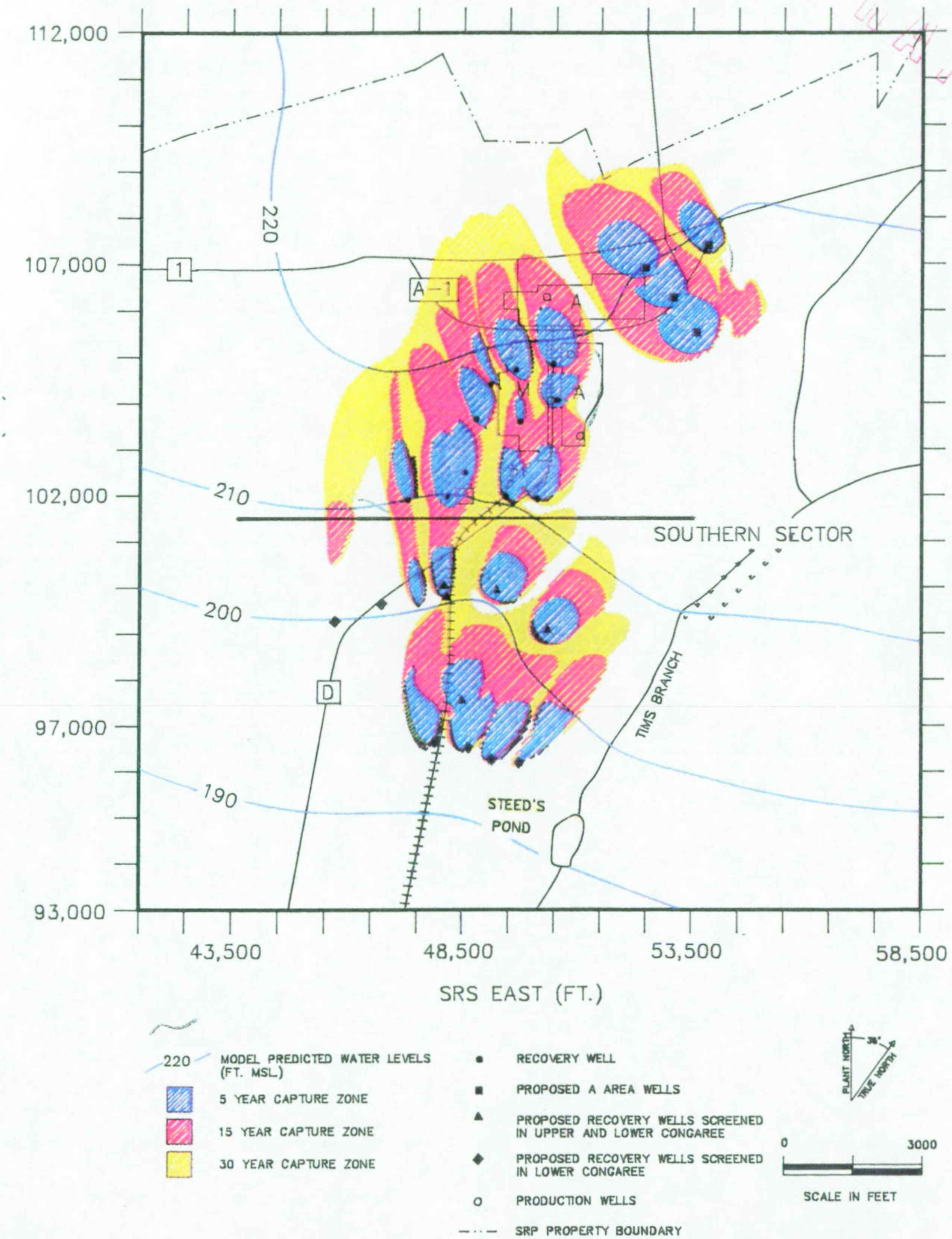

Figure 15. **Scenario 2B: Proposed Southern Sector Recovery Wells Pumping 50 GPM. Downgradient Wells Pumping from Lower Congaree Only**

