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June 4, 2014

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Dr. Bonczek,

Accompanying this letter is an electronic copy of the deliverable for Kentucky Research Consortium for Energy and Environment (KRCEE) FFY13 GW Model support activities, *Revision of Appendix E: Assessment of Groundwater Contamination Plume Extent under Different Response Actions.*

The modeling activities summarized in the attached report are an interim update of the groundwater modeling conducted for the PGDP (Paducah Gaseous Diffusion Plant) Property Acquisition Study, http://www.ukrcee.org/Outreach/Public_Outreach/property_acquisition.aspx. The Property Acquisition Study (PAS) was conducted by KRCEE in order to meet requirements established in the Energy and Water Development Appropriations Bill, 2006 (US Senate Report 109-084).

PAS groundwater modeling activities were undertaken to depict future extents of groundwater contamination from the PGDP based on a range of potential groundwater remedial approaches from no action to complete containment and source removal. A pre-2008 version of the PGDP MODFLOW model was utilized for the original study. The modeling activities conducted for the attached report utilized the CY 2008 PGDP Groundwater Model which reduces some uncertainties in pre-2008 PGDP groundwater models via inclusion of updated site data, application of significant groundwater modeling technique/tool developments, and improved computing capability.

A number of uncertainties are identified in the report relative to inputs and assumptions upon which the various remedial scenarios were modeled. Significant uncertainty is identified relative to: 1) anthropogenic recharge characterization/zonation utilized in the model; 2) water level measurements available for model calibration; and 3) sources/source terms from the Northeast Plume. KRCEE recommends that the modeling conducted for the attached report be updated in the near term to reflect GW Model improvements in recent model recalibration work conducted for optimization of the Northwest and Northeast Plume pump and treat systems.

Groundwater modeling activities undertaken by the Kentucky Geological Survey, Water Section are supported by the Center for Applied Energy Research – Kentucky Research Consortium for Energy and Environment (KRCEE) through Department of Energy Award Number DE- FG05-03OR23032.

Dr. Junfeng Zhu of the Kentucky Geological Survey and KRCEE look forward to engaging in and supporting ongoing groundwater modeling activities relative to the PGDP and its environs.

This attached report will be posted to the KRCEE website, www.ukrcee.org and the link above.

Sincerely,

Steve Hampson

Steve Hampson

cc w attachments: Dr. Rodney Andrews, CAER
Dr. Alan Fryar, UK/EES
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Reassessment of the Extent of the Groundwater Contamination Plume at the Paducah Gaseous Diffusion Plant

Junfeng Zhu and Steven Hampson

Contract Report 60 Series XII, 2014

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Technical Level

General Intermediate Technical

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Reassessment of the Extent of the Groundwater Contamination Plume at the Paducah Gaseous Diffusion Plant

Junfeng Zhu and Steven Hampson

Introduction

To meet requirements in the Energy and Water Development Appropriations Bill of 2006 (U.S. Senate Report 109-084), the Kentucky Research Consortium for Energy and Environment conducted a property acquisition study for areas near the Paducah Gaseous Diffusion Plant (Kentucky Research Consortium for Energy and Environment, 2007). As a part of this study, potentially affected properties were assessed using a numerical model that simulated future migration of contaminated groundwater relative to four potential response actions (Table 1).

Multiple versions of numerical models for the plant have been developed since 1990. The numerical models used in the property acquisition study were a version developed in 1997 (U.S. Department of Energy, 1997b). An update to the models was conducted in 2008, which made significant changes to the 1997 models, including domain discretization, boundary conditions, flow calibration, and transport modeling.

In this report, the 2008 version of the numerical models (Paducah Gaseous Diffusion Plant Modeling Group, 2008) was used to simulate the migration of groundwater contamination plumes under the same four potential scenarios used in the properties acquisition study. Each response action scenario was modeled for two potential situations: (1) continued operation of the Paducah Gaseous Diffusion Plant and (2) shutdown of the plant. The plume migration results were then used to assess potentially impacted properties over the next 100 yr.

Table 1. Potential response action scenarios (from Kentucky Research Consortium for Energy and Environment, 2007). P&T = pump and treat. URD = response scenario including the Upper Continental Recharge System, Regional Gravel Aquifer, dissolved source. PTZ = permeable treatment zone.

Scenario	*ID*	*Description*
1	P&T	Existing pump and treat action
2	C400	Source reduction of contamination at C400 building
3	URD	Source reduction of contamination from all sources, with dissolved phase treatment of southwest plume
4	URD-PTZ	Source reduction of contamination from all sources, with dissolved phase treatment of southwest plume and permeable treatment zone at the Paducah Gaseous Diffusion Plant security fence

Model Description

The 2008 numerical models consisted of a groundwater flow model, a TCE (trichloroethene) transport model, and a ^{99}Tc (technetium-99) transport model. The flow model was built using MODFLOW-2000 (Harbaugh and others, 2000) and the transport models were built using MT3D (Zheng, 1999). PEST (Doherty, 2005) was used to assist in flow and transport model calibration. A brief summary of the 2008 models is given below. Details of these models can be found in Paducah Gaseous Diffusion Plant Modeling Group (2008) and a review of these models is provided by Zhu and Hampson (2013).

Conceptual Model

A hydrogeological conceptual model describes the groundwater flow system for a site and provides a basis for building numerical models. At the Paducah Gaseous Diffusion Plant site, sediments of Cretaceous, Tertiary, and Quaternary age overlie Mississippian limestone (U.S. Department of Energy, 1997a). The sediments average approximately 300 ft thick and are further divided into three hydrogeologic stratigraphic units, in descending order: the Upper Continental Recharge System, the Regional Gravel Aquifer, and the McNairy Flow System. The Upper Continental Recharge System is predominantly silts and clays with laterally discontinuous sand and gravel horizons. Groundwater flow in the Upper Continental Recharge System is primarily vertical downward. The Regional Gravel Aquifer is the main aquifer, consisting of gravel and coarse sand with a veneer of fine to medium sand. The McNairy Flow System is composed of silt, micaceous clay, and fine sand.

Major surface hydrologic features affecting the groundwater system at the site are the Ohio River, Metropolis Lake, Bayou Creek, and Little Bayou Creek.

Flow and Transport Model Configuration

The 2008 flow and transport models encompassed the plant and the area between the plant and the Ohio River, covering approximately 18.6 mi^2. The model used a uniform grid spacing of 50 ft. Vertically, the model encompassed only the Regional Gravel Aquifer, which was divided into three layers with equal thickness. The horizontal extent of the model is shown in Figure 1. The groundwater flow was considered as steady state and was calibrated to 76 water-level targets measured in February 1995.

