Delineation of Time-of-Travel Capture Zones for Public Supply Wells Within and Around the Santa Rosa County Well Field Protection Area

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Introduction

As part of a Regional Water Supply Plan, the Northwest Florida Water Management District (District) has identified the inland Sand-and-Gravel aquifer between the Blackwater and Yellow Rivers as an alternative source of water supply to augment the continued use of the Floridan aquifer along the coast. Two public supply utilities currently withdraw water from the Sand-and-Gravel aquifer within the Santa Rosa County portion of the identified area. The two utilities are East Milton Water System, Inc. (East Milton) and Fairpoint Regional Utilities System, Inc. (FRUS). East Milton and FRUS are permitted to withdraw an annual average of 1.92 million gallons per day (Mgal/d) and 6.08 Mgal/d from the Sand-and-Gravel aquifer, respectively.

In 2010, Santa Rosa County created a Wellfield Protection Area (WPA) Overlay District as part of its Land Development Code (Ordinance 6.05.25) to expand on existing wellhead protection in the area and help protect this water supply source. The WPA covers approximately 27,000 acres between Hwy 90 on the north, the Santa Rosa/Okaloosa County line on the east, the Yellow River to the south, and Hwy 87 to the west. An Aquifer Vulnerability Assessment conducted by Advanced GeoSpatial Inc. (2011) recommended, in part, ground water modeling to determine the five-year time-of-travel capture zones for each of the East Milton/FRUS public supply wells.

At the request of the Santa Rosa County Board of County Commissioners (BCC), the District has delineated five-year and twenty-year time-of-travel capture zones for each of the East Milton/FRUS public supply wells using a previously developed numerical model (Countryman, 2012). As such, the capture zones contained herein are subject to the assumptions and limitations inherent to that previous work. Those assumptions and limitations include the appropriateness of the following modeling aspects: the underlying conceptual model, the modeled boundary conditions, the modeled hydraulic properties, and the original calibration.

Capture Zone Delineation

Capture zones are delineated for twelve public supply wells in the East Milton area using the USGS modeling codes MODFLOW-2000 (Harbaugh and others, 2000) and MODPATH (Pollock, 1994). MODFLOW was used to simulate regional and local-scale ground water flow and MODPATH was used to delineate the time-of-travel capture zones. The three-dimensional, ground water flow model used to delineate the capture zones incorporates components of both horizontal and vertical flow. The size and shape of a well's capture zone depends on several factors which affect the ground water flow field. These factors include the hydraulic properties of the aquifer, hydrologic conditions, and pumping rates.

The hydraulic property values and distributions used to delineate the capture zones were the same as those used in the calibrated regional model (Countryman, 2012). Zonation of the hydraulic properties, as in the regional model, can cause distortions in the shape of the capture zones where the capture zones cross property zone boundaries. Preliminary modeling did not indicate any capture zone shape distortion as a result of hydraulic property zonation in the regional model. Therefore, it was unnecessary to modify the hydraulic property zonation for the local-grid scale modeling and capture zone analysis. To determine the time-of-travel of a simulated particle, an estimate of the aquifer porosity is required. Based on the analysis of soil samples collected during the regional ground water resource assessment, the formation porosity of the Sand-and-Gravel aquifer was estimated to range between 0.2 and 0.3. A mean porosity value of 0.25 was used for all particle tracking simulations.

In addition to aquifer properties, the size and shape of the capture zones depends on simulated hydrologic conditions. An average recharge value of 20 inches/year was uniformly applied to the water table for the regional and local-grid simulations. This recharge estimate is based on previous stream-baseflow analysis and ground water modeling results. Also, average hydrologic conditions were applied to head-dependent model boundaries which represent creeks, major streams, and Blackwater Bay. Average (Q50) values of flow and stage based on an evaluation of available data were assigned to these boundaries.

The magnitude and distribution of simulated pumping also influences the size and shape of the capture zones. As previously stated, East Milton and FRUS are currently permitted to withdraw an annual average 1.92 Mgal/d and 6.08 Mgal/d from the Sand-and-Gravel aquifer, respectively. The permitted average daily rates were apportioned among the wells of the respective utilities based on the maximum well capacities as listed on their water use permits. For example, the maximum permitted daily yield for East Milton #1 is 864,000 gallons which represents 16.9 % of the maximum daily yield for all wells in the system. Therefore, the simulated pumping for East Milton #1 is 16.9 % of the permitted average daily rate (ADR) of 1.92 Mgal/d, or 324,507 gallons per day. Table 1 summarizes how the simulated pumping was apportioned among wells for these two public supply systems. Pumping for all wells was simulated simultaneously to incorporate the effects of nearby pumping on the shape of the capture zones.

Table 1. Summary of Simulated Pumping used to Delineate Capture Zones.

East Milton Water System, Inc. Permitted ADR [(1)]: 1,920,000 gpd [(2)] from the S&G Aquifer			
Well#	max daily yield (gpd)	% system max	simulated ADR pumping (gpd)
1	864,000	16.9%	324,507
2	864,000	16.9%	324,507
4	1,440,000	28.2%	540,845
5	864,000	16.9%	324,507
6	1,080,000	21.1%	405,634

(1) ADR – average daily rate, (2) gpd – gallons per day

Table 1 (continued). Summary of Simulated Pumping used to Delineate Capture Zones.