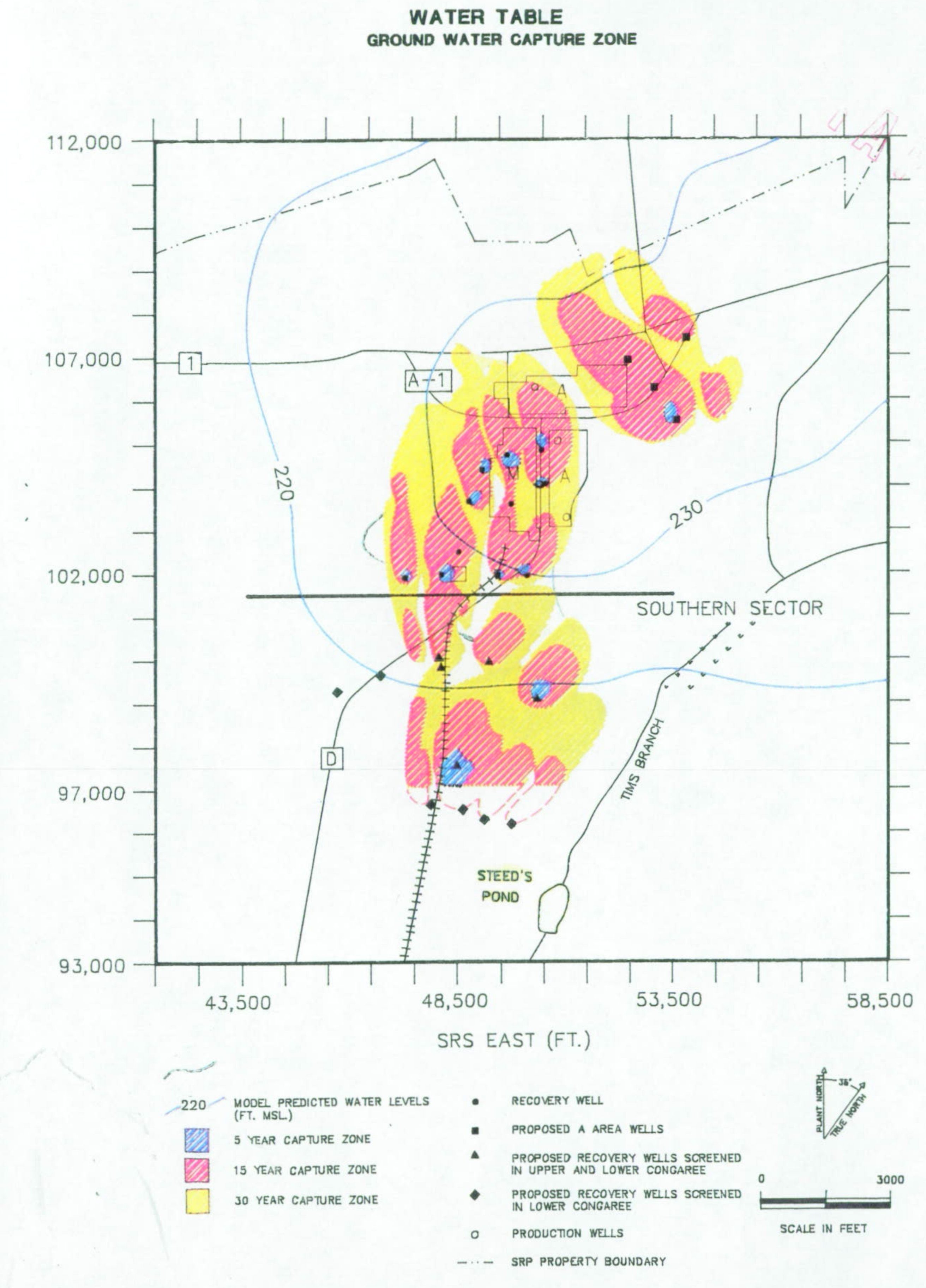

Figure 16. **Scenario 2B: Proposed Southern Sector Recovery Wells Pumping 50 GPM. Downgradient Wells Pumping from Lower Congaree Only.**

