ECF-100BC5-16-0059
Revision 0

2016 Modeling of RI/FS Design Alternatives for 100-BC-5

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

P.O. Box 1600
Richland, Washington 99352

Approved for Public Release;
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Terms and Acronyms

ABS	always below standard
ARAR	applicable or relevant and appropriate requirement
AWQS	aquatic water quality standard
C90	90th percentile of concentrations
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CHPRC	CH2M HILL Plateau Remediation Company
Cmax	maximum concentration
COC	contaminant of concern
CPS	calcium polysulfide
Cr(VI)	hexavalent chromium
CTS	Contaminant Treatment System
DOE	U.S. Department of Energy
DWS	drinking water standard
ECF	environmental calculation
EPA	U.S. Environmental Protection Agency
EW	extraction well
GPM	gallons per minute
HISI	Hanford Information Systems Inventory
IC	institutional control
ISR	in situ remediation
IW	injection well
M/YR	meters per year
MNA	monitored natural attenuation
MNW2	Multi Node Well Package
NFA	no further action
OU	operable unit
P&T	pump and treat
PRG	preliminary remediation goal
PRZ	periodically rewetted zone

ROD	Record of Decision
SSP&A	S.S. Papadopulos and Associates, Inc.

1 Purpose

The purpose of this environmental calculation brief is to present the results of groundwater flow and contaminant transport modeling for the *Comprehensive Environmental Response, Compensation and Liability Act of 1980* (CERCLA) *Remedial Investigation/Feasibility Study for the 100-BC-1, 100-BC-2, and 100-BC-5 Operable Units* (DOE/RL-2010-96), undertaken for the 100-BC-5 portion of the Hanford Site that will support final remedy selection and provide the basis for a final Record of Decision (ROD) for 100-BC-5. The modeling effort focused on the evaluation of remedy alternatives to prevent the migration of contaminants of concern (COC) toward the Columbia River and lower COC concentrations in the aquifer to below target values.

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2 Background

The groundwater COCs at 100-BC-5 include hexavalent chromium (Cr(VI)), strontium-90, and tritium. Remedial action for Cr(VI) and strontium-90 is required to restore unconfined aquifer beneficial uses and to protect Columbia River water quality. Other than compliance monitoring, no remedial action for tritium is required because it meets applicable or relevant and appropriate requirements (ARARs) in the unconfined aquifer.

Groundwater modeling was conducted to establish baseline aquifer conditions to compare and evaluate groundwater remediation alternatives against no further action. Results of groundwater modeling provide a prediction of COC plumes and trends under no action, monitored natural attenuation (MNA), and active remediation alternatives. Groundwater model simulations were run for 125 years to evaluate the progress of groundwater plume remediation.

In developing and evaluating alternative components for groundwater, a numerical groundwater flow and contaminant transport model was used as an evaluation and design concept tool. Groundwater flow and transport simulations and particle tracking were performed to determine the feasibility of each design concept and estimate time frames to achieve preliminary remediation goals (PRGs).

2.1 Design Elements

Quantitative and qualitative evaluations were performed as part of a screening process for assessing the feasibility of various configurations of remedial design elements, and determining the most suitable components of the proposed alternatives. Quantitative evaluations were performed using groundwater flow and transport modeling to assess plume migration patterns, discharges to the Columbia River, and the effect of suspected continuing sources to concentration levels in the dissolved plume along with the corresponding cleanup time frames under various design scenarios. Qualitative evaluations included considerations related to the implementability and effectiveness of alternative designs, given the nature and extent of the dissolved plumes and suspected continuing sources.

Groundwater remedial design configurations included the following key design elements:

- No further action
- Pump and treat (P&T)
- Chemical reduction in source areas
- Flushing in source areas or selected zones

The screening process of design configurations focused on evaluating their effectiveness on the following basis:

- The duration of implementation of active elements, such as P&T
- The number and location of P&T wells
- The timing, extent, and efficacy of chemical reduction at source areas
- The implementability of chemical reduction and/or flushing over extended areas

2.2 Evaluation of Alternative Configurations

Under no further action, it is assumed that contaminant transport occurs under ambient flow conditions, with contaminant plumes ultimately discharging to the river. Cr(VI) and strontium-90 concentrations emanating from the suspected source areas commingle with the dissolved plumes in the saturated zone, as described in Chapter 5 of DOE/RL-2010-96. Strontium-90 is present only in the shallow part of the

aquifer; however, chromium is also present in the deeper part of the aquifer, migrating slowly downgradient toward the river.

P&T configurations were developed considering the extent of the chromium and strontium-90 plumes across the entire thickness of the aquifer and near the Columbia River shoreline. Extraction well locations were selected to ensure hydraulic containment of these plumes for preventing further discharges to the river and capturing dissolved concentrations emanating from the suspected source areas near the shoreline, as well as expediting mass removal. For this purpose, flow and transport modeling was conducted to evaluate shallow and deep well locations downgradient of waste sites 116-B-1, 116-B11, and 116-C-1 (Figure 2-1). The potential for recovering the portion of the chromium plume extending under the riverbed near the pumping station was evaluated by simulating the operation of deep extraction wells in that area. Finally, injection well locations were evaluated to facilitate recirculation in the aquifer of treated water while increasing groundwater velocities within the core of the contaminant plumes, thereby expediting mass recovery. Several P&T configurations were developed for different operation time frames and pumping rates, to determine the duration and capacity required to ensure river protection by lowering projected discharging concentrations below the aquatic water quality standard (AWQS) of 10 μg/L, and to shorten aquifer cleanup time frames.

Qualitative and quantitative evaluations were performed to assess the effectiveness of in situ treatment technologies for providing control of vadose zone and periodically rewetted zone (PRZ) sources, formed due to residual mobile contamination in the vadose zone remaining after previous remediation, or high concentration plume segments in groundwater. As described in the *Evaluation of Leaching Characteristics of Hexavalent Chromium from Contaminated 100-BC Sediments at Hanford Site to Estimate Time Dependent Mass Flux for Fate and Transport Modeling* (ECF-100BC5-16-0028, 2016), the conceptual model for the distribution of Cr(VI) in the vadose zone and groundwater includes two areas where continuing groundwater Cr(VI) sources are suspected: the PRZ below the 100-C-7/100-C-7:1 excavation footprint, and the vadose zone and or PRZ beneath previously remediated waste site 116-B-11. Design configurations were developed and tested, using the groundwater flow and transport model, to evaluate the long-term effect on cleanup time frames of chemical reduction at those sources areas. Substrate injection was considered for reducing chromium mass in the PRZ and scenarios were developed for reduction at either source area, to evaluate if and where implementation of in situ treatment can control the migration of the emanating dissolved plume from those areas and reduce cleanup time frames.