Fairpoint Regional Utility System, Inc. Permitted ADR [1] 6,080,000 gpd [2] from the S&G Aquifer			
Well#	max daily yield (gpd)	% system max	simulated ADR pumping (gpd)
1	2,160,000	26.3%	1,600,000
3A	576,000	7.0%	426,667
3B	576,000	7.0%	426,667
4	1,440,000	17.5%	1,066,667
5	1,440,000	17.5%	1,066,667
6	1,440,000	17.5%	1,066,667
7	576,000	7.0%	426,667

(1) ADR – average daily rate, (2) gpd – gallons per day

Using the previously calibrated aquifer properties, average hydrologic conditions, and the above summarized pumping rates, the regional ground water model was run to simulate the three-dimensional ground water flow field. The delineation of the time-of-travel capture zones using the numerical modeling method can produce unnatural distortions in the size and shape of the zones as a result of the spatially discretized nature of the model grid. The regional model is vertically discretized into three layers of variable thickness and horizontally discretized into a regularly-spaced grid of cells with dimensions of 656 feet x 656 feet. The resulting horizontal grid consists of 95 rows and 230 columns. To better resolve and smooth the shape of the capture zones, the vertical discretization was increased to seven layers. The thin, low permeability zone (LPZ) was divided into two equal layers and the thicker main-producing zone was divided into four equal layers. Also, the horizontal grid spacing around each well was reduced to approximately 50 feet x 50 feet using the Telescopic Mesh Refinement method. This resulted in eleven local-grid models which vary in total number of rows and columns. To provide boundary heads for the local-grid models, the regional model was run in transient mode for a period of twenty years. Transient simulations take into account the change in water levels along the local-grid model boundaries.

Once the local-grid models were run, the resulting ground water flow fields were used by MODPATH to backtrack virtual particles toward the water table. Run in reverse mode, MODPATH tracks the direction and velocity of the virtual particles within each model cell back toward recharge areas. Within each local-grid model, the vertical column of model cells, which includes the simulated well, was “seeded” with 5,360 virtual particles. This number of virtual particles was found through testing to result in more refined capture zone delineations, while allowing the processing of the cell-by-cell particle traces to be executed in a reasonable amount of time. Individual particle traces were imported into the GIS application ArcMap to complete the capture zone delineations. The particle traces which intersected the simulated water table were used to generate polygons that represent the extent of the five-year and twenty-year time-of-travel capture zones. Due to the close proximity of public supply wells FRUS #3A and FRUS #3B, the twenty-year time-of-travel capture zones overlap and are represented by a single polygon.

Conceptually, the respective time-of-travel capture zones are associated with water particles starting at the water-table surface and do not take into account the time necessary for water at land surface to reach the water table. In upland areas where the water table may be as much as 90 – 100 feet below land surface, the travel time through the unsaturated zone may be significant. Therefore, it is important to note that when evaluating land use activities at the surface, the travel times associated with the capture zones are conservative (i.e. the travel time from land surface to the well is longer than the time associated with the capture zone).

Results

The 5-year and 20-year time-of-travel capture zones were delineated for twelve public supply wells in the East Milton area using the above described procedure. The capture zones for all public supply wells are shown in Figure 1 in relation to the existing WPA Overlay District and the Florida Department of Environmental Protection (FDEP) Source Water Protection Areas. Table 2 summarizes the area covered by the respective capture zone polygons for each public supply well. The table also breaks down how much area of the delineated 20-year time-of-travel capture zones is within and outside of the existing WPA. As delineated, approximately 79% is within the existing WPA and approximately 21% is outside; indicating a good portion of the recharge area for the public supply wells is being protected by the existing wellfield ordinance. More detailed maps of the capture zones for the individual wells are provided in Figures 2 through 12. Information provided in this report can be used by the Santa Rosa County BBC and the local community to evaluate the sufficiency of the existing public supply wellhead protection program in the East Milton area.

Table 2. Summary of the Areal Extent of the 5-year and 20-year Time-of-Travel Capture Zones.

	Capture Zone Area (acres)		20-yr TOT Inside WPA		20-yr TOT Outside WPA	
Well Name	5-yr TOT	20-yr TOT	Acres	%	Acres	%
East Milton #1	7.43	109.15	82.89	76%	26.26	24%
East Milton #2	10.51	115.17	115.17	100%	0.00	0%
East Milton #4	19.08	185.35	17.30	9%	168.05	91%
East Milton #5	8.65	108.92	0.00	0%	108.92	100%
East Milton #6	14.76	147.94	0.00	0%	147.94	100%
FRUS #1	44.52	542.62	458.42	84%	84.21	16%
FRUS #3A	18.29	323.45	323.45	100%	0.00	0%
FRUS #3B	18.74					
FRUS #4	45.69	392.91	392.91	100%	0.00	0%
FRUS #5	43.84	379.22	379.22	100%	0.00	0%
FRUS #6	52.07	388.71	388.71	100%	0.00	0%
FRUS #7	16.12	151.00	99.18	66%	51.82	34%
		Total	2,257.25	79%	587.21	21%

Capture Zone Sensitivity to Hydrologic Conditions

To evaluate the sensitivity of the size and shape of the capture zones to a change in hydrologic conditions (e.g. periods of extended drought), 20-year time-of-travel capture zones were delineated for FRUS #1 and East Milton #5 under low hydrologic conditions. Low hydrologic conditions were simulated as a uniform recharge value of 13 inches/year and Q90 flow and stage values for the head-dependent boundaries. Under average hydrologic conditions, FRUS #1 was the largest delineated capture zone (542.62 acres) and East Milton #5 was the smallest delineated capture zone (108.92 acres). Under low hydrologic conditions, the shapes of the 20-year time-of-travel capture zones were essentially the same, but the size of the capture zones for FRUS #1 and East Milton #5 increased to 804.72 acres and 158.93 acres, respectively. This represents a capture zone area increase of approximately 48% for FRUS #1 and 46% for East Milton #5. Although capture zones for the other wells were not delineated under low hydrologic conditions, it is estimated that their size would also increase by the same proportions.

References:

Advanced Geospatial Inc., 2011, Assessment of the Extent and Effectiveness of the WPA and Wellfield Protection Ordinance; Final Report to Santa Rosa County, Florida, AGI Project No. PR2011-03.

Countryman, T., 2012 (report in review), Three Dimensional Transient Ground Water Flow Model of the Inland Sand-and-Gravel Aquifer Between the Blackwater and Yellow Rivers, Santa Rosa and Okaloosa Counties, Florida: Northwest Florida Water Management District, Water Resource Assessment ##, 102 p.

Harbaugh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G., 2000, MODFLOW-2000, the U.S. Geological Survey modular ground-water model – User guide to modularization concepts and the ground-water flow process: U.S. Geological Survey Open-File Report 00-92, 121 p.