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APPENDICES

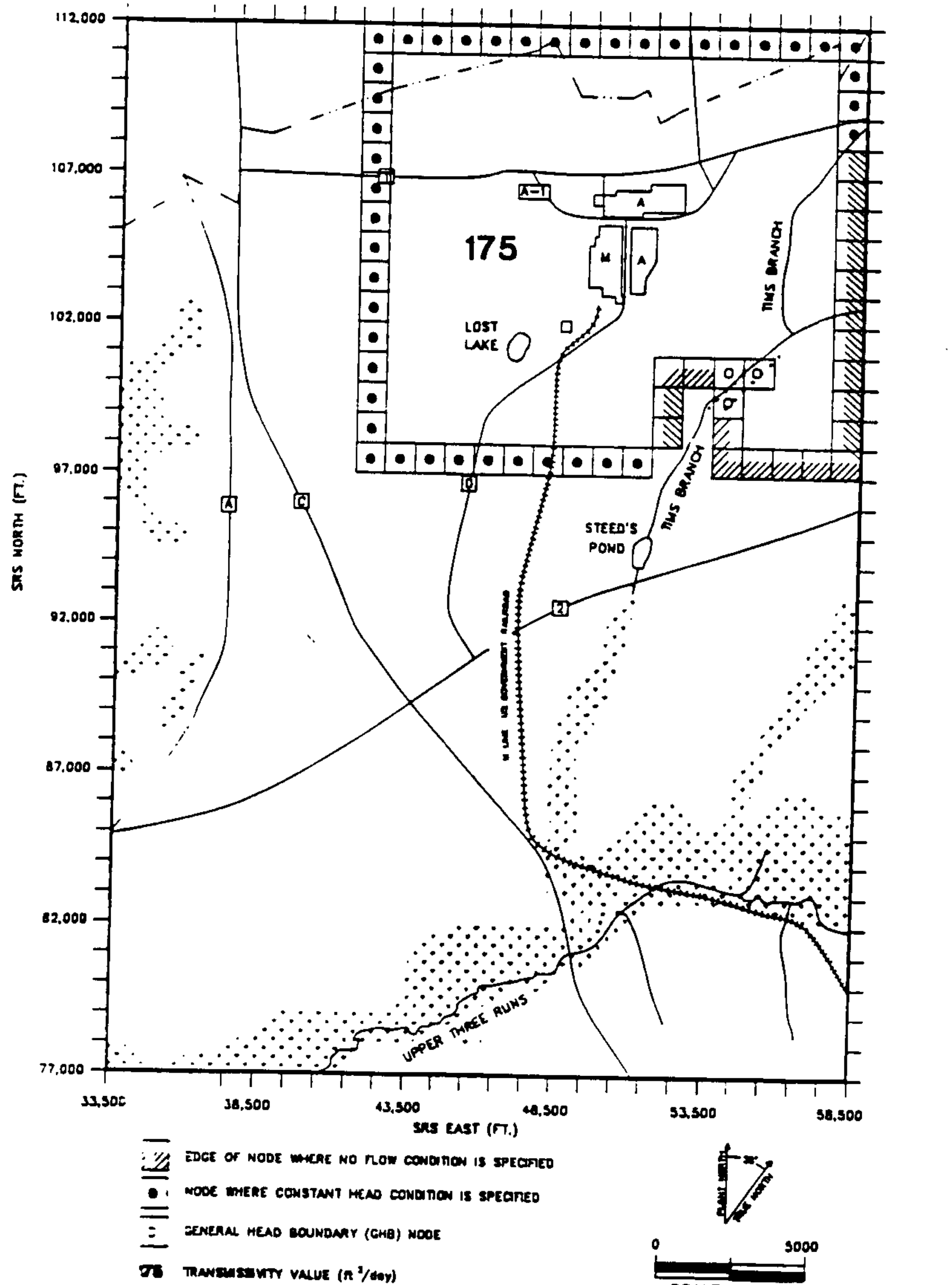


Figure 15. **Boundary Conditions and Transmissivity in Model Layer 1.**

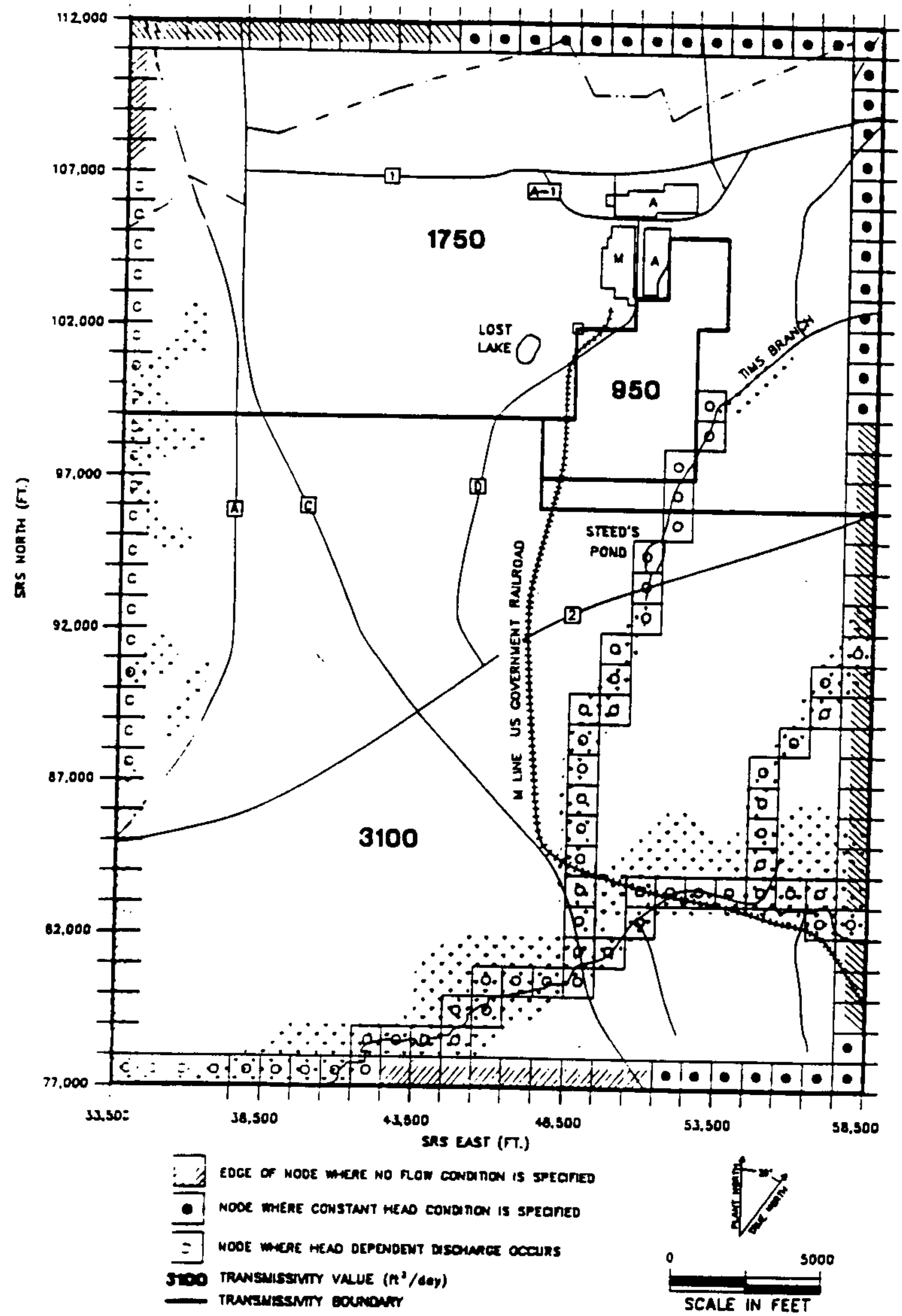


Figure 16. **Boundary Conditions and Transmissivity in Model Layer 2.**