The 2008 models simulated transport of TCE and ^{99}Tc plumes for a 42-yr period from 1966 through 2008. TCE was simulated as biodegradable with a half-life of 10 yr, whereas ^{99}Tc was simulated as a conservative solute. The transport models were calibrated through adjustment of source locations and historical loading rates to match measured plume geometry.

In the calibrated transport TCE model, the loads for the northwest plume, the southwest plume, and the northeast plume were two concentration boundary cells, 10 groups of recharge cells, and three concentration boundary cells, respectively. Concentrations of the two concentration boundary cells for the northwest plume were constant through time, representing a DNAPL (dense nonaqueous phase liquid) source. Each group of recharge cells for the southwest plume had constant concentration through time, but the concentrations varied from group to group. Concentrations of the three concentration boundary cells for the northeast plume varied significantly through time. The source loads for ^{99}Tc were three recharge zones of temporally uniform concentration and one cell of constant concentration.

Future Scenario Simulation

Predictive models based on the 2008 models were created to predict the spatial extent of both TCE and ^{99}Tc plumes over a 100-yr period starting from the beginning of 2009. The initial concentration condition was assumed to be the same as the simulated final TCE and ^{99}Tc concentrations in the 2008 models (Fig. 2). The TCE and ^{99}Tc loads were assumed constant over time and their values were

Figure 1. The extent of the 2008 models.

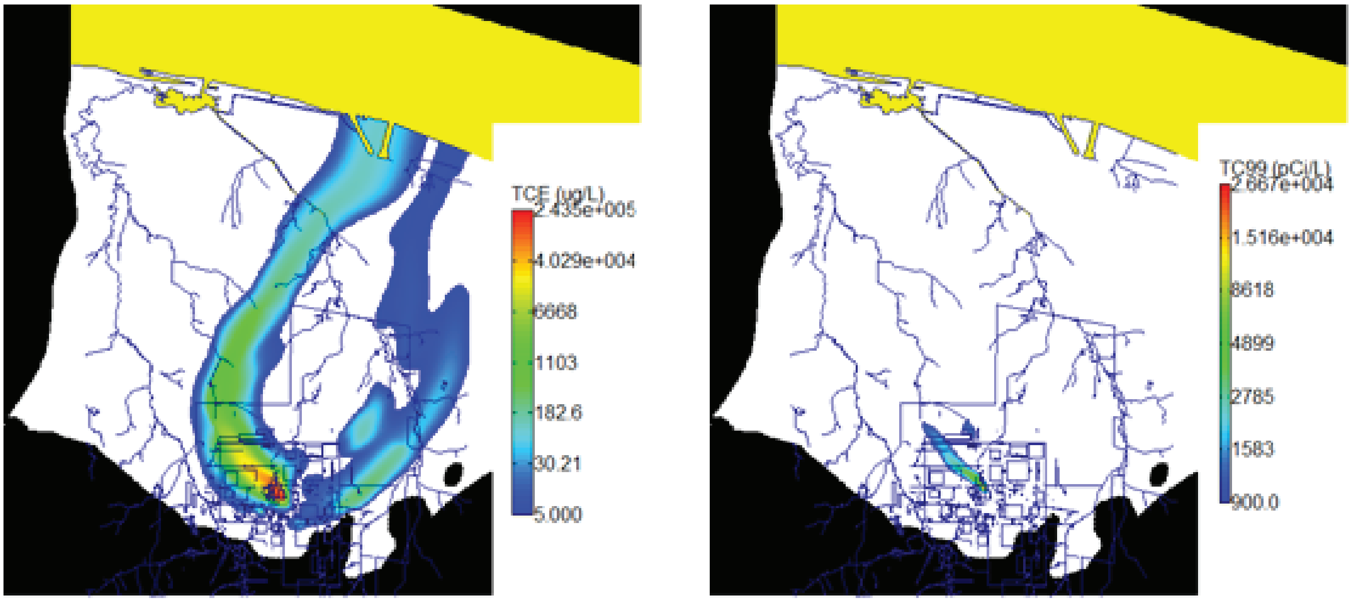

Figure 2. Simulated final concentrations in the 2008 models. Left: TCE; right: ^{99}Tc.

assumed to be the same as the loads of the final time step in the 2008 models (Fig. 3).

The 2008 models used a checkerboard pattern zoning method to adjust anthropogenic recharges within the plant, which resulted in different recharge values throughout the plant (Fig. 4). Under plant shutdown conditions, the anthropogenic recharges at the plant site was assumed to be ceased and the only recharge at the plant was assumed to be from the precipitation. The modeled total anthropogenic recharge at the plant was approximately 1.21 million gal/d for the continued Paducah Gaseous Diffusion Plant condition. Under the plant shutdown condition, the total recharge at the plant was 0.33 million gal/d, which was

Figure 3. Simulated source locations in the 2008 models (red). Left: TCE; right: ^{99}Tc.

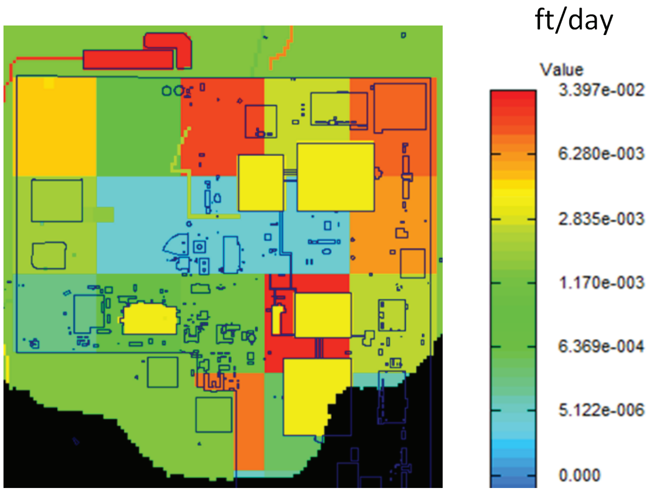

Figure 4. Modeled anthropogenic recharges at the Paducah Gaseous Diffusion Plant in the 2008 models.

calculated using the precipitation recharge rate of 7.44 in./yr modeled in the 2008 models.

Technetium-99 Predictive Model Results

The ^{99}Tc plume was simulated using a no-action scenario under continued plant operation conditions, which represents the maximum possible ^{99}Tc plume extent in the future. The predicted extent of the ^{99}Tc above the maximum contaminant level of 900 pCi/L at 100 yr is shown in Figure 5. The predicted ^{99}Tc plume above the MCL are mostly confined within the DOE property boundary and a small part of the West Kentucky Wildlife Management Area. Consequently, no additional reaction scenarios were simulated for ^{99}Tc.