The nature and extent of strontium-90 (DOE/RL-2010-96; Chapter 4) and trend analysis results (DOE/RL-2010-96; Section 5.5.2.3) suggest residual strontium-90 contamination may remain in the deep vadose zone and in aquifer sediments. Strontium-90 distribution in the vadose zone and PRZ is diffuse in nature, characterized by relatively low concentrations that do not vary significantly over an extended area. As a result, implementing chemical reduction via jet apatite injection over an area in the vadose zone of relatively elevated concentrations would not impact concentrations of similar levels outside that area in the vadose zone and/or the dissolved plume. Therefore, implementation of this technology would not reduce strontium-90 concentrations in the aquifer and, hence, remedial time frames would remain practically unchanged. The groundwater flow and transport model was used for simulating conditions of reduced mass loadings from the vadose zone due to treatment of aquifer sediments for strontium-90 using liquid apatite injection and to evaluate impacts to the dissolved plume. Model results suggested that chemical reduction via liquid apatite injection did not significantly decrease remedial time frames and produced undesirable consequences (increased remedial time frames and elevated COC concentrations near the shoreline). Therefore, apatite injection was not incorporated into any of the alternatives. Figure 2-2 depicts the strontium-90 distribution in the saturated zone, considering an alternative configuration and assuming P&T well operation near the downgradient waste sites after 20 years, when apatite injection could be implemented. The depicted distribution illustrates the short range of dissolved concentrations

within and outside potential chemical treatment zones (i.e., waste sites or areas of relatively high dissolved concentrations), which deems ineffective the implementation of strontium-90 reduction in the vadose and/or saturated zone.

Finally, flushing of the suspected source areas with clean water was also considered as a design configuration and its efficacy was evaluated using the groundwater flow and transport model. Several scenarios were evaluated, assuming different flushing rates and areal extents of the flushing zones. Model results suggested that flushing scenarios assuming areal recharge over the suspected source zone at 116-B-11 can result in elevated chromium concentrations in the aquifer that could be contained by the downgradient extraction wells. Flushing was also considered over an extended zone encompassing suspected sources areas like 116-B-11, but also other waste sites in its general vicinity. In that case, flushing effects were evaluated using particle tracking to assess whether the number, location, and flow rates of the P&T extraction wells could provide sufficient hydraulic containment to ensure river protection. Even though implementation of flushing over such an extended area could not be warranted, model results suggested that hydraulic containment is feasible under the P&T scenarios considered. However, similarly to apatite injection, model results indicated that flushing resulted in increased strontium-90 concentrations in the aquifer over an extended area. Even though source concentrations were decreased, the resulting introduction of higher concentrations in the aquifer led to prolonged cleanup time frames, as the primary mechanism for reduction of strontium-90 concentrations in the aquifer is radioactive decay rather than advection/dispersion.

Table 2-1 summarizes the combinations of the design elements discussed here and the variations of their associated components, as developed and evaluated during the screening process.

2.3 Proposed Alternative Designs

Based on the evaluations discussed, the following groundwater alternative designs are proposed:

1. Alternative 1: no further action
2. Alternative 2: MNA with institutional controls (ICs)
3. Alternative 3: P&T
4. Alternative 4: P&T with Cr(VI) source treatment

Alternatives 1 and 2 are essentially identical in terms of their groundwater flow and contaminant transport components. In both cases, the aquifer flow field is mainly influenced by river-stage oscillations that are reflected in the model boundary conditions, resulting in plume migration under ambient flow conditions. The Cr(VI) and strontium-90 dissolved plumes commingle with contributions from continuing sources in the vadose zone and PRZ, which are depleting over time.

Alternative 3 assumes operation of four shallow extraction wells downgradient of 116-B-11 that provide sufficient hydraulic containment to protect the Columbia River from further discharges of Cr(VI) and strontium-90, and capture the dissolved Cr(VI) migrating to the river as well as the plume emanating from the continuing source at 116-B-11. These extraction wells also accelerate aquifer restoration by removing mainly Cr(VI) from the shallow aquifer. Two deep extraction wells near the pumping station provide additional mass recovery in the deeper zone of the aquifer and underneath the bottom of the river, also accelerating aquifer restoration. Four inland extraction wells recirculate the extracted water in the aquifer, expediting the cleanup process by increasing hydraulic gradients in the shallow aquifer. System operation is assumed for 40 years to achieve hydraulic containment and ensure that concentrations discharging to the river do not exceed the PRGs for Cr(VI) and strontium-90.

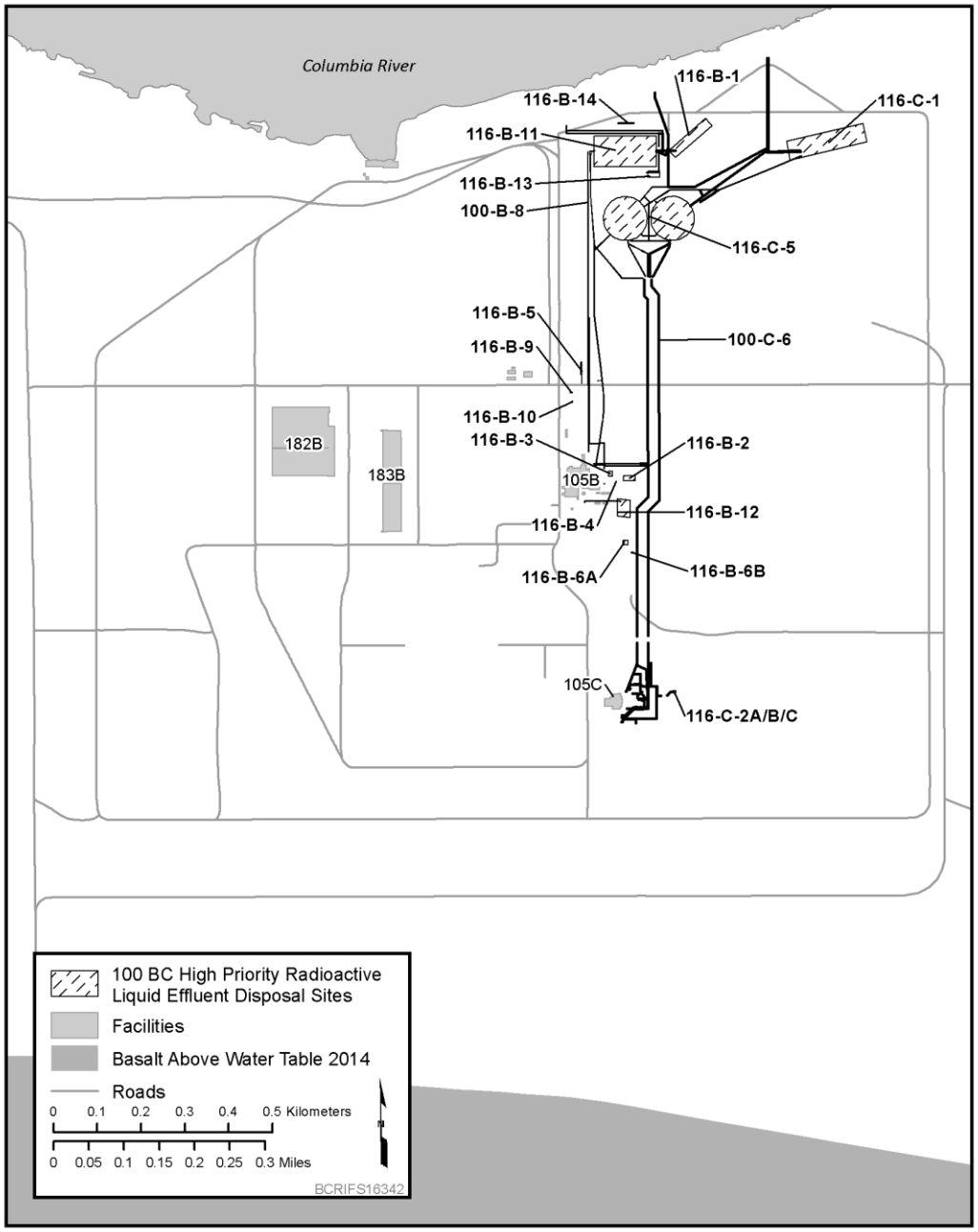

Figure 2-1. 100-BC High-Priority Radioactive Liquid Effluent Disposal Sites (Source: DOE/RL-2010-96)