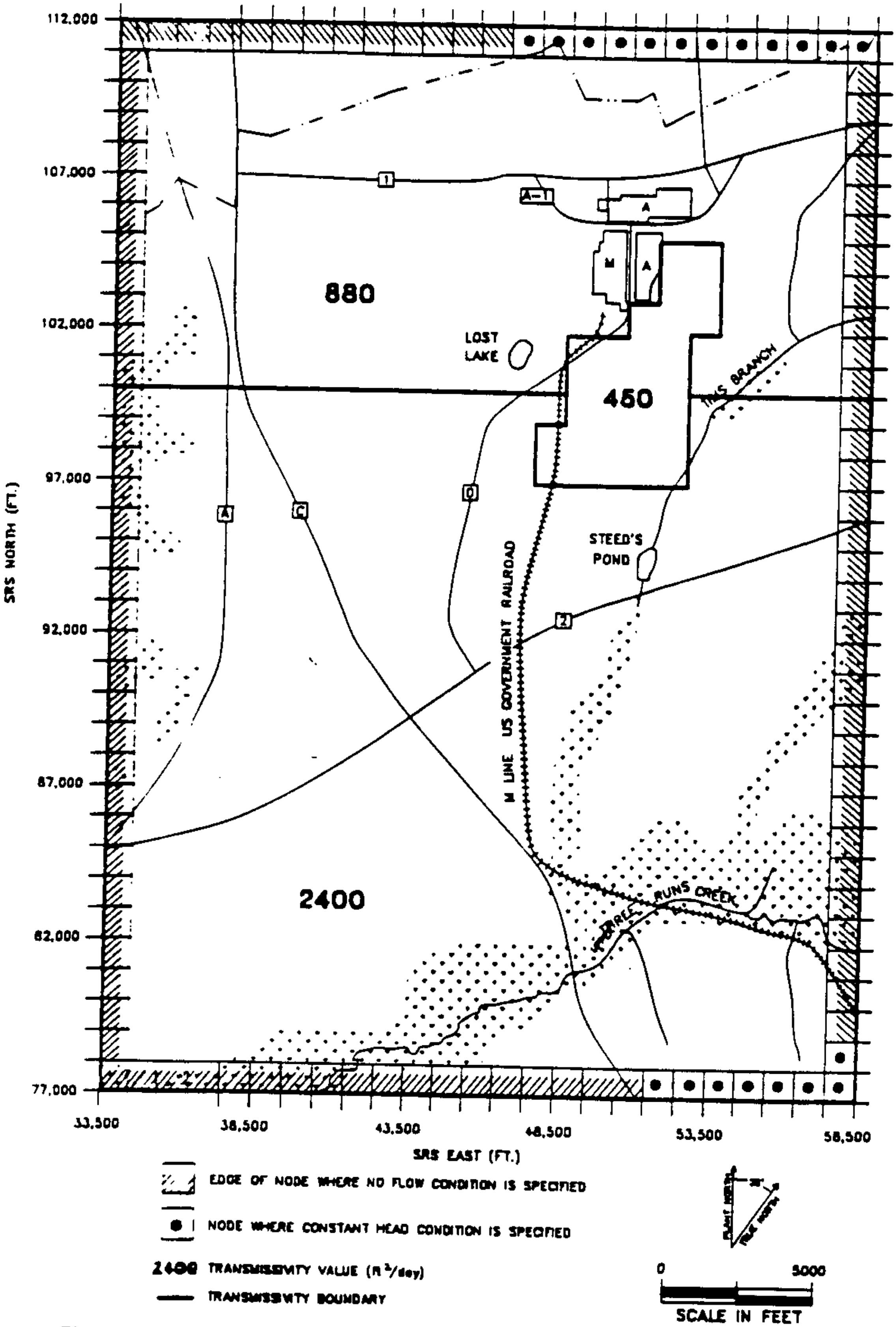


Figure 17. **Boundary Conditions and Transmissivity in Model Layer 3.**

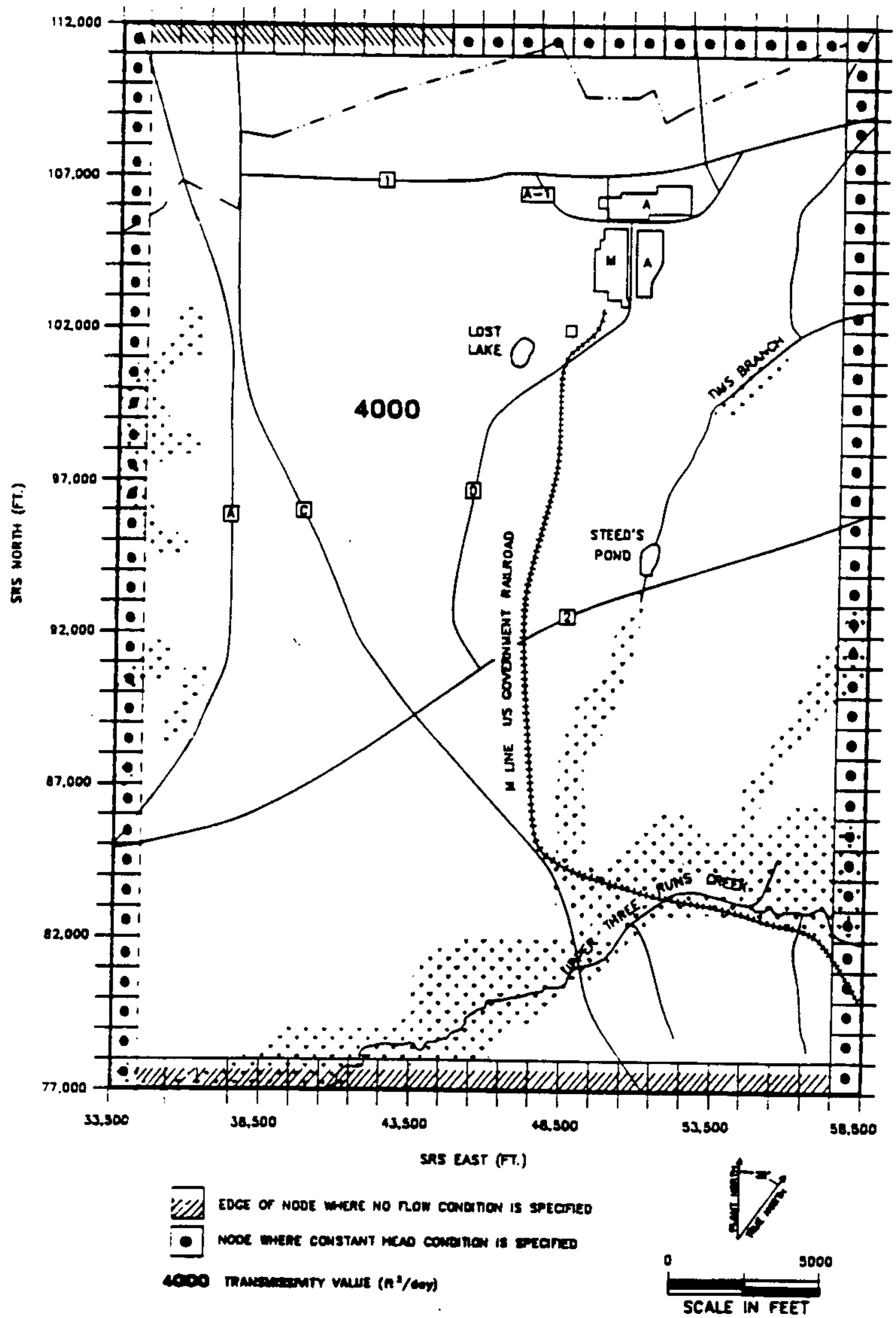


Figure 18. Boundary Conditions and Transmissivity in Model Layer 4.