Pollock, D.W., 1994, User's Guide for MODPATH/MODPATH-PLOT, Version 3: A particle tracking post-processing package for MODFLOW, the U.S. Geological Survey finite-difference ground-water flow model, U.S. Geological Survey Open-File Report 94-464

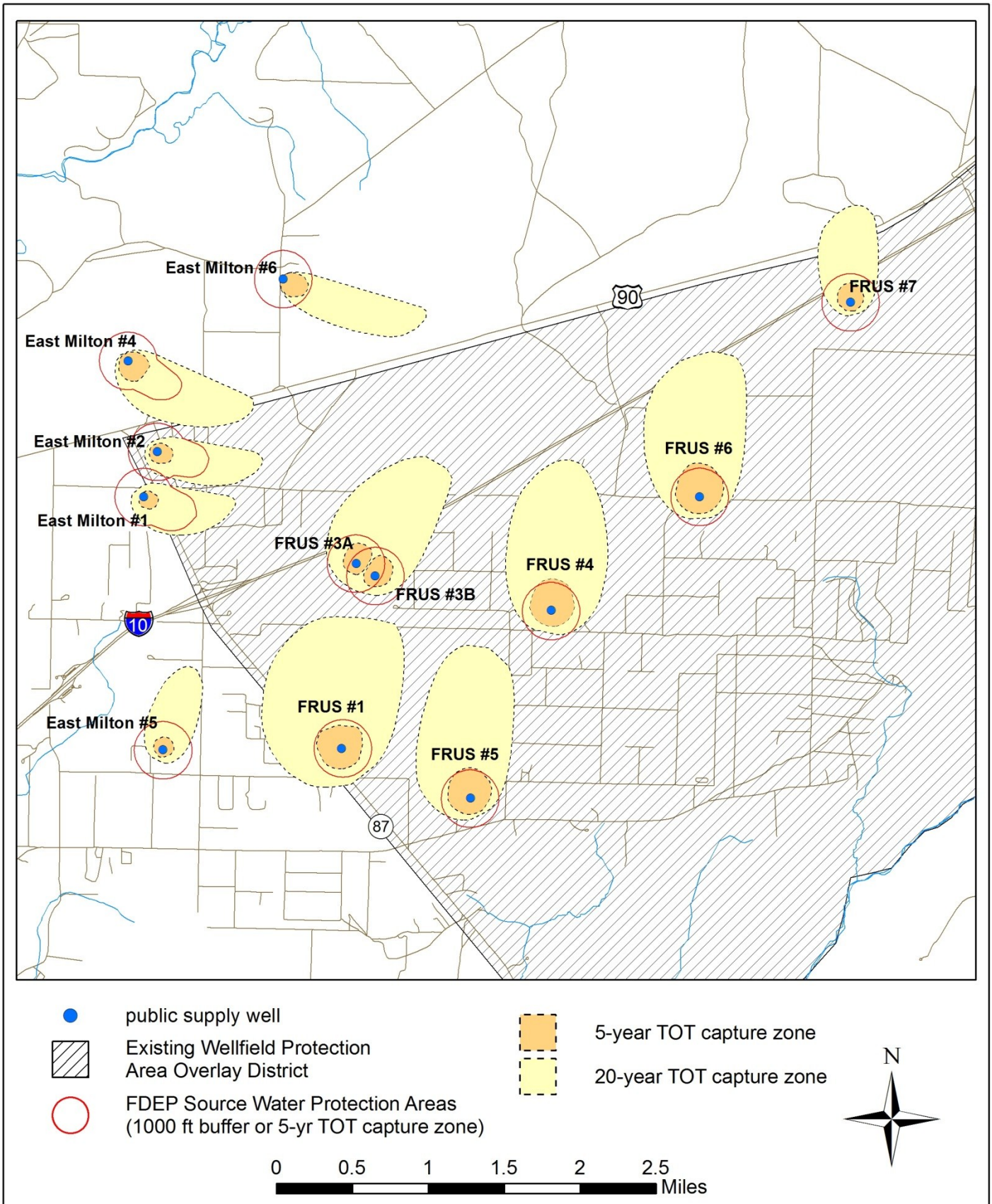

Figure 1. Five and 20-year Time-of-Travel Capture Zones for all Public Supply wells in the East Milton Area