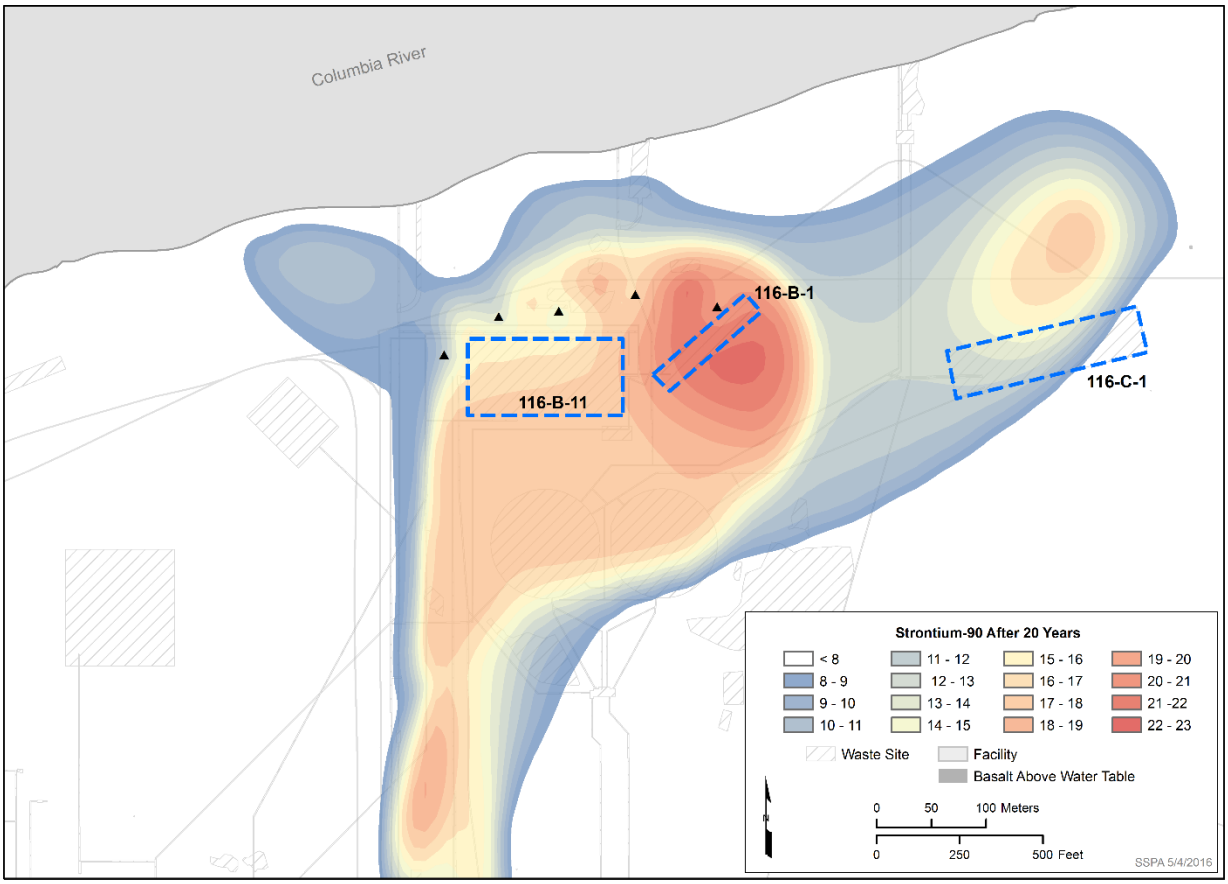

Figure 2-2. Strontium-90 Concentrations after 20 Years in the Vicinity of Waste Sites near the Shoreline

Model forecasts suggest that Cr(VI) concentrations in groundwater at the southernmost area (PRZ beneath 100-C-7/100-C-7:1) attenuate to below the AWQC (10 µg/L) before reaching the Columbia River, and that treatment of this source area would not significantly reduce the time frame for achieving the shoreline RAOs for Cr(VI). However, model forecasts indicate that treatment of the northernmost source area (vadose zone/PRZ beneath 116-B-11) could reduce the time for P&T to reach shoreline PRGs. Therefore, Alternative 4 assumes operation of extraction and injection wells as part of a P&T system similar to Alternative 3, with an additional shallow extraction well, but it also implements a source treatment component for Cr(VI), applied at 116-B-11. A solution of calcium polysulfide is considered as the substrate to be injected in the vadose zone and PRZ, which reduces source mass in those zones by 50 percent, thereby reducing mass loadings to the aquifer and associated cleanup time frames. System operation for Alternative 4 is designed for 15 years, with source treatment implemented during the first year of system operation.

For Alternatives 3 and 4, it is assumed that implementation of the proposed remedial designs occurs after four years of plume migration under ambient flow conditions. This time frame corresponds to time required for final remedy selection and issuing the final ROD.

When a P&T system is implemented for Cr(VI), strontium-90 is recirculated in the aquifer without in situ or ex situ treatment for the proposed alternative designs. To ensure that strontium-90 concentrations in the reinjected water do not exceed the PRG of 8 pCi/L, concentrations at the extraction wells are calculated for strontium-90 in Alternatives 3 and 4, where a P&T system is implemented for Cr(VI). Extracted

concentrations do not exceed the strontium-90 PRG and, therefore, concentration at each of the injection wells, which is equal to the blended effluent concentration from the treatment plant, is also below the PRG.

Details on system configuration for each alternative design are presented in Section 4. Modeling results are presented in Section 7.

Table 2-1. Design Element Configurations for the Remedial Alternatives

Design Element	No Further Action	Pump and Treat Only	Pump and Treat with Chemical Mass Loading Reduction and Flushing	Pump and Treat with Chemical Mass Loading Reduction	
Common Components	Continuing sources: (a) Cr(VI): 100-C-7:1 and 116-B-11; (b) strontium-90: distributed				
	Transport parameters for Cr(VI) and strontium-90 same in all remedial alternatives				
	No further action during the first 4 years (2015 to 2018)				
P&T	Flow and transport under ambient aquifer conditions	• 4 extraction wells by 116-B-11 • 2 deep extraction wells by pumping station • 4 injection wells inland	• 4 extraction wells by 116-B-11 • 2 deep extraction wells by pumping station • 4 injection wells inland • 4 extraction wells by 116-C-1	• 4 extraction wells by 116-B-11 • 2 deep extraction wells by pumping station • 4 injection wells inland • 4 extraction wells by 116-C-1	• 5 extraction wells by 116-B-1/116-B-11 • 2 deep extraction wells by pumping station • 4 injection wells inland
		Total Pumping: 400 gpm	Total Pumping: 700 gpm	Total Pumping: 400 gpm	Total Pumping: 400 gpm
P&T Duration		10 yr of P&T	10 yr of P&T	10 yr of P&T	
		20 yr of P&T	20 yr of P&T	15 yr of P&T	
		40 yr of P&T	40 yr of P&T	20 yr of P&T	
		30 yr of P&T		40 yr of P&T	
Changes in Mass Loading: Cr(VI)			50% mass loading reduction at 100-C-7:1 source area (substrate injection in summer 2019)	50% mass loading reduction at 116-B-11 source area (substrate injection in summer 2019)	