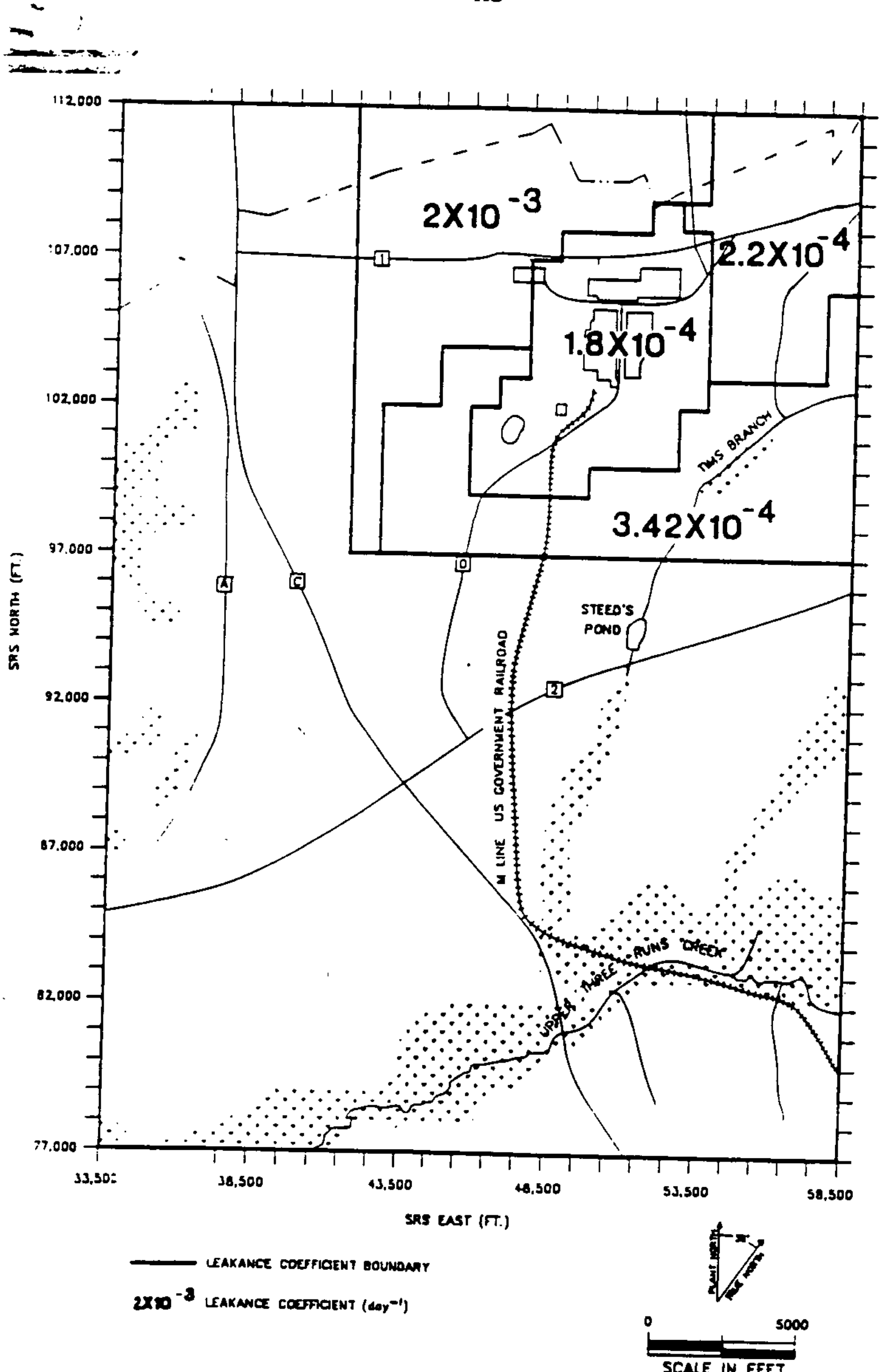


Figure 19. Calibrated Leakance Map for Model Layer 1.

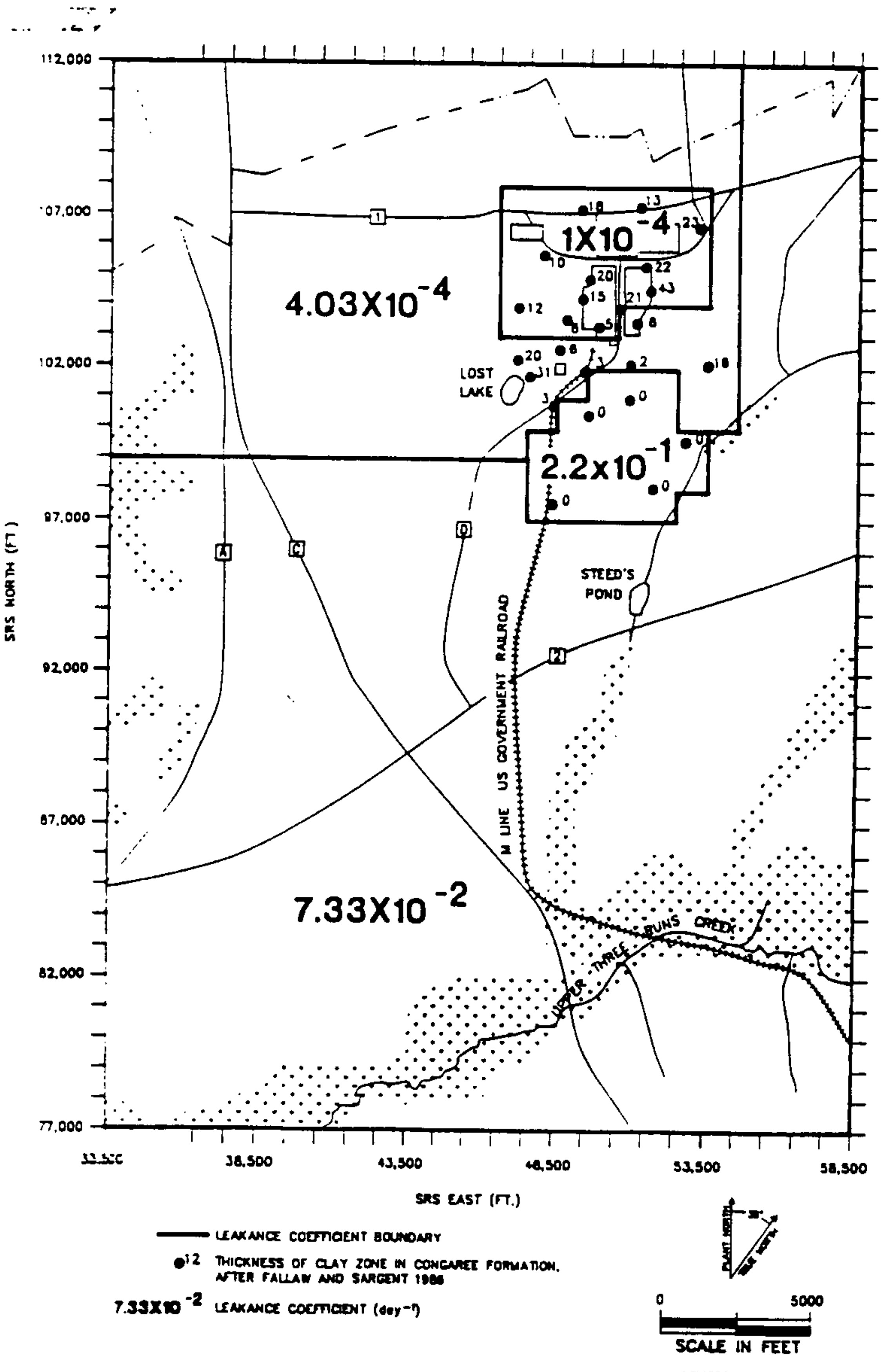


Figure 20. Calibrated Leakance Map for Model Layer 2.