TCE Predictive Model Results

Four different potential remedial response action scenarios for TCE were simulated. Assumptions about TCE concentration reductions were made to accommodate these scenarios (Table 2). Because the 2008 models exclude the Upper Continental Recharge System, some assumptions were slightly different from those used in the original property acquisition study. Each scenario was simulated for two conditions: (1) continued plant operation and (2) plant shutdown. The predicted spatial extents of MCL concentration for TCE (5 μg/L) at 10, 30, 50, and 100 yr for each scenario under both conditions are shown in Figures 6 through 13. Properties potentially affected by the predicted plumes over time are listed in Table 3.

Model Uncertainties

The predicted TCE and ^{99}Tc plumes were modeled using the 2008 version of groundwater flow and transport models, which were calibrated to existing site data. As a result, there is no guarantee that the predicted results will accurately match future conditions. In addition, the 2008 models have several limitations that increase the predictive uncertainties. First, the 2008 models did not encompass the Upper Continental Recharge System but there were known contaminant sources in the recharge system. Different assumptions about the source zone reduction had to be made from the original property acquisition study in the predictive runs to accommodate potential actions 2 and 3. The modeled anthropogenic recharges in the 2008 models were known to be inconsistent with field groundwater temperature data. But flow-vector analysis for the 2008 flow model suggested that these recharges have a strong impact on the migration of plumes, especially on the bifurcation pattern observed in the plant. The predictive plume extents can be improved with a better estimation of the anthropogenic recharges. Finally, because of the lack of field data, the source loads for the northeast TCE plume were not modeled with certainty in the 2008 models. The modeled source loads were highly variable over time and were zero at the final stress period, leaving no sources for the northeast plume in the predictive models. As a result, the predicted northeast plumes totally disappeared after 30 yr in all potential action scenarios (Figs. 6–13).

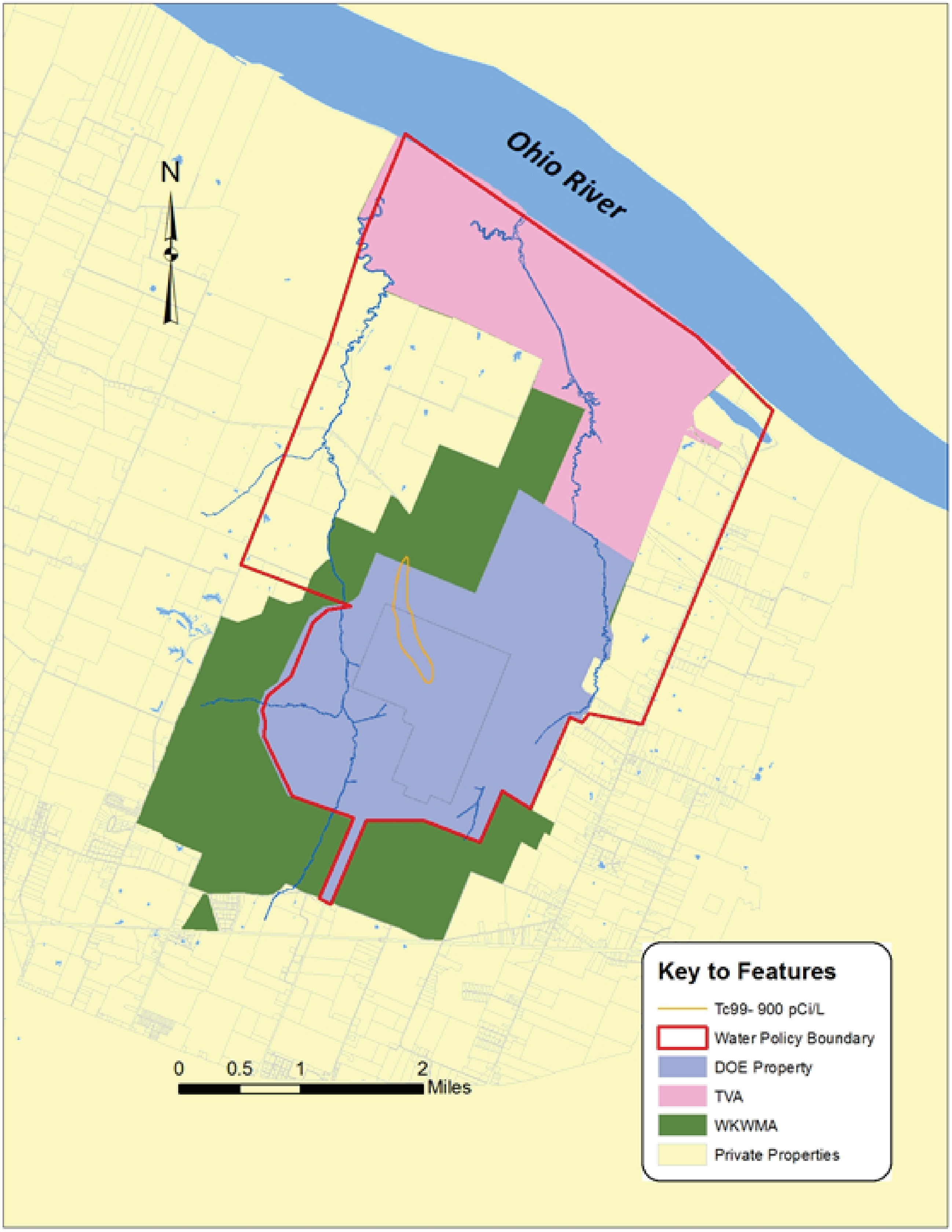

Figure 5. Predicted ^{99}Tc plume at the end of the 100-yr simulation.

Table 2. Model assumptions for potential response action scenarios. P&T = pump and treat. URD = response scenario including the Upper Continental Recharge System, Regional Gravel Aquifer, dissolved source. PTZ = permeable treatment zone.

Scenario	*ID*	*Assumed TCE Concentration Reduction*		
		C-400	*C-720*	*SWMU1 and SWMU4*
1	P&T	0%	0%	0%
2	C400	*97%	0%	0%
3	URD	*97%	95%	95%
4	URD-PTZ	*97%	95%	95%

*In Kentucky Research Consortium for Energy and Environment (2007), removal of TCE 99% in Regional Gravel Aquifer and 95% in Upper Continental Recharge System was used.