Table 2-1. Design Element Configurations for the Remedial Alternatives

Design Element	No Further Action	Pump and Treat Only	Pump and Treat with Chemical Mass Loading Reduction and Flushing		Pump and Treat with Chemical Mass Loading Reduction	
Changes in Mass Loading: Strontium-90			Additional mass loading due to flushing. Extracted mass recirculated at injection wells during P&T operations		Apatite jet injection in vadose zone and/or liquid injection in saturated zone at 116-C-1 and/or 116-B-11/116-B-1 (50% mass loading reduction in that area; apatite injection after completion of 90% of P&T for Cr(VI))	Extracted mass recirculated at injection wells during P&T operations
Flushing			Flushing at 116-B-11: 1 m/yr	Flushing at 116-B-11: 3 m/yr		
Flushing Duration			10 yrs of P&T/flushing	10 yrs of P&T/flushing		
			20 yrs of P&T/flushing	20 yrs of P&T/flushing		
			40 yrs of P&T/flushing	40 yrs of P&T/flushing		
			• 10 yrs of flushing • 20 yrs of P&T			
			• 10 yrs of P&T • Flushing: extended area	• 10 yrs of P&T • Flushing: extended area		

Cr(VI) = hexavalent chromium

P&T = pump and treat

1

3 Calculation Methods

The following sections discuss the calculation methodology using a groundwater flow and contaminant transport model.

3.1 Groundwater Flow and Contaminant Transport Modeling

Simulations of groundwater flow and contaminant transport were conducted using a numerical model developed by INTERA[1] specifically for 100-BC-5, as detailed in *100-BC Scale-Appropriate Fate and Transport Model* (SGW-59365, Draft A). Contaminant transport for Cr(VI) and strontium-90 assumes migration of a dissolved plume in the aquifer and contributions from continuing sources in the vadose zone.

Predictive model simulations are conducted for ambient flow conditions, operation of extraction and injection wells as part of a P&T system, and P&T combined with source treatment for Cr(VI) to reduce contribution from continuing sources.

Aboveground treatment is assumed for Cr(VI), using an ion exchange treatment system. Strontium-90 passing through the treatment system is not removed under the assumed treatment process, but is recirculated in the aquifer via injection at the injection wells connected to the treatment plant. Strontium-90 concentrations reinjected into the aquifer are equal to the blended influent concentration at the treatment plant.

In situ treatment (reduction) for Cr(VI) is based on injection of a calcium polysulfide solution into the vadose zone and PRZ, applied to waste site 116-B-11. Implementation of source treatment for chromium in the model is facilitated via a recharge term with distributed infiltration within the model cells corresponding to the treatment zone indicated previously. Mass loadings, reduced by 50 percent due to the implementation of the substrate injection, are calculated externally to the model, as detailed in ECF-100BC5-16-0081.

3.2 Predictive Modeling Process

For each alternative design, a systematic process was followed to develop model input files, to perform the model simulation, and to post-process the model results to evaluate system performance. This procedure is described by the following steps:

1. Well locations for injection and extraction wells were proposed, discussed, and selected.
2. Injection and extraction rates were proposed, discussed, and assigned to each well.
3. An input file for the MODFLOW Multi-Node Well (MNW2) Package (Revised Multi-Node Well (MNW2) Package for MODFLOW Ground-Water Flow Model, Konikow et al., 2009) was constructed to describe the spatial and temporal configuration of the well operations.
4. An input file for areal recharge is amended, when necessary, to reflect the additional infiltration associated with the implementation of Cr(VI) source treatment.
5. The flow model was executed to simulate transient hydraulic head distributions, together with accessory outputs including model-wide and cell-by-cell flow budgets.

[1] INTERA Geoscience and Engineering Solutions, Austin, TX 78754

6. Input files for the advective-dispersive contaminant transport model were constructed for each COC, including the initial distribution, and COC-specific transport parameters such as decay rate, where applicable.

7. Input files for representing the contribution to the dissolved COC plumes from continuing sources in the vadose zone and PRZ were constructed.

8. The contaminant transport model was executed to simulate the advective-dispersive transport of each COC and the results were post-processed.

9. Post-processing of the contaminant transport simulations was completed, comprising the following:

    a. Maps of the simulated distribution for Cr(VI) after 4, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 110, and 120 years of elapsed model simulation time.

    b. Maps of the simulated distribution for strontium-90 after 4, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, and 70 years of elapsed model simulation time.

    c. Summary concentration statistics time series including concentration statistics in the aquifer (maximum and 90th percentile) and impacted shoreline length (that is, where concentrations are above the applicable standard).

    d. Estimated cleanup times based on the calculated concentration statistics and the corresponding applicable standard.

4 Assumptions and Inputs

Assumptions and inputs for the calculations presented in this calculation brief are discussed in the following subsections.

4.1 Model Structure

A numerical groundwater flow and transport model of the 100-BC-5 Operable Unit (OU) area (100-BC Model) was developed by INTERA for use by CH2M HILL Plateau Remediation Company in support of remedy design evaluation. A detailed discussion of the numerical model is presented in *100-BC Scale-Appropriate Fate and Transport Model* (SGW-59365, Draft A).

The model was developed to simulate conditions for the period 2006-2015, with stress periods ranging from 5 to 30 days. The model was calibrated to data from the period 2012-2014 and a predictive flow and transport model was then developed, repeating the 2006-2015 conditions for 125 years.

4.2 Contaminant Transport Processes

Contaminant transport processes simulated by the 100-BC model are discussed in detail in SGW-59365.

4.3 Continuing Sources

Continuing groundwater Cr(VI) sources are suspected in the PRZ below the 100-C-7 / 100-C-7:1 excavation footprint, and the vadose zone and or PRZ beneath previously remediated waste site 116-B-11. Residual strontium-90 contamination may remain in the deep vadose zone and in aquifer sediments and is distributed across a large area.

Contribution to the dissolved plumes from these sources are detailed in Hexavalent Chromium Source Term Estimates for 100-BC, Rev. 0 (ECF-100BC5-16-0081, 2016) for Cr(VI), and Calibration of Continuing Source for Strontium-90 in the 100-BC-5 Operable Unit, Rev. 0 (ECF-100BC5-16-0051, 2016) for strontium-90.

4.4 Cr(VI) Source Treatment

Source treatment for Cr(VI) assumes injection of a substrate solution in the bottom of the vadose zone and top of the PRZ. Calculations for the required amount of solution are based on calcium polysulfide (CPS) as the main component of the solution, which also contains potable water, corn syrup, and ammonium chloride.