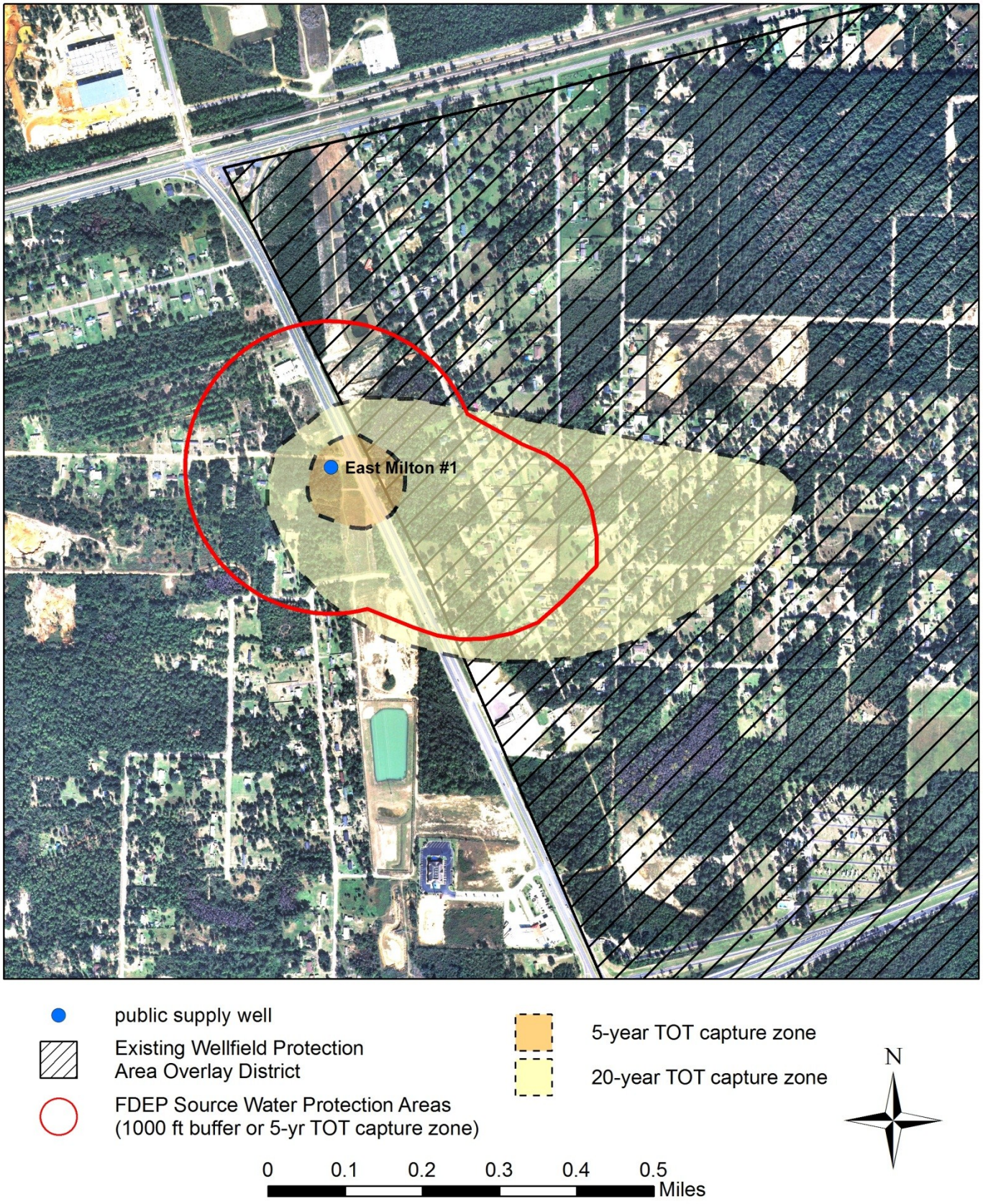

Figure 2. Five and 20-year Time-of-Travel Capture Zones for East Milton #1 (Billy Bob Lane)

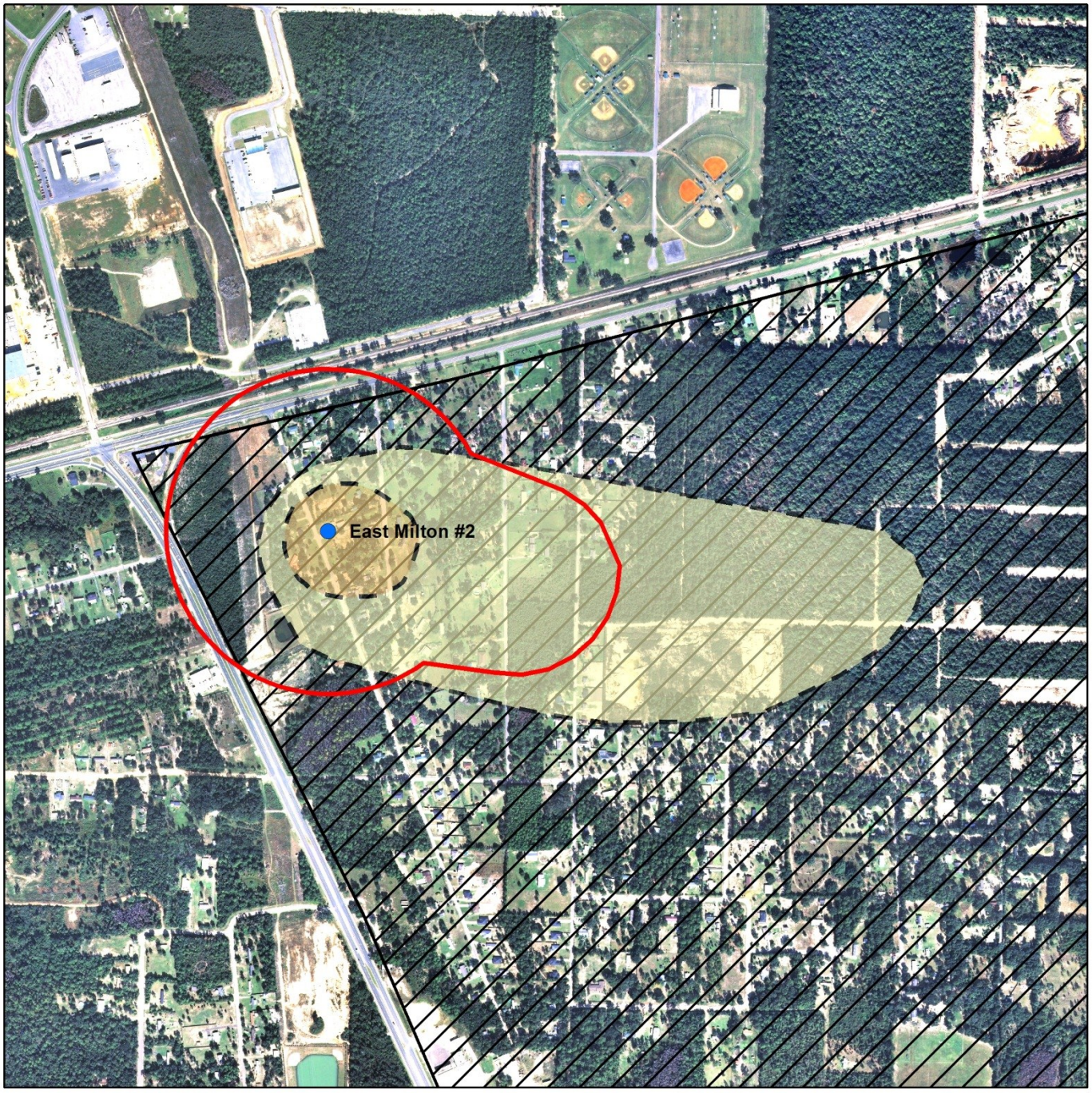

Figure 3. Five and 20-year Time-of-Travel Capture Zones for East Milton #2 (Tracy Drive)