Table 3. Number of properties potentially affected under potential response action scenarios. P&T = pump and treat. URD = response scenario including the Upper Continental Recharge System, Regional Gravel Aquifer, dissolved source. PTZ = permeable treatment zone.

Year	*Continued Plant Operation*				*Plant Shutdown*			
	P&T	*C400*	*URD*	*URD-PTZ*	*P&T*	*C400*	*URD*	*URD-PTZ*
5	55	69	69	69	43	52	52	52
10	59	76	76	76	49	58	58	58
15	5	54	54	51	13	60	60	60
30	5	9	9	5	5	4	4	0
50	9	7	4	2	4	4	3	0
100	9	5	4	0	4	0	0	0

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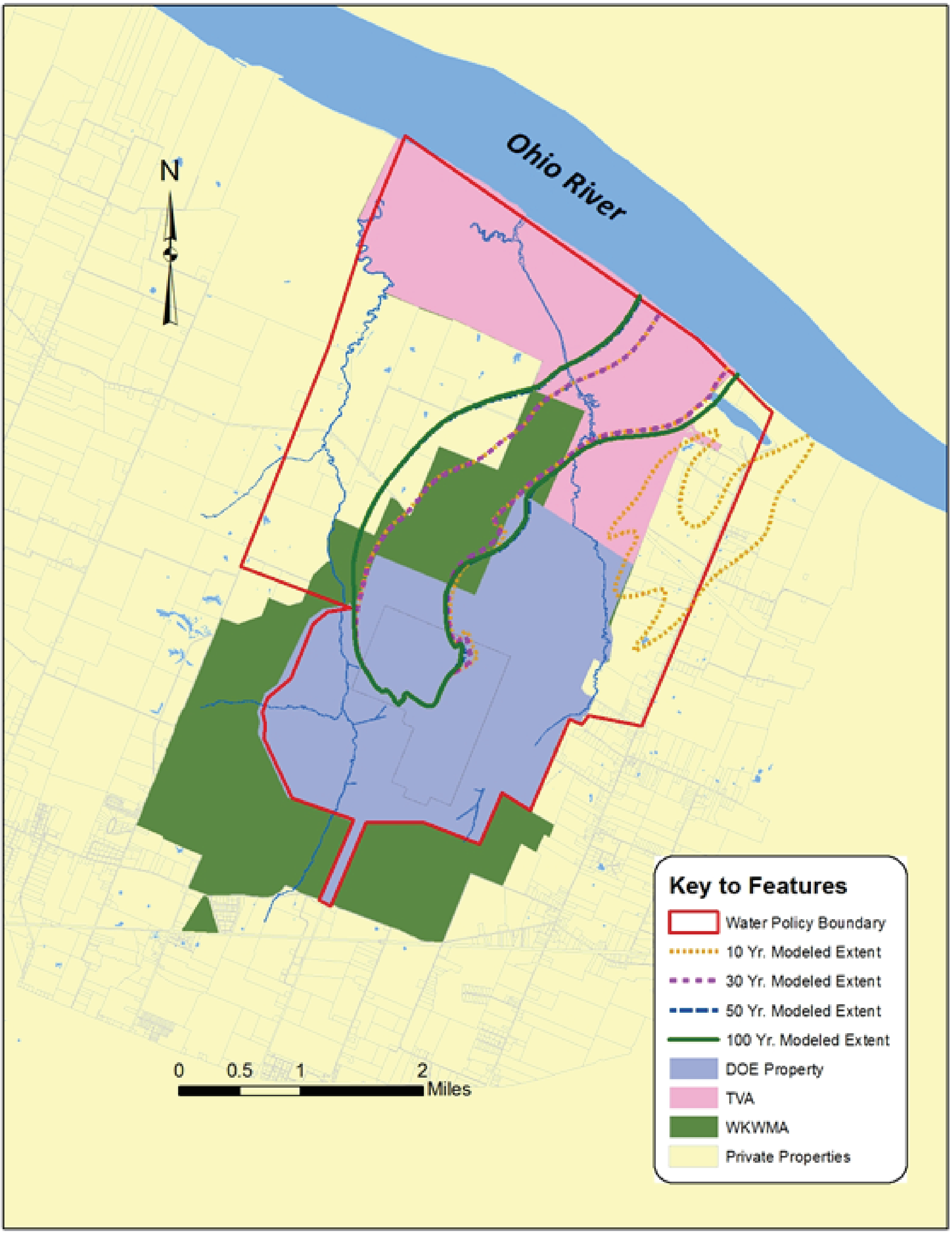

Figure 6. Predicted TCE plume contours (5 µg/L) over time under scenario 1: existing pump and treat action (assuming continued plant operation).