CPS reacts readily with Cr(VI), reducing it to Cr(III). As shown in the following equation, during the reaction between CPS and Cr(VI), polysulfide is oxidized to elemental sulfur while chromium is simultaneously reduced from hexavalent to trivalent:

$$2CrO_4^{-2} + 10H^+ + 3CaS_5 \rightarrow 3Ca^{+2} + 2Cr(OH)_3 + 15S^0 + 2H_2O \qquad \text{Equation (1)}$$

The Cr(VI) mass assumed present in the vadose zone underneath the 116-B-11 waste site is calculated in ECF-100BC5-16-0081, and is approximately 150 kilograms. The corresponding mass as CrO_4^{-2} is 328 kilograms and, assuming 50 percent reduction, the mass to be treated is 164 kilograms. CPS required for that reduction is about 425 kilograms or about 15,000 gallons of solution. This amount should be increased in order to address uncertainties associated with the effectiveness of the injection process (e.g., number of wells, radius of influence, sediment permeability). Assuming an area of about 5,500 square meters, a porosity of 20 percent, and a safety factor of 10, an areal infiltration rate of 0.02 meters per day is applied to the model cells encompassed within this area, during the sixth month of the fifth year of

simulation, to account for the recharge to the aquifer while ideal source treatment for Cr(VI) is implemented.

4.5 Treatment System Recirculation

The groundwater flow and transport model was also configured to simulate the circulation of extracted strontium-90 within the P&T system while Cr(VI) is actively treated. During this process, strontium-90 is recovered at the extraction wells, passes untreated through the treatment system, and is returned to the groundwater domain via injection wells. Blending of the extracted water occurs within the aboveground treatment system so the effluent concentration is generally lower (more dilute) than the highest influent concentration measured at the wellhead. This movement of contaminants through a P&T system is simulated using the Contaminant Treatment System (CTS) package implemented in MT3DMS (Bedekar et al, 2011).

4.6 Initial Distribution of COCs

The initial distribution of Cr(VI) and strontium-90 in groundwater within the 100-BC-5 OU was obtained using maximum sampled COC concentrations at each monitoring location in 2014. Samples from well 199-B4-4 were excluded from the dataset, as its screened interval is different from other nearby monitoring wells and, therefore, concentration data are not considered representative of the shallow aquifer at that location.

Calculation of the initial distribution used a systematic approach to develop contaminant plume maps via an integrated numerical interpolation methodology that includes data transformation and implementation of Ordinary Kriging interpolation. This was presented in *Hanford Site Groundwater Monitoring for 2015* (DOE/RL-2016-09, Rev. 0) and detailed in *Calculation and Depiction of Groundwater Contamination for the Calendar Year 2015 (CY2015) Hanford Site Groundwater Monitoring Report* (ECF-Hanford-16-0061, Rev.0).

Figures 4-1 and 4-2 depict the initial distribution of Cr(VI) and strontium-90, respectively.

4.7 Wells

Flow and transport model simulations were performed for four alternative remedy designs. Alternatives 1 and 2 consider only ambient aquifer conditions while Alternatives 3 and 4 comprise extraction and injection wells. The following subsections present detailed descriptions of the well configuration for each Alternative.

4.7.1 Alternative 1: No Further Action

Under Alternative 1, plume migration is simulated under ambient aquifer conditions. No extraction or injection wells are considered.

4.7.2 Alternative 2: Monitored Natural Attenuation

Like Alternative 1, plume migration under Alternative 2 is simulated under ambient aquifer conditions considering only MNA and ICs. No extraction and/or injection wells are considered. No separate model simulations are performed for Alternative 2 as, from a modeling standpoint, flow and transport conditions are equivalent to those described in Alternative 1.