Figure 4. Five and 20-year Time-of-Travel Capture Zones for East Milton #4 (East Milton Rd)

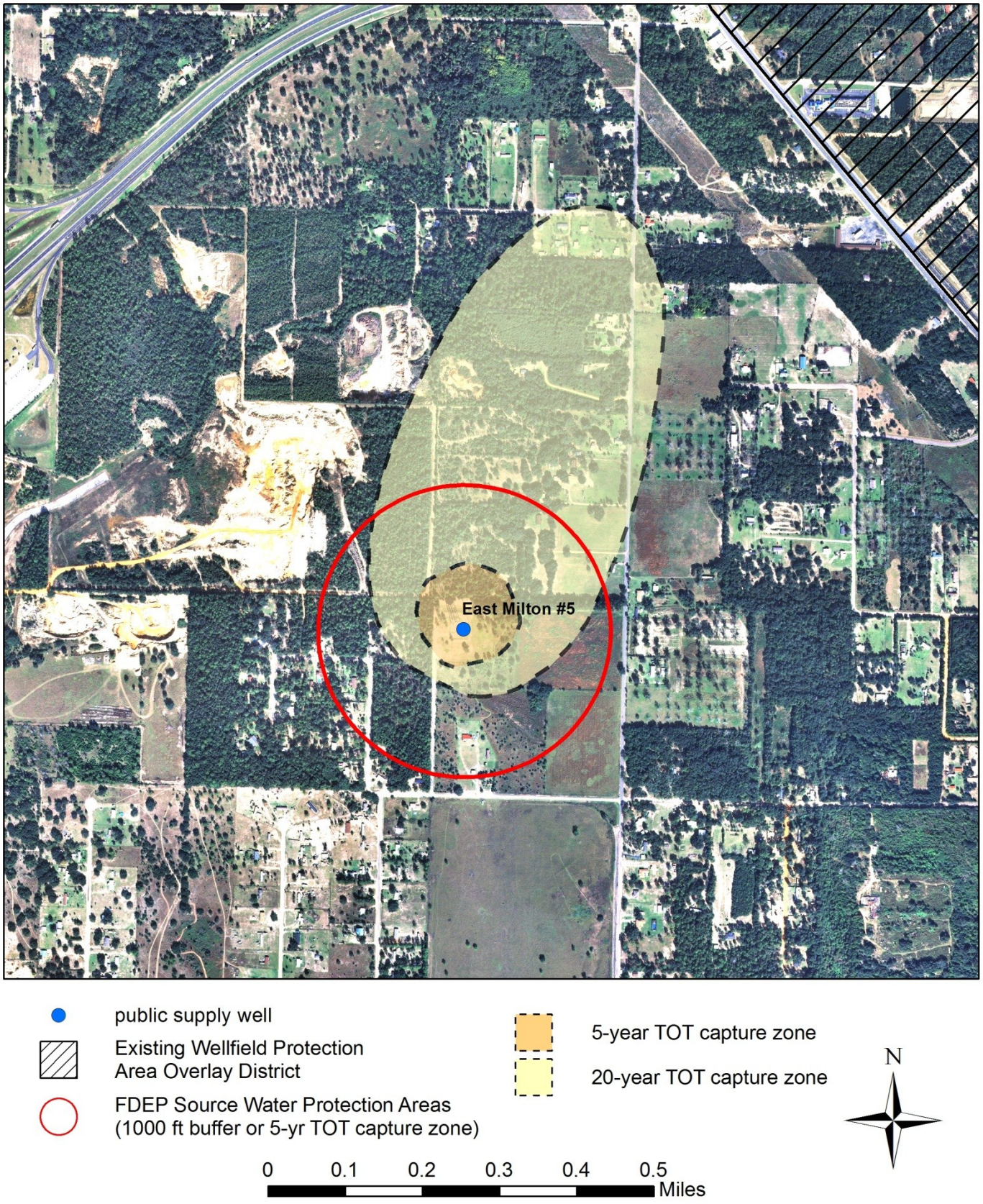

Figure 5. Five and 20-year Time-of-Travel Capture Zones for East Milton #5 (Fortune Rd)

Figure 6. Five and 20-year Time-of-Travel Capture Zones for East Milton #6 (Jeff Ates Rd)