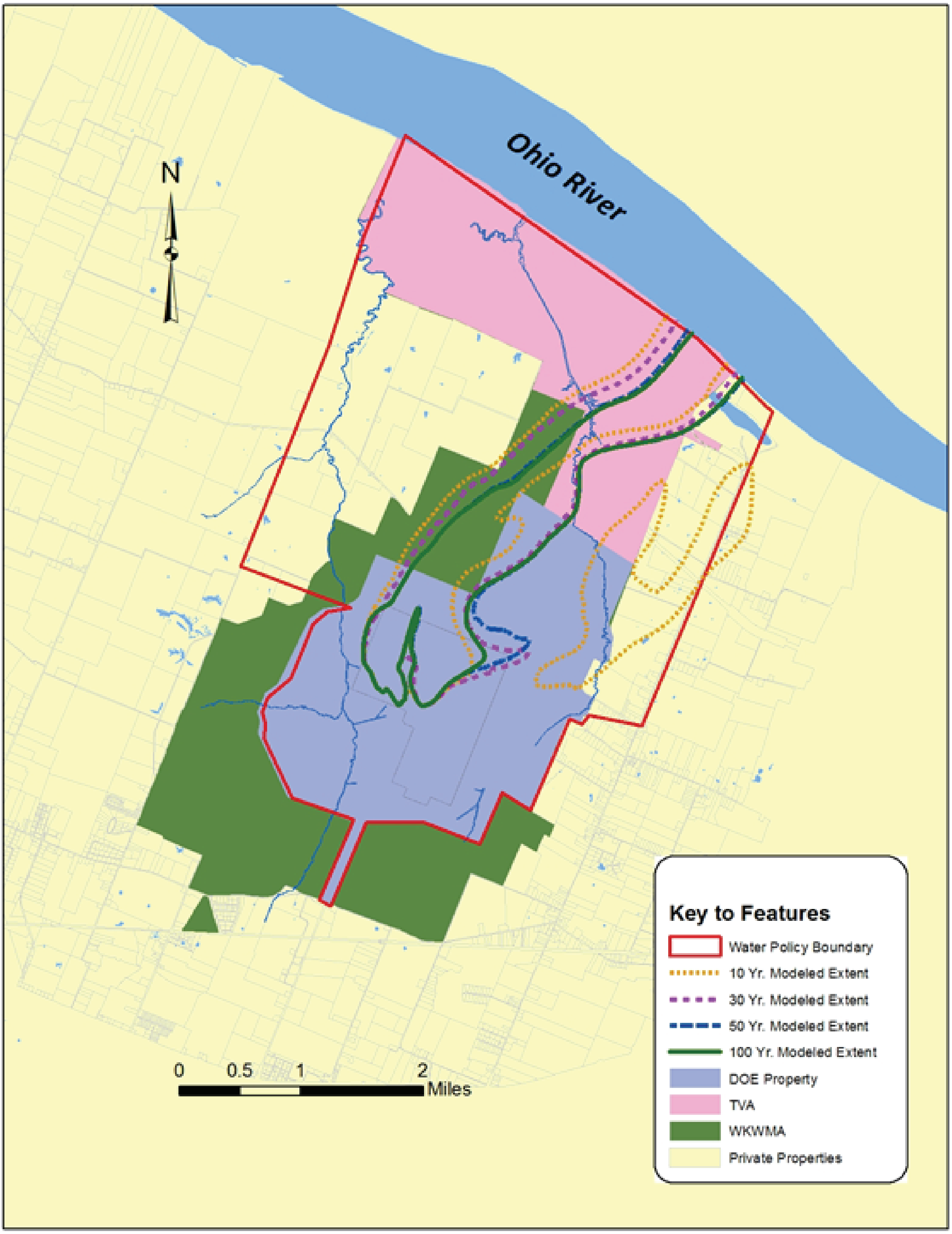

Figure 7. Predicted TCE plume contours (5 µg/L) over time under scenario 1: existing pump and treat action (assuming plant shutdown).

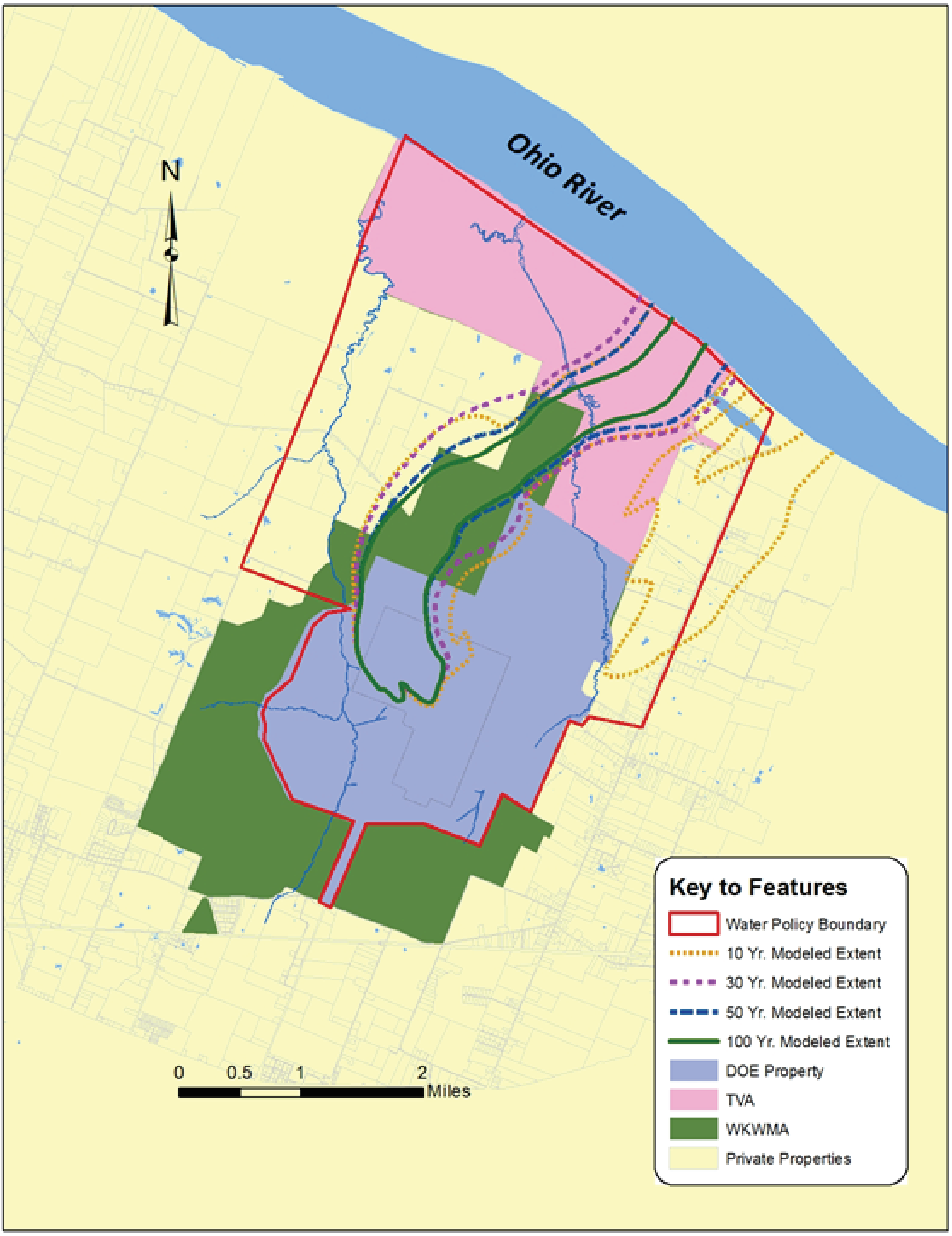

Figure 8. Predicted TCE plume contours (5 µg/L) over time under scenario 2: source reduction at C-400 Building (assuming continued plant operation).