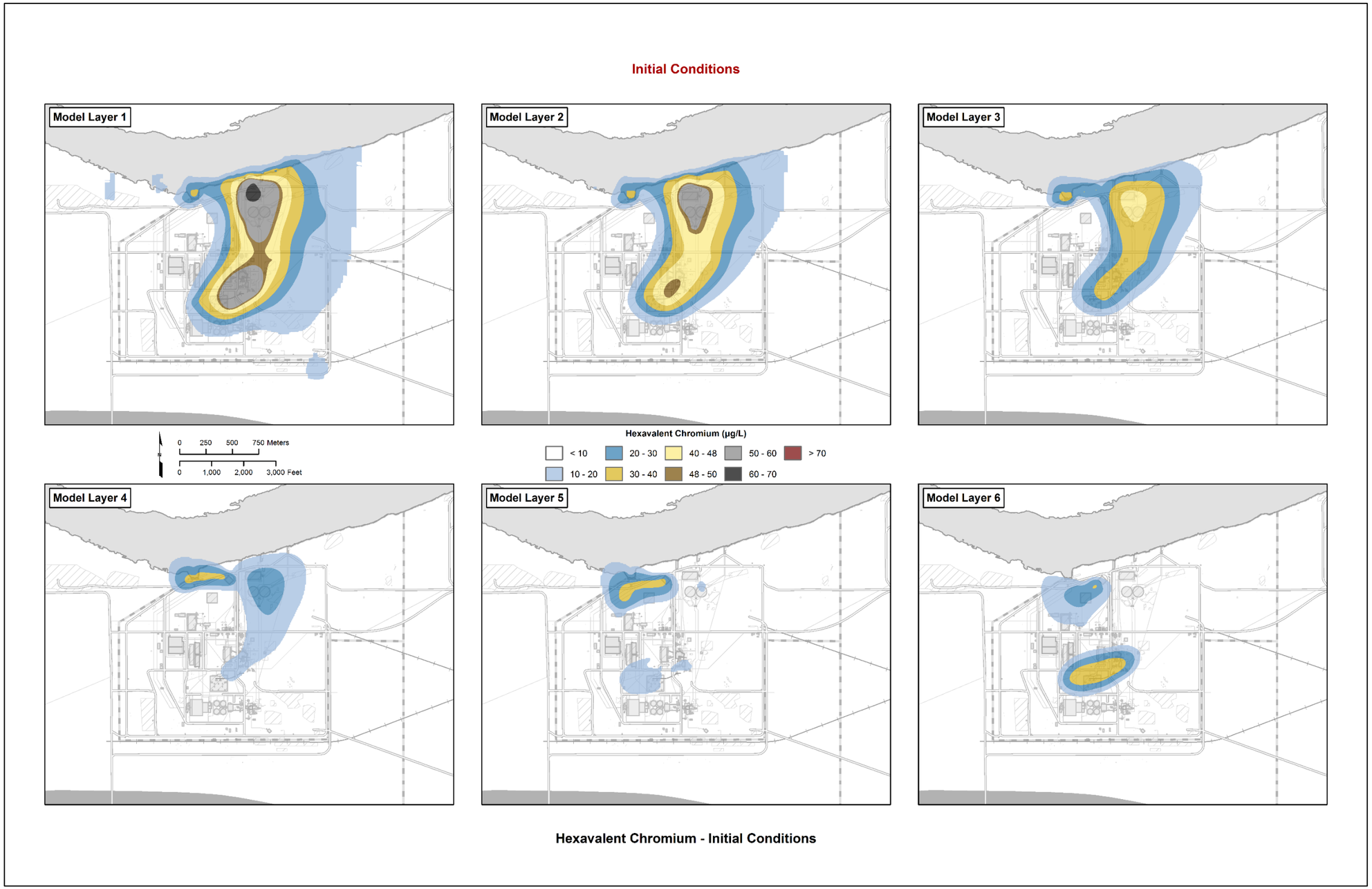

Figure 4-1. Initial Cr(VI) Distribution in each Model Layer

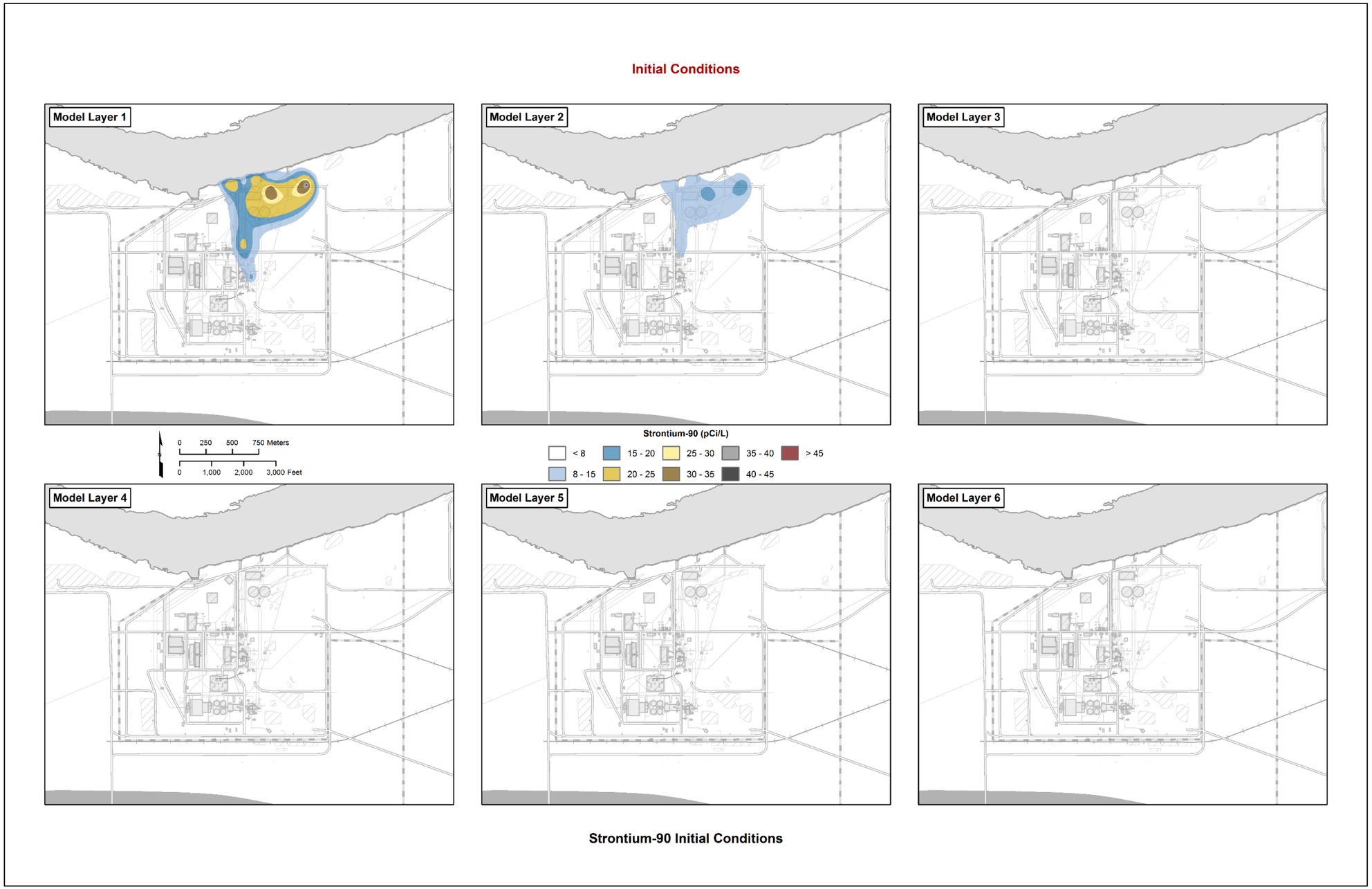

Figure 4-2. Initial Strontium-90 Distribution in Each Model Layer

4.7.3 Alternative 3: P&T

Alternative 3 assumes operation of four (4) shallow extraction wells downgradient of 116-B-11 which provide sufficient hydraulic containment to (a) protect the Columbia River from further discharges of Cr(VI) and strontium-90, and (b) capture the dissolved Cr(VI) migrating to the river as well as the plume emanating from the continuing source at 116-B-11. These extraction wells also accelerate aquifer restoration by removing mainly Cr(VI) from the shallow aquifer. Two (2) deep extraction wells in the vicinity of the pumping station provide additional mass recovery in the deeper zone of the aquifer and underneath the bottom of the river, also accelerating aquifer restoration. Four (4) inland injection wells recirculate the extracted water back into the aquifer, expediting the cleanup process by increasing hydraulic gradients in the shallow aquifer. System operation is assumed for 40 years to achieve hydraulic containment and ensure that concentrations discharging to the river do not exceed the PRGs for Cr(VI) and strontium-90. Total system flow rate is 400 gpm.

It is assumed that implementation of the proposed remedial design occurs after four (4) years of plume migration under ambient flow conditions. This timeframe corresponds to time required for final remedy selection and issuing the final ROD.

Figure 4-3 shows the extraction and injection well configuration for Alternative 3 in each model layer. Detailed account of the pumping rates for all wells is included in Table 4-1.

4.7.4 Alternative 4: P&T with Cr(VI) Source Treatment

Alternative 4 considers installation and operation of an expanded P&T extraction and injection well network similar to Alternative 3, with an additional shallow extraction well, but it also implements a source treatment component for Cr(VI), applied at 116-B-11. System operation for Alternative 4 is assumed to be 15 years, with source treatment implemented during the first year of system operation. Total system flow rate is 400 gpm.

Similarly to Alternative 3, it is assumed that implementation of the proposed remedial design occurs after four years of plume migration under ambient flow conditions. This time frame corresponds to time required for final remedy selection and issuing the final ROD.

Figure 4-4 shows the extraction and injection well configuration for Alternative 4 in each model layer. Detailed account of the pumping rates for all wells is included in Table 4-2.

4.8 Model Assumptions and Limitations

Conceptual and parameter uncertainties associated with the groundwater flow and contaminant transport model are presented in SGW-59365.

Consistent with recommendations made throughout the remedy design process, simulated COC distributions in the future, under a variety of potential remedy alternatives, should be interpreted as relative estimates, not as absolute predictions of actual plume migration patterns. Numerical transport modeling over long time frames such as these should be used principally for comparative remedy selection, i.e., to identify the likely benefits of one remedy versus another through qualitative assessments of long-term plume migration patterns, rather than accurately calculating such long-term predictions of point concentrations.

Upon implementation of any remedy design, monitoring data should be compiled and analyzed to further improve estimation of the parameters associated with the simulation of the fate and transport of the COCs and performance of the implemented remedies. The model should be updated to provide improving estimates of remedy performance. The same procedure should be followed if well operation and

performance in the future are different from those described for each alternative design, as predicted plume migration patterns are contingent upon the extraction/injection well operation and the performance on which those predictions were based.