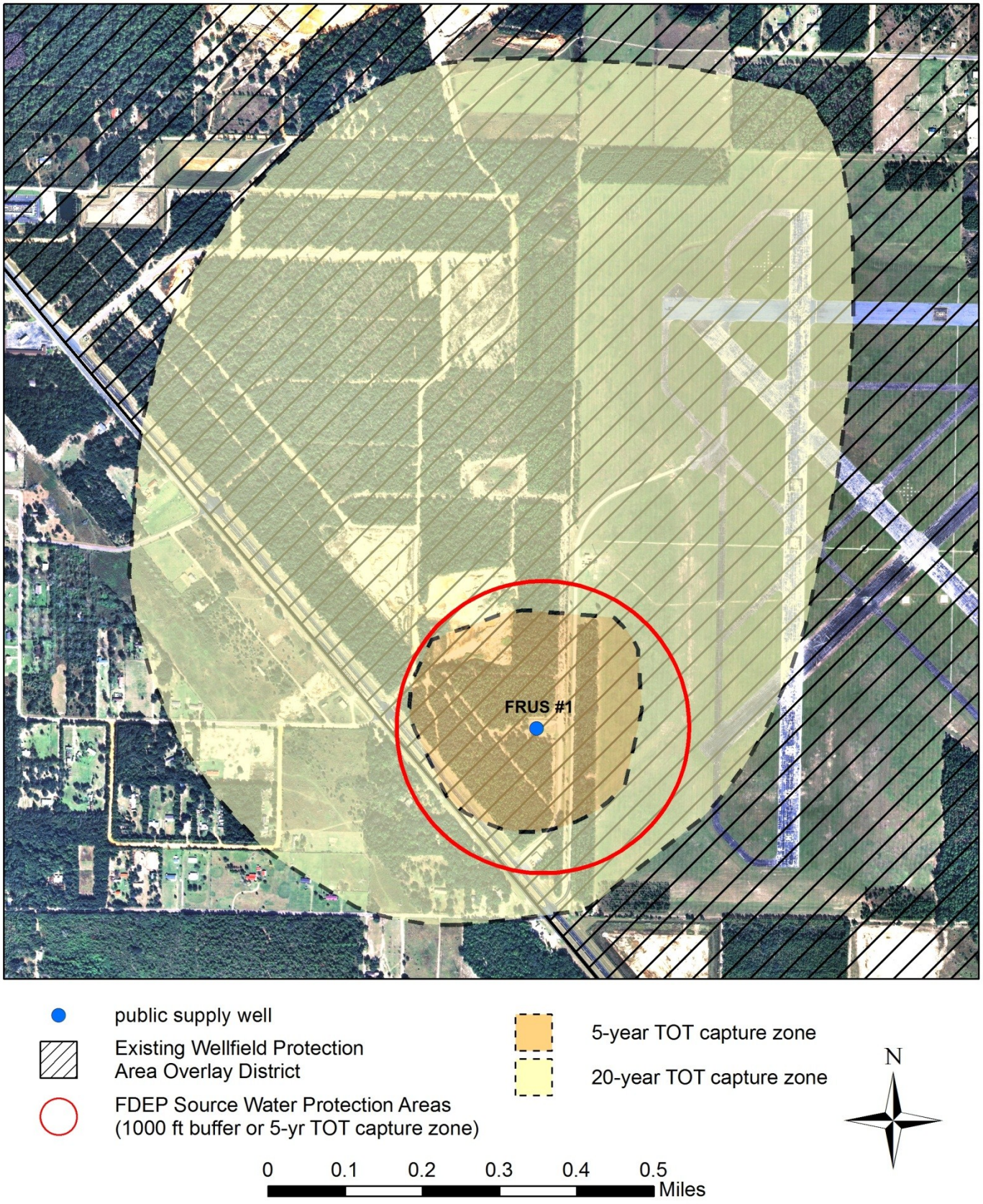

Figure 7. Five and 20-year Time-of-Travel Capture Zones for FRUS #1 (CR 87)

Figure 8. Five and 20-year Time-of-Travel Capture Zones for FRUS #3A and FRUS #3B (Hay Meadow Rd)

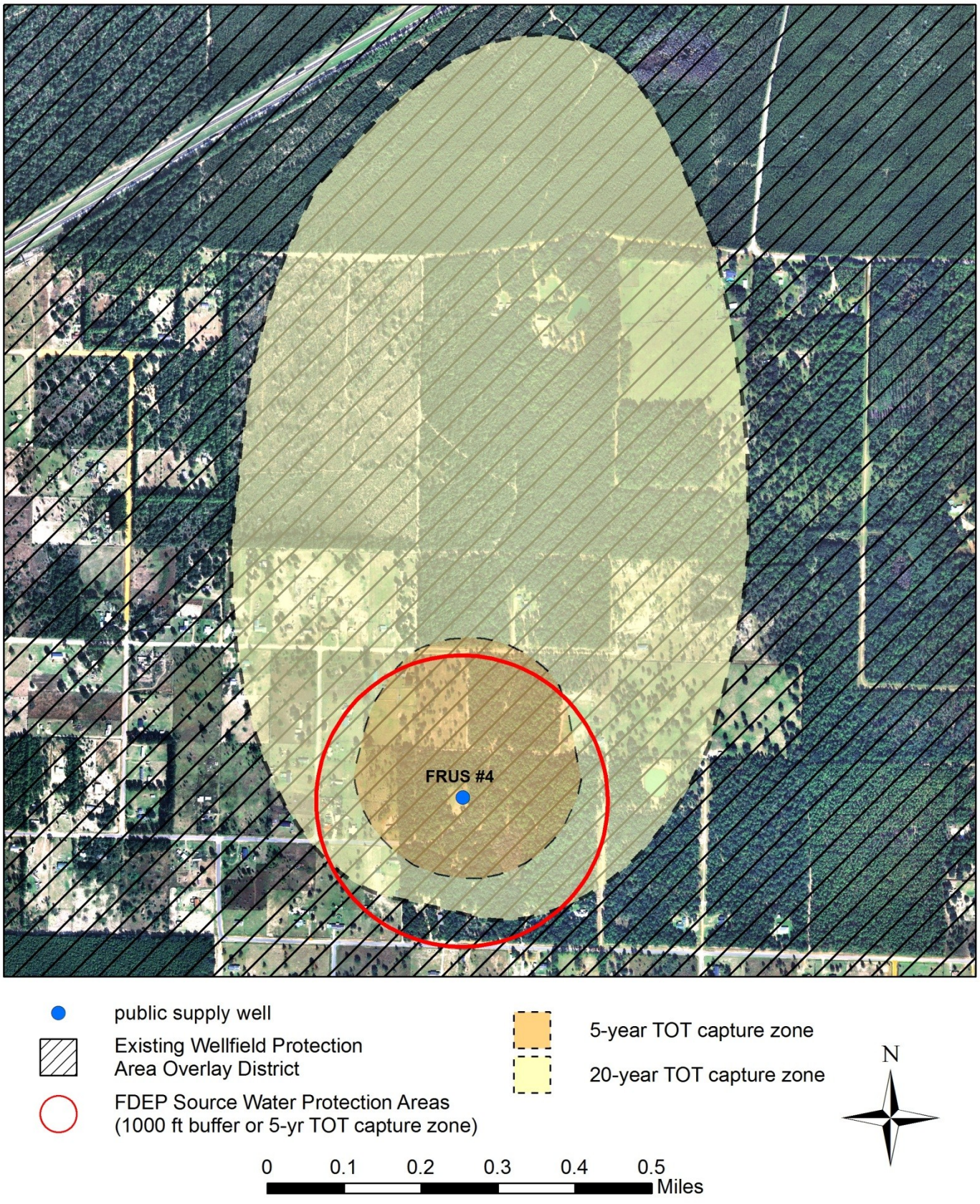

Figure 9. Five and 20-year Time-of-Travel Capture Zones for FRUS #4 (Cornfield Way)