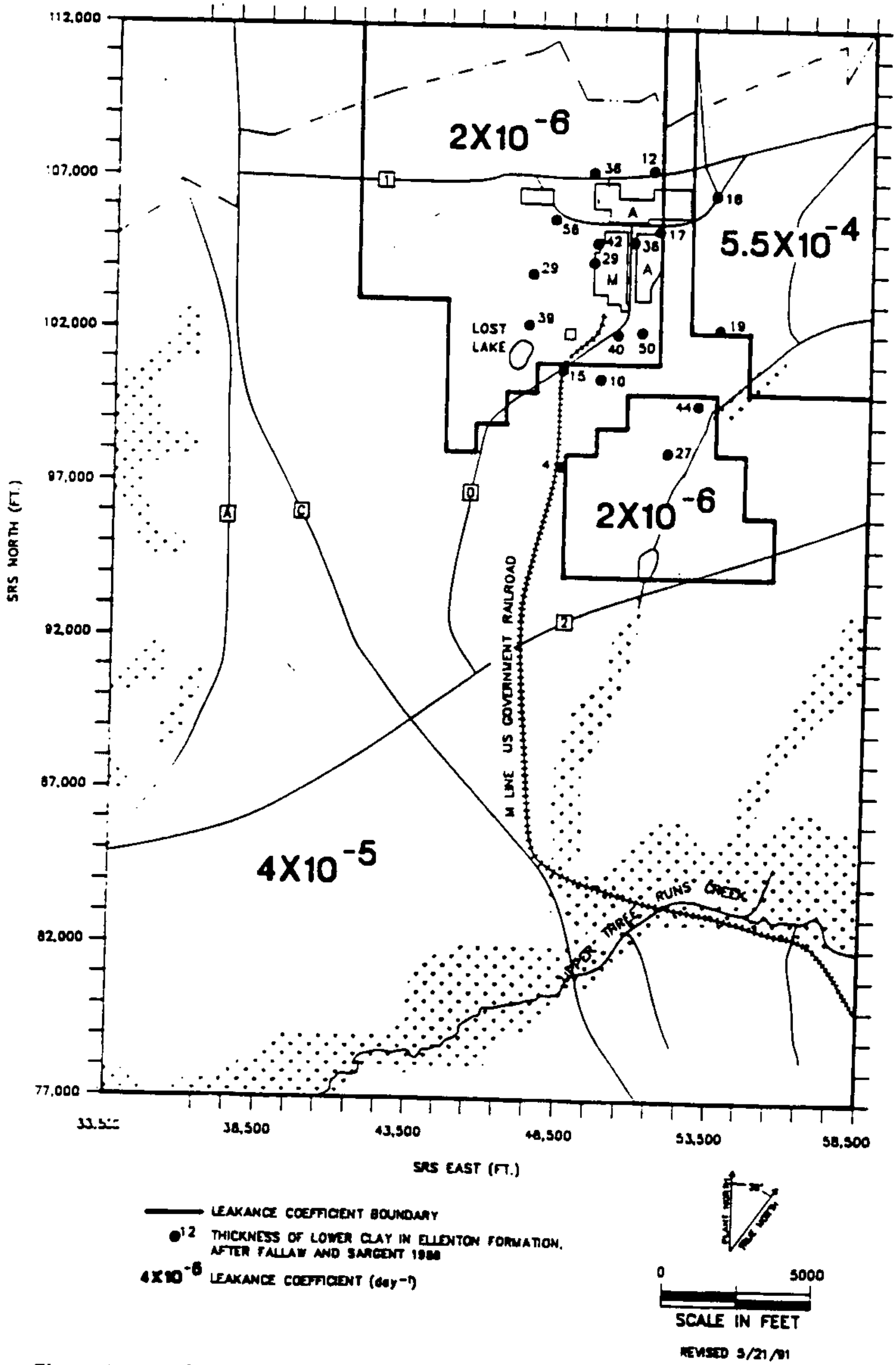


Figure ::. Calibrated Leakance Map for Model Layer 3.

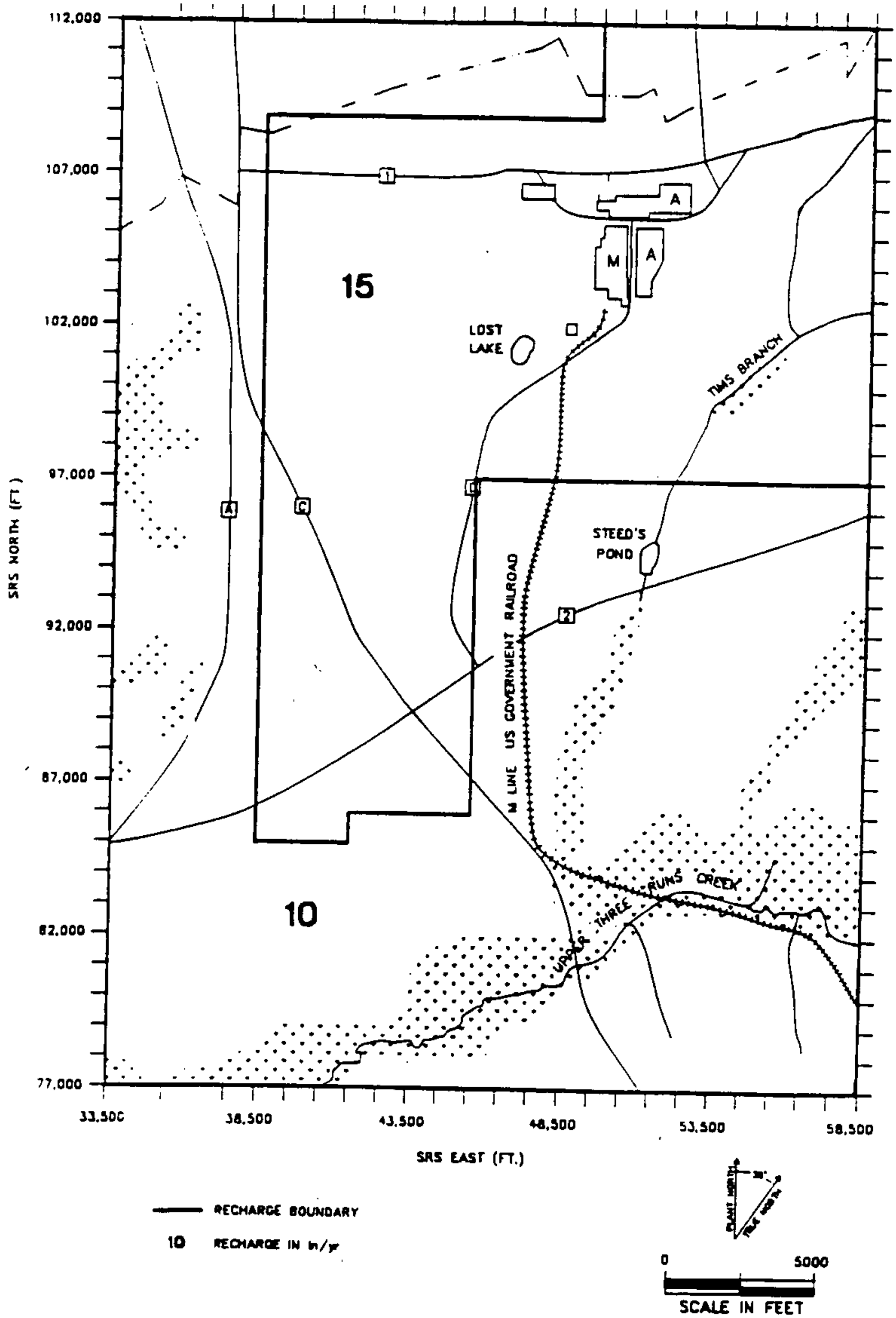
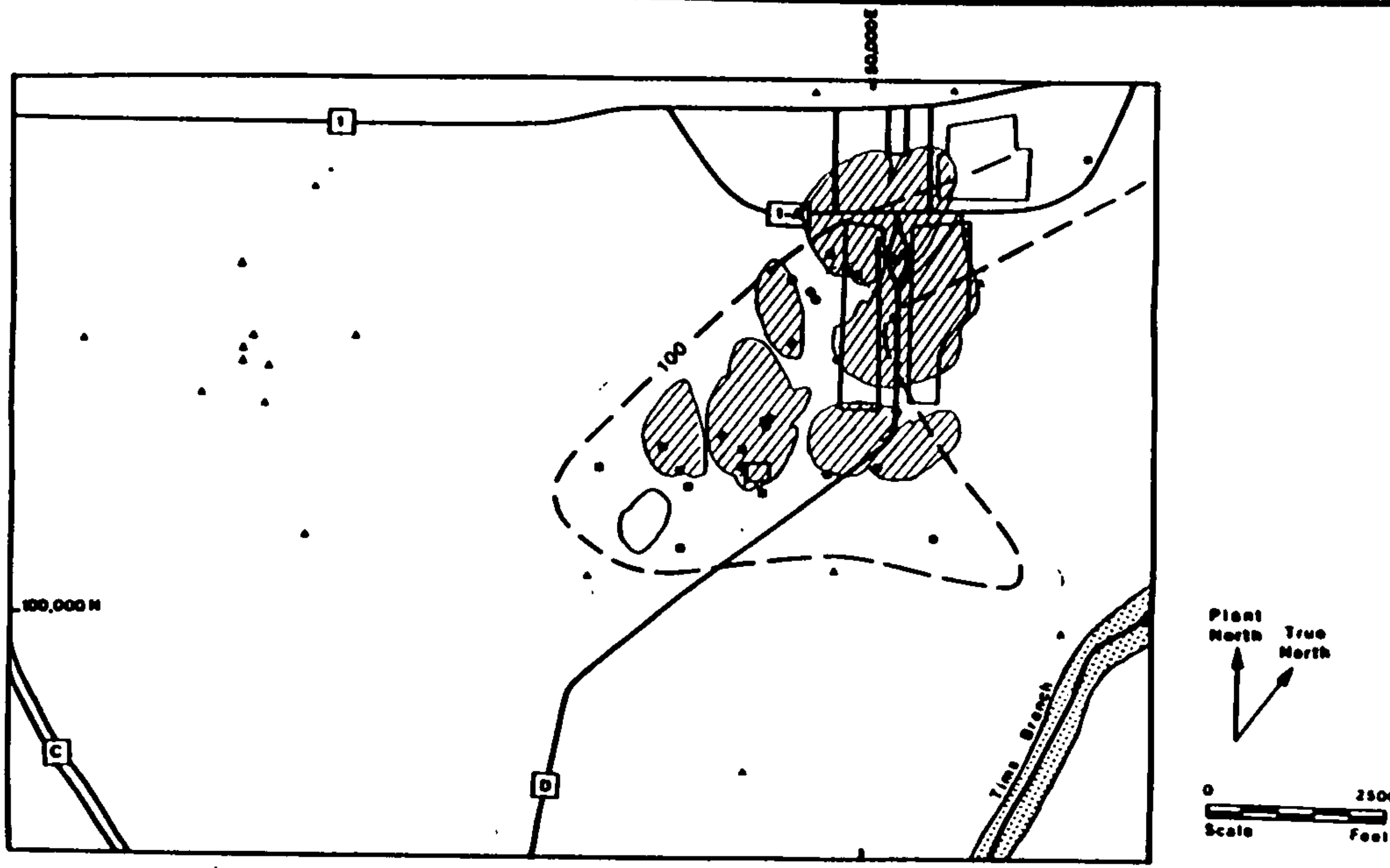