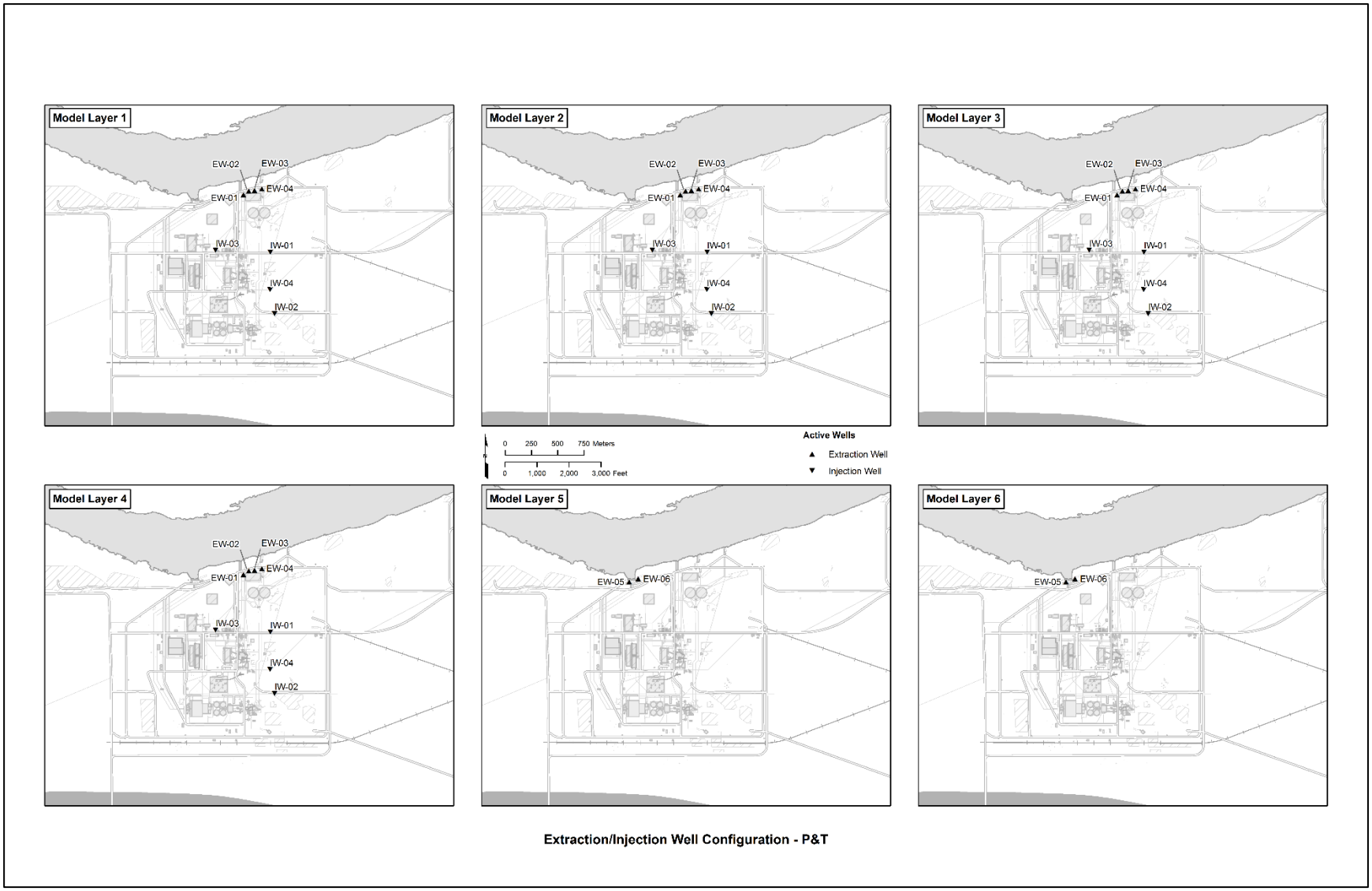

Figure 4-3. Extraction/Injection Well Configuration in each Model Layer – Alternative 3: P&T

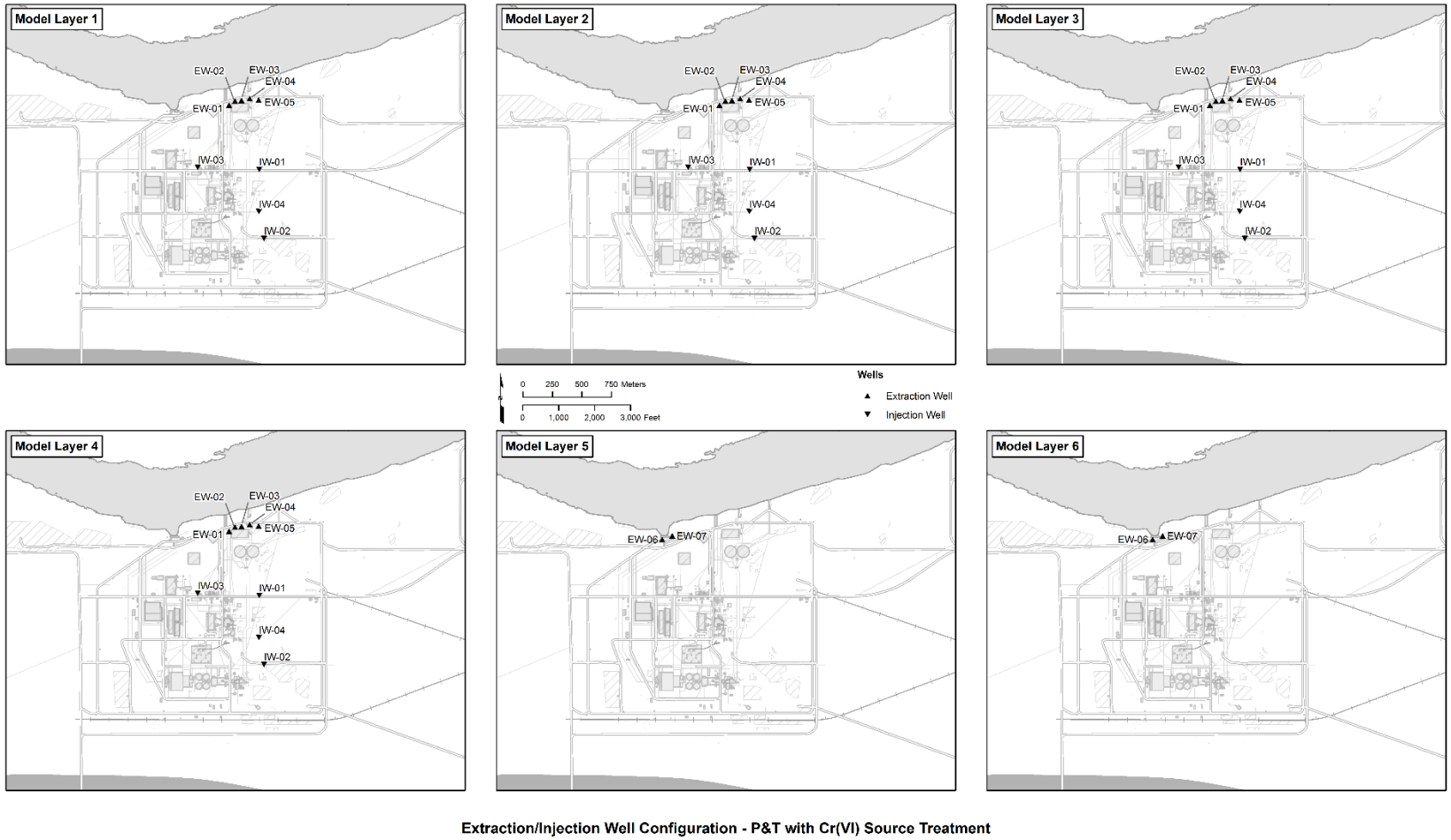

Figure 4-4. Extraction/Injection Well Configuration in each Model Layer – Alternative 4: P&T with Cr(VI) Source Treatment