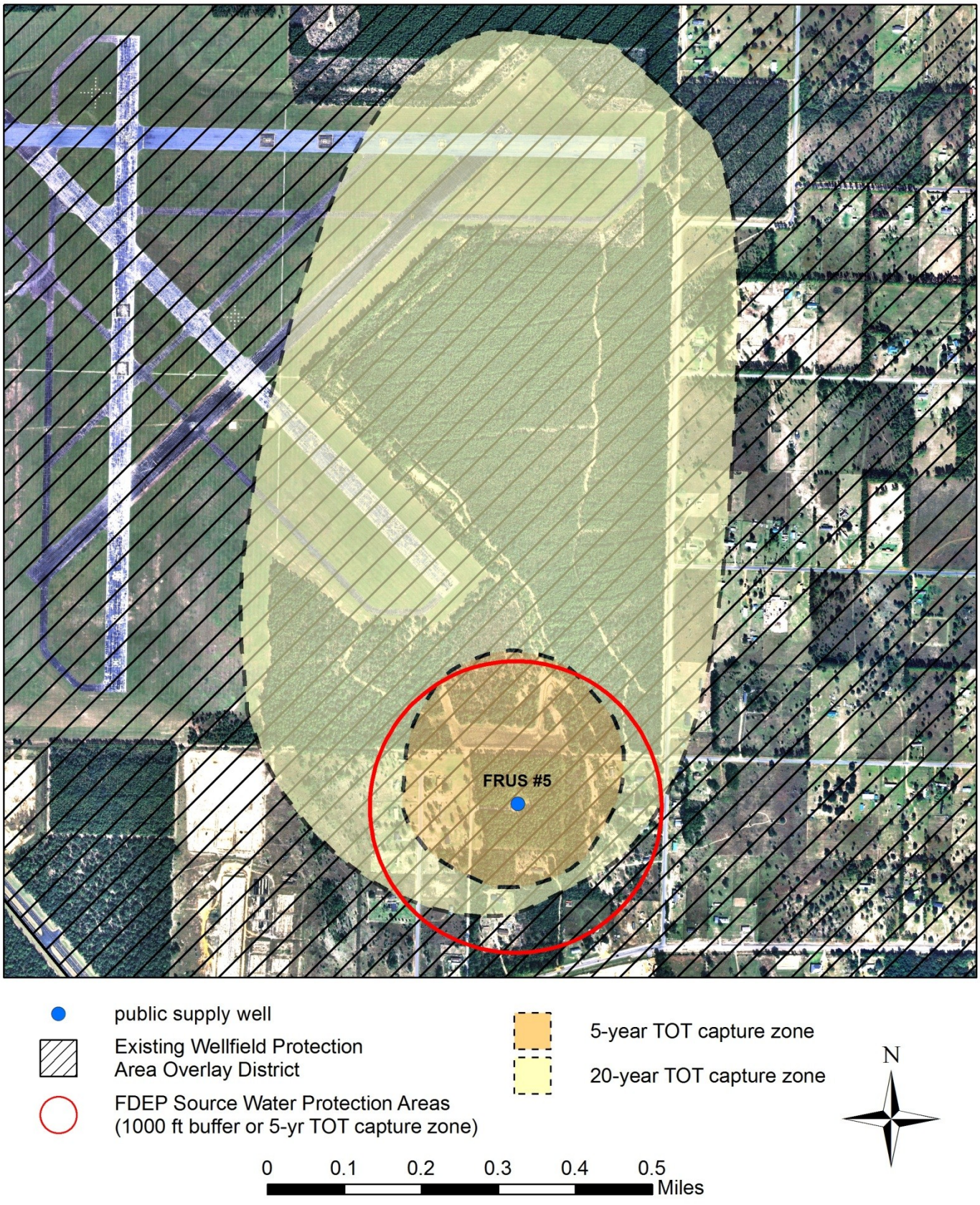

Figure 10. Five and 20-year Time-of-Travel Capture Zones for FRUS #5 (Nichols Lake Rd)