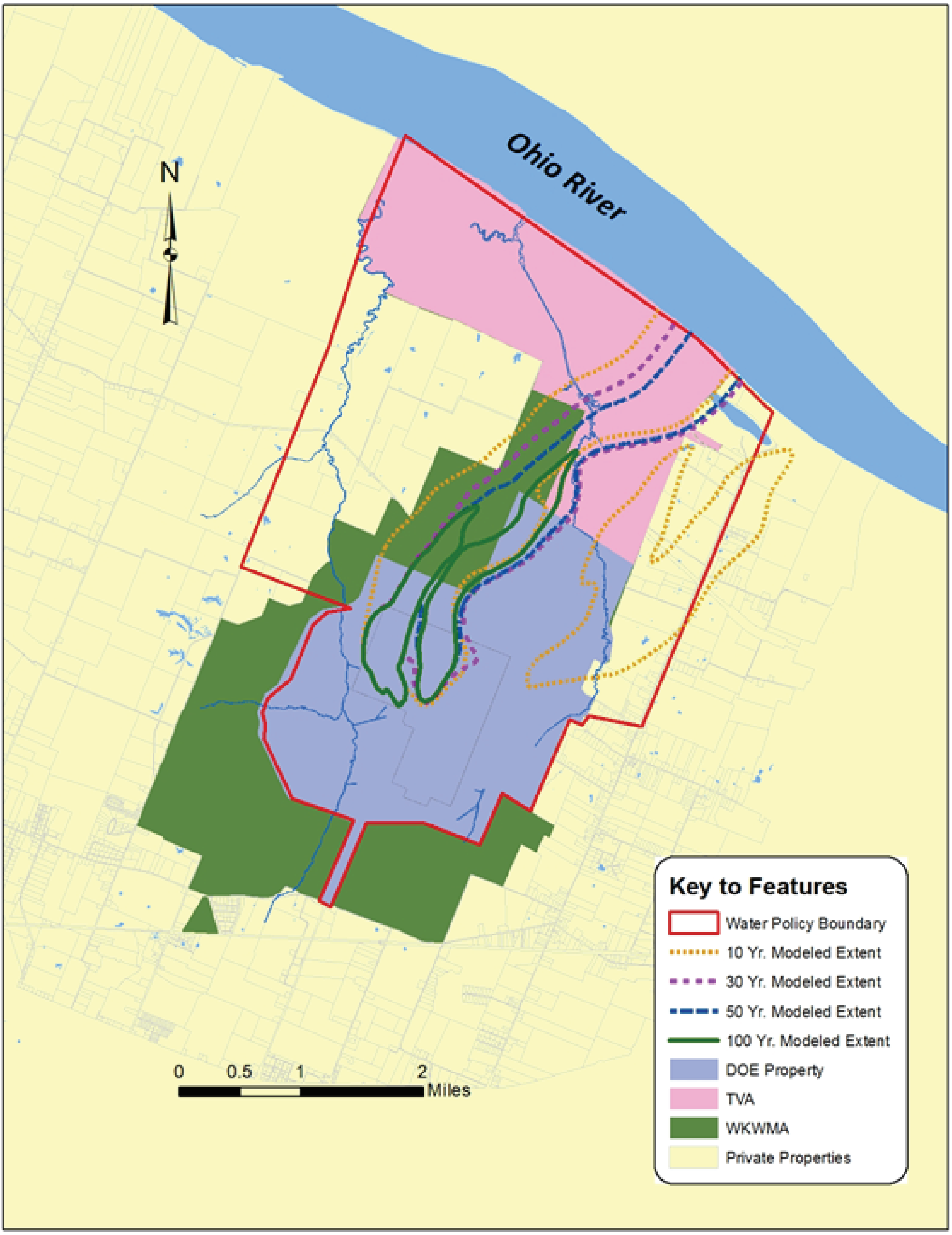

Figure 9. Predicted TCE plume contours (5 μg/L) over time under scenario 2: source reduction at C-400 Building (assuming plant shutdown).

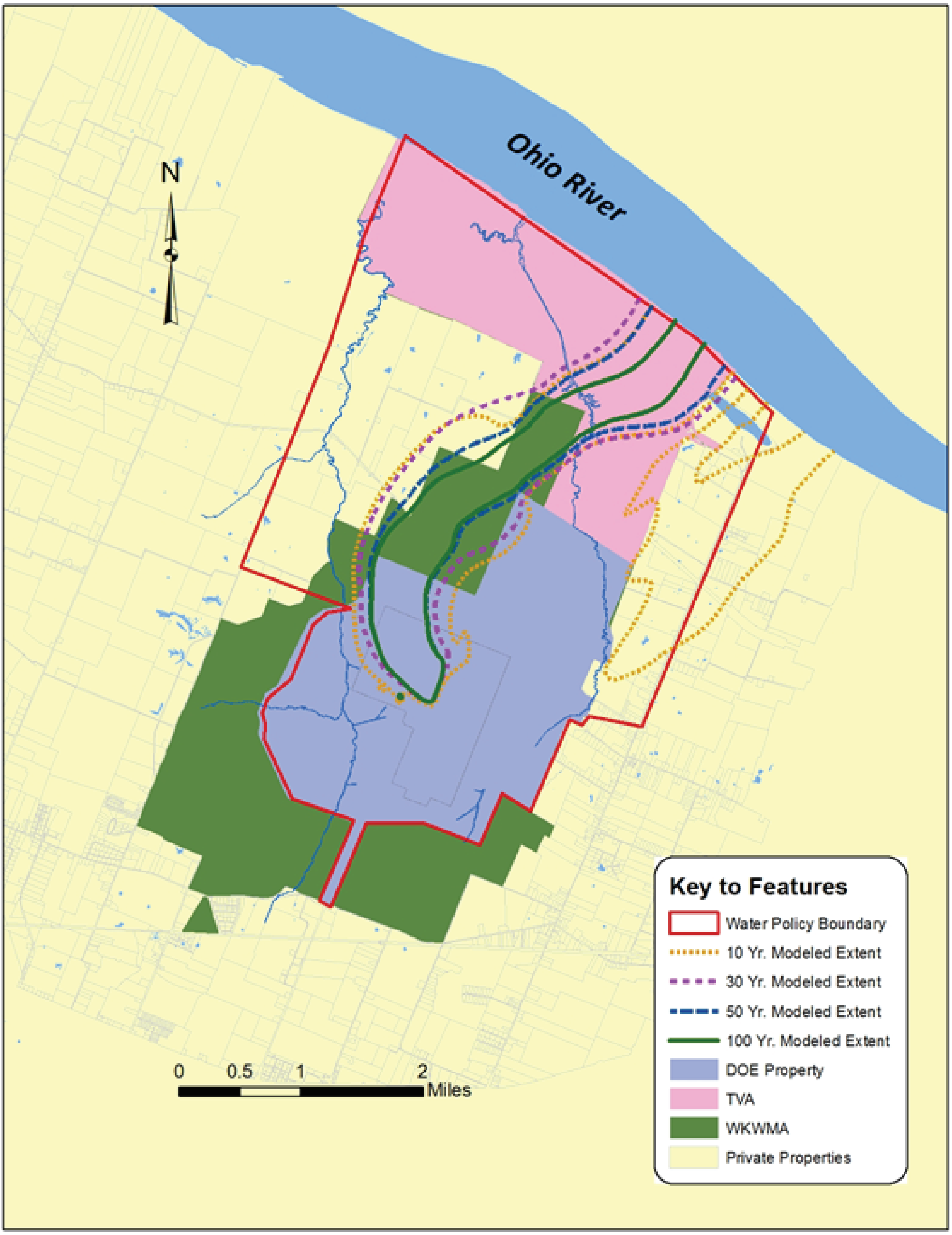

Figure 10. Predicted TCE plume contours (5 µg/L) over time under scenario 3: source reduction at C-400, C-720, SWMU1, and SWMU4, including dissolved phase treatment of the southwest plume (assuming continued plant operation).