Figure 22. Modeled Rainfall Recharge.



EXPLANATION

Calculated Extent of Zone of Capture

Symbol	Value	
△	< 10	Average Total Volatile Organic Concentration in 1985, in ppb
▲	10-100	
■	100-1,000	
●	> 1,000	

—— 100 —— Estimated extent of ground water containing total volatile organics greater than 100 ppb

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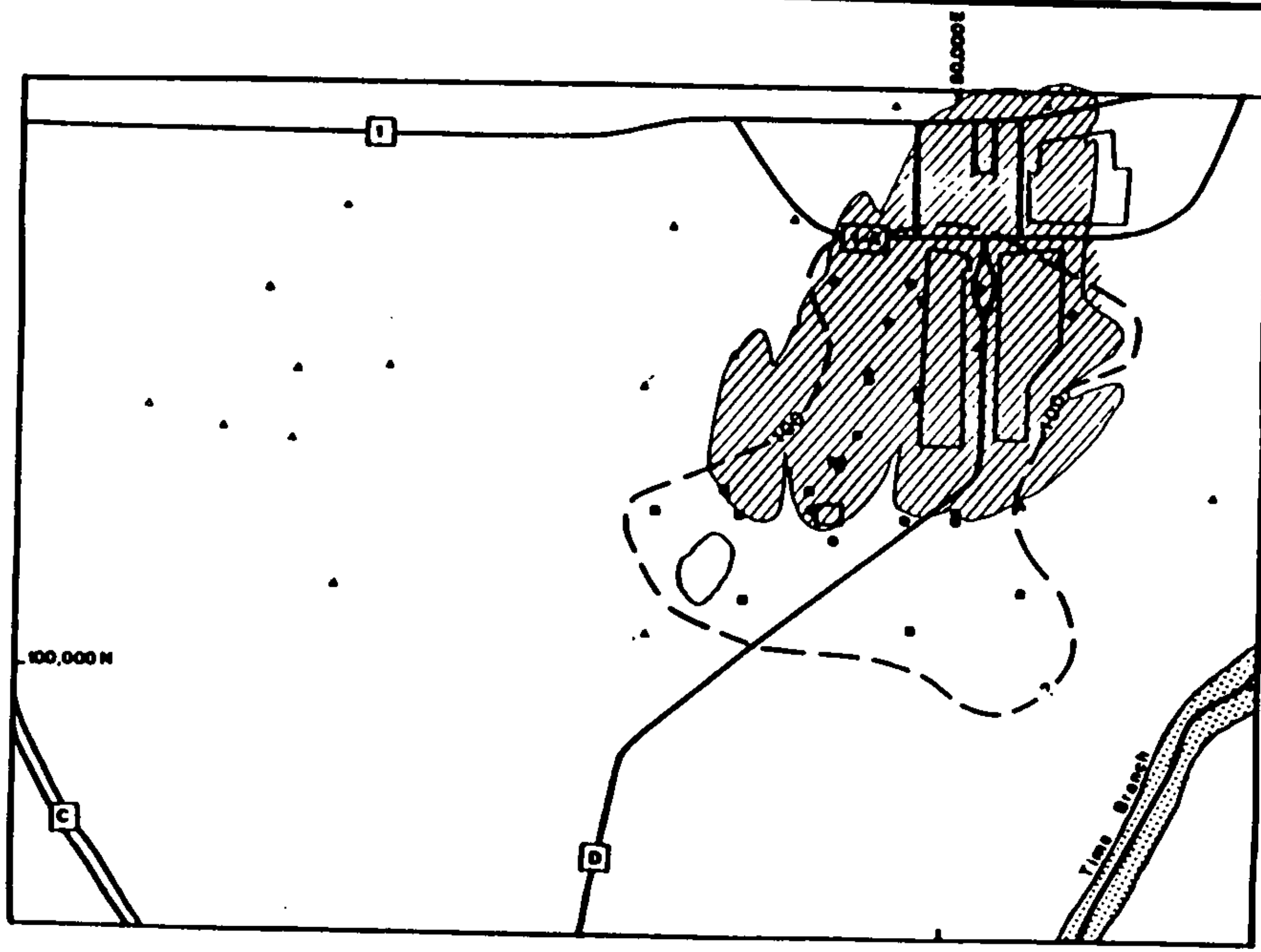
AVERAGE TOTAL VOLATILE ORGANIC CONCENTRATIONS IN 1985 AND CALCULATED AREAL EXTENT OF ZONE OF CAPTURE IN LAYER 3