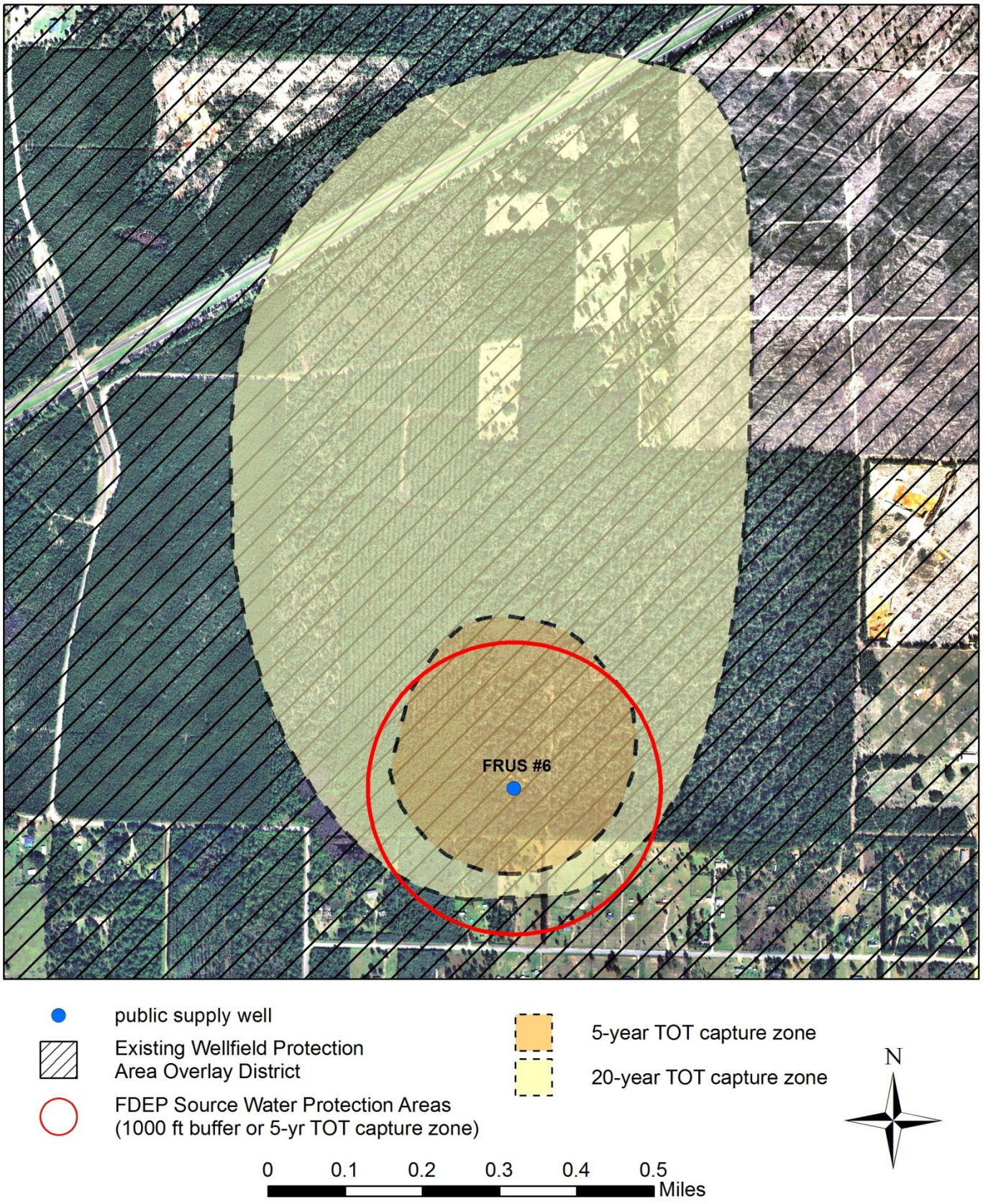

Figure 11. Five and 20-year Time-of-Travel Capture Zones for FRUS #6 (Jeno Rd)

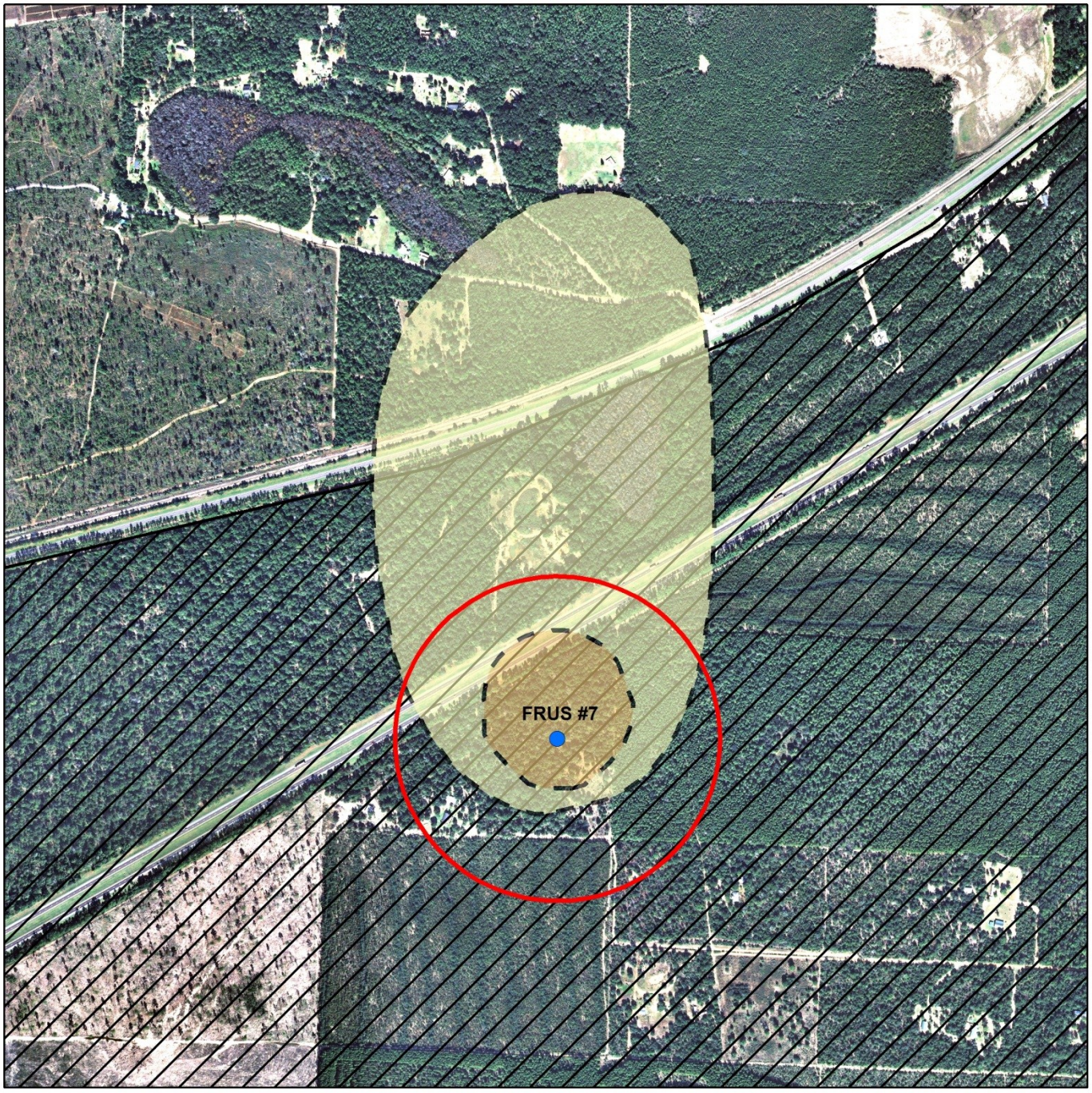

Figure 12. Five and 20-year Time-of-Travel Capture Zones for FRUS #7 (proposed)