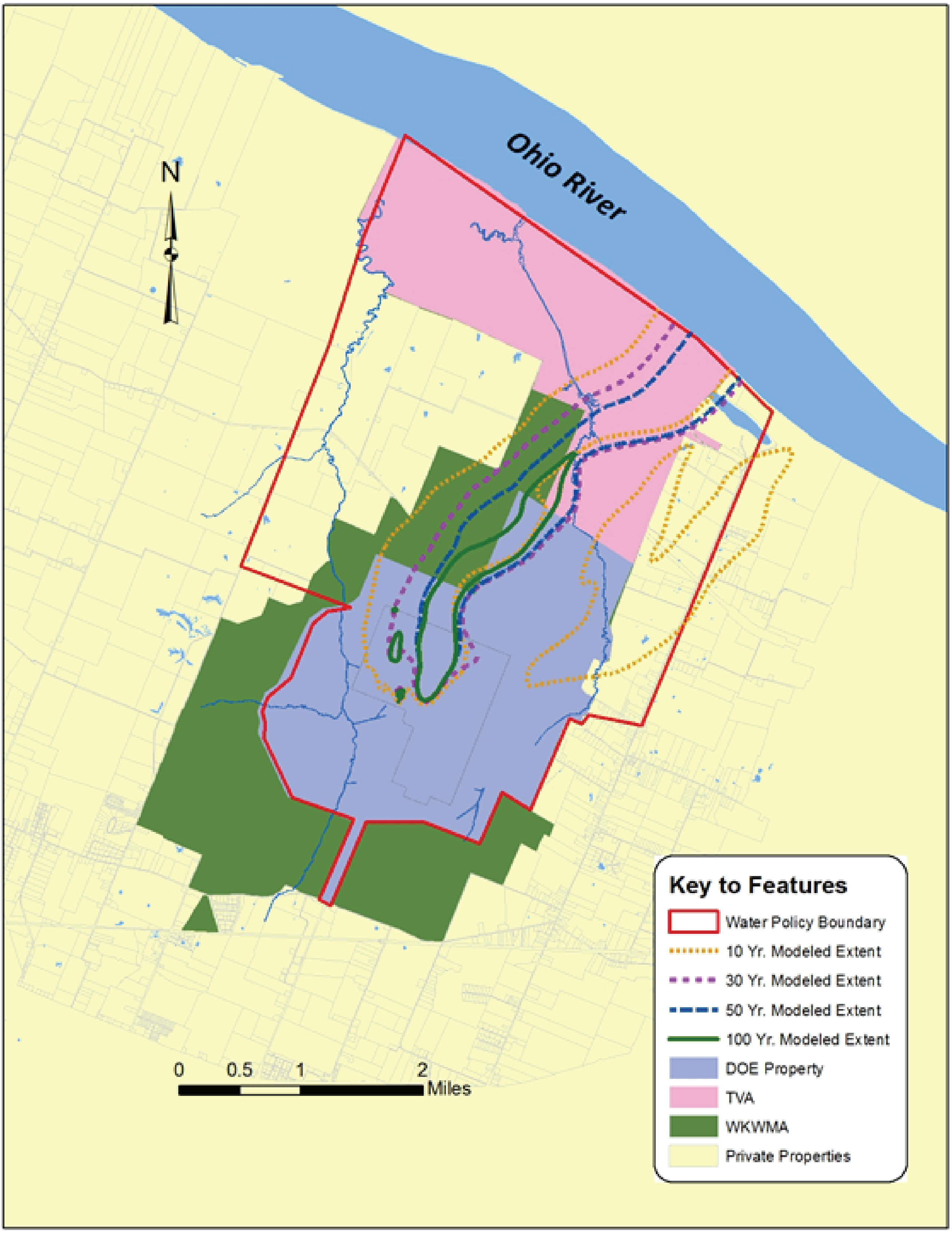

Figure 11. Predicted TCE plume contours (5 µg/L) over time under scenario 3: source reduction at C-400, C-720, SWMU1, and SWMU4, including dissolved phase treatment of the southwest plume (assuming plant shutdown).