FIGURE 5



EXPLANATION

Calculated Extent of Zone of Capture

- △ < 10
- ▲ 10-100
- ■ 100-1,000
- ● > 1,000

(Average Total Volatile Organic Concentration in 1985, in ppb)

—·100·— Estimated extent of ground water containing total volatile organics greater than 100 ppb

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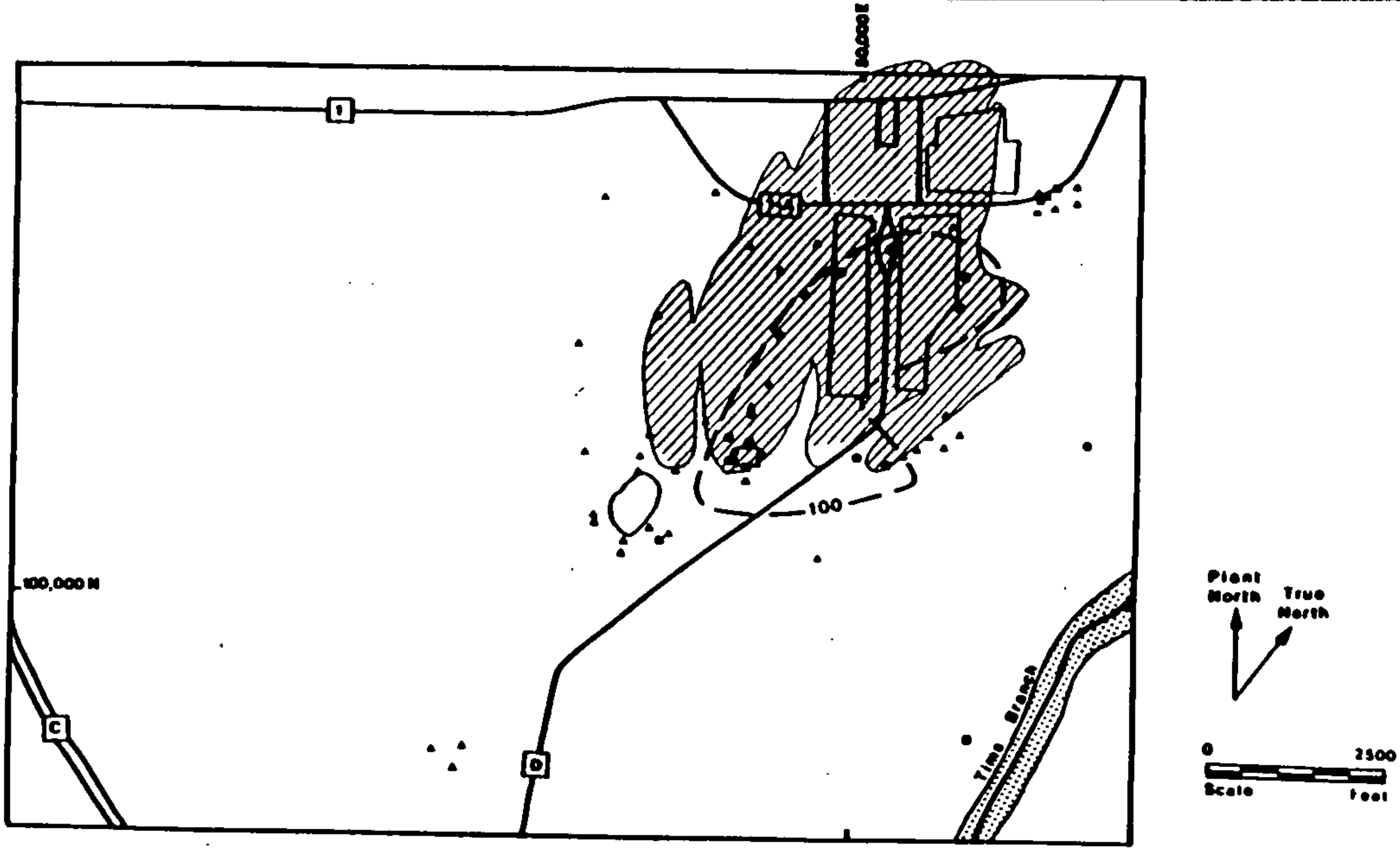
AVERAGE TOTAL VOLATILE ORGANIC CONCENTRATIONS IN 1985 AND CALCULATED AREAL EXTENT OF ZONE OF CAPTURE IN LAYER 2

FIGURE 6



EXPLANATION

Calculated Extent of Zone of Capture

Average Total Volatile Organic Concentration in 1985, in ppb:
- △ < 10
- ▲ 10–100
- ■ 100–1,000
- ● > 1,000

—— 100 —— Estimated extent of ground water containing total volatile organics greater than 100 ppb

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AVERAGE TOTAL VOLATILE ORGANIC CONCENTRATIONS IN 1985 AND CALCULATED AREAL EXTENT OF ZONE OF CAPTURE IN LAYER 1

FIGURE 7