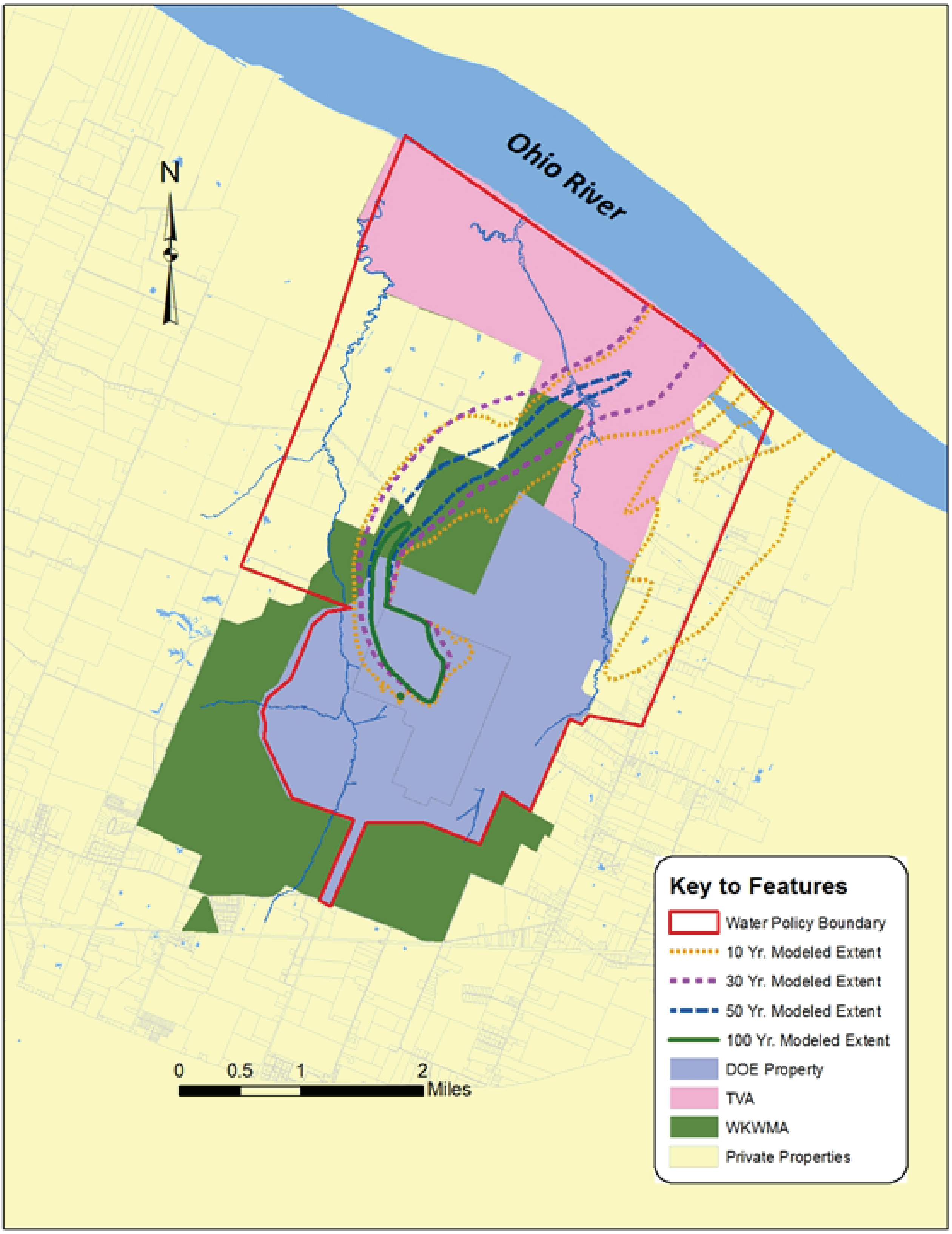

Figure 12. Predicted TCE plume contours (5 µg/L) over time under scenario 4: source reduction at C-400, C-720, SWMU1, and SWMU4, including dissolved phase treatment of the southwest plume and permeable treatment zone at the facility fence (assuming continued plant operation).

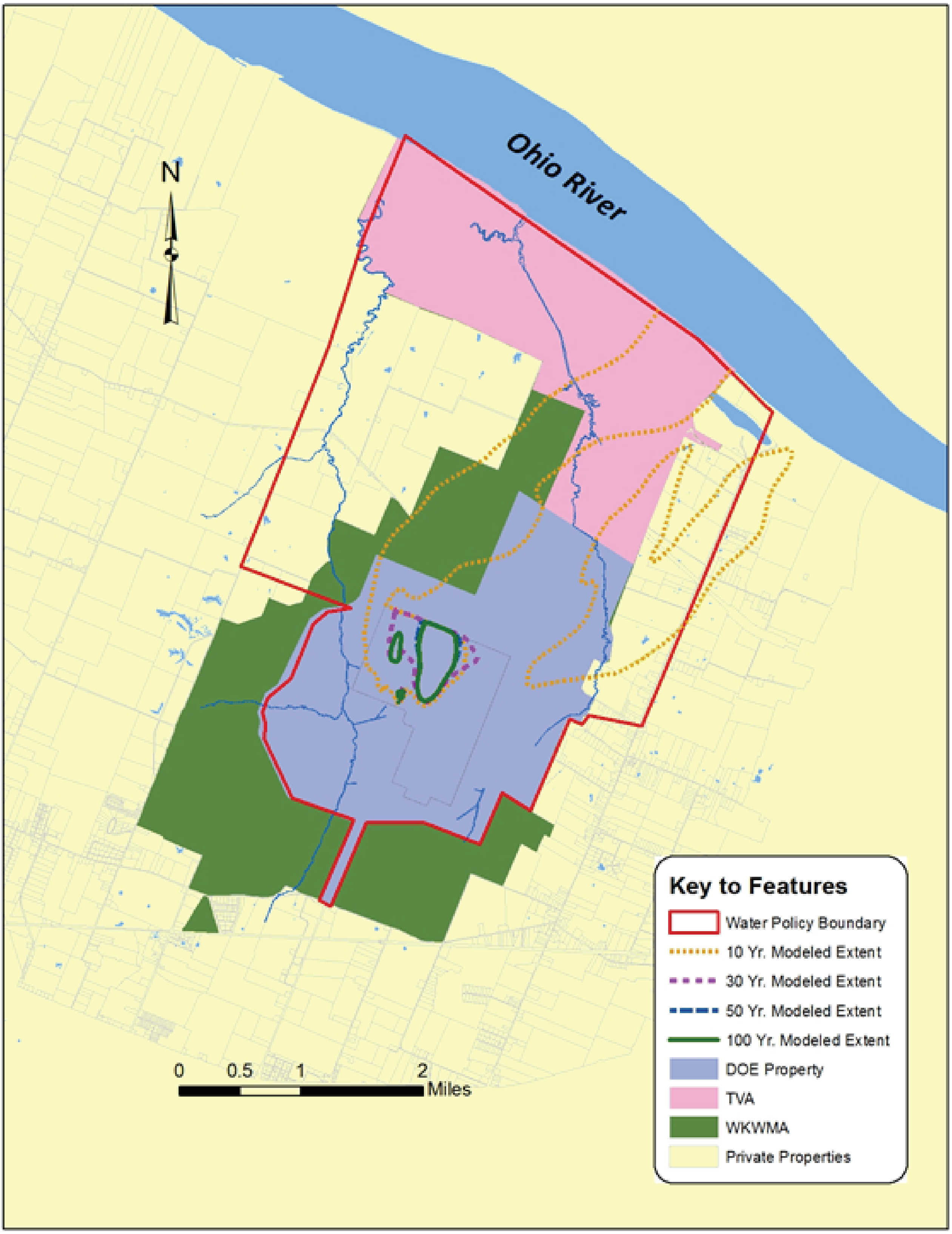

Figure 13. Predicted TCE plume contours (5 µg/L) over time under scenario 4: source reduction at C-400, C-720, SWMU1, and SWMU4, including dissolved phase treatment of the southwest plume and permeable treatment zone at the facility fence (assuming plant shutdown).