Table 4-1. Names, Geographic Coordinates, and Extraction and Injection Rates of 100-BC-5 Wells – Alternative 3

Well Name	Easting	Northing	Pumping Rate
EW-01	565472.5	145337.5	-75[a,b]
EW-02	565402.5	145322.5	-75
EW-03	565347.5	145317.5	-75
EW-04	565297.5	145282.5	-75
EW-05	564812.5	145212.5	-50
EW-06	564897.5	145242.5	-50
IW-01	565552.5	144737.5	100
IW-02	565593.0	144153.0	100
IW-03	565031.0	144756.0	100
IW-04	565550.0	144381.0	100

a. Pumping rates in gallons per minute (gpm).

b. Negative values indicate extraction.

Table 4-2. Names, Geographic Coordinates, and Extraction and Injection Rates of 100-BC-5 Wells – Alternative 4

Well Name	Easting	Northing	Pumping Rate
EW-01	565472.5	145337.5	-70 [a,b]
EW-02	565402.5	145322.5	-70
EW-03	565347.5	145317.5	-70
EW-04	565297.5	145282.5	-70
EW-05	564812.5	145212.5	-25
EW-06	564897.5	145242.5	-25
EW-07	565547.5	145326.5	-70
IW-01	565552.5	144737.5	100
IW-02	565593	144153	100
IW-03	565031	144756	100
IW-04	565550	144381	100

a. Pumping rates in gallons per minute (gpm).

b. Negative values indicate extraction.

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5 Software Applications, Descriptions, Installation and Checkout, and Statements of Validity

Software use for this calculation was in accordance with PRC-PRO-IRM-309, *Controlled Software Management*, Rev. 0.

5.1 Approved Software

The following software was used to perform calculations and was approved and compliant with PRC-PRO-IRM-309 (PRC-PRO-IRM-309, Controlled Software Management). This software is managed under the following documents consistent with PRC-PRO-IRM-309:

- CHPRC-00257 Rev. 1, MODFLOW and Related Codes Functional Requirements Document
- CHPRC-00258 Rev. 3, MODFLOW and Related Codes Software Management Plan
- CHPRC-00259 Rev. 3, MODFLOW and Related Codes Software Test Plan
- CHPRC-00260 Rev. 8, MODFLOW and Related Codes Acceptance Test Report
- CHPRC-00261 Rev. 8, MODFLOW and Related Codes Requirements Traceability Matrix

CHPRC-00258 Rev. 3 distinguishes between safety software and support software based on whether the software managed calculates reportable results or provides run support, visualization, or other similar functions. Brief descriptions of the software follow.

5.2 Descriptions

Software descriptions are provided in the following paragraphs.

5.2.1 MODFLOW (Controlled Calculation Software)

- Software Title: MODFLOW-2000 (Open File Report 00-92, MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model—User Guide to Modularization Concepts and the Ground-Water Flow [Harbaugh et al., 2000]); solves transient groundwater flow equations using the finite-difference discretization technique.

- Software Version: Version 1.19.01 modified by S.S. Papadopulos and Associates, Inc. (SSP&A) to address dry cell issues and to use the Orthomin solver; approved as CH2M HILL Plateau Remediation Company (CHPRC) Build 8 using the executable “mf2k-mst-chprc08dpv.exe” compiled to default double precision for real variables and optimized for speed.

- Hanford Information Systems Inventory (HISI) Identification Number: 2517 (Safety Software, graded Level C).

- Workstation type and property number (from which software is run):
  - S.S. Papadopulos and Assoc., Inc., FE407.

5.2.2 MT3DMS (Controlled Calculation Software)

- Software Title: MT3DMS (Zheng and Wang 1999), MT3DMS: A Modular Three-dimensional Multispecies Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems; Documentation and User's Guide); MT3DMS V5.3 Supplemental User’s Guide [Zheng 2010])

- Software Version: Version 5.3 modified by S.S. Papadopulos and Associates, Inc. (SSP&A) to address dry cell issues; approved as CHPRC Build 8 using executable “mt3d-mst-chprc08dpv.exe” compiled to default double precision for real variables and optimized for speed.
- HISI Identification Number: 2518 (Safety Software, graded Level C).
- Workstation type and property number (from which software is run):
  - S.S. Papadopulos and Assoc., Inc., FE407.

5.3 Support Software

The following programs are classified as Support Software.

5.3.1 MODFLOW Suite Support Software

- Groundwater Vistas™: (Guide to Using Groundwater Vistas [Rumbaugh and Rumbaugh, 2011].) Provided graphical tools used for model quality assurance and model input/output review.
- ArcGIS™: (The ESRI Guide to GIS Analysis, Volume 1: Geographic Patterns and Relationships [Mitchell, 1999].) Provided visualization tool for assessing simulated plume distributions, identifying extraction/injection well coordinates and mapping auxiliary data.

The following scripts have been developed internally:

- ALLOCATEQWELL: Constructs a MODFLOW well package (WEL) or a multi-node well (MNW) package file.
- READBIN_WRITEASC.EXE: Reads binary output files generated by MODFLOW or MT3D and creates ASC files for plotting the spatial distribution of heads or concentrations, respectively.
- readoutgetmnw2nodes.exe: Constructs the MT3D recirculation input file (CTS Package) based on the flow model solution and MNW2 structure.
- Postproccalsmassconc.exe: calculates blended influent concentration at each treatment system.

5.4 Software Installation and Checkout

Safety Software is checked out in accordance with procedures specified in CHPRC-00258. Executables are obtained from the CHPRC software owner who maintains the configuration managed copies in MKS Integrity, installation tests identified in CHPRC-00259 are performed and successful installation confirmed, and Software Installation and Checkout Forms are required and must be approved for installations used to perform model runs. Approved Users are registered in HISI for safety software. Copies of the *Software Installation and Checkout* Forms are provided in Appendix A of this ECF.

5.4.1 Statement of Valid Software Application

- Use of the software identified here was consistent with intended use for CHPRC as identified in CHPRC-00257 and is a valid use of this software for the problem addressed in this application.
- The software was used within its limitations as identified in CHPRC-00257.
- R and Python have not been identified in CHPRC-00258, but is scheduled by the software owner to be included as support software in the next revision to that document. They are publically available, open-source freeware.

6 Calculation

The groundwater flow and contaminant transport model was used for the simulation of the alternative remedy designs in 100-BC-5. Model results were post-processed to evaluate system performance under each alternative. Upon completion of model simulations for all alternatives and COCs and post-processing of the model results, the following maps and graphs were constructed to provide the basis for evaluation of system performance:

1. Maps of the simulated distribution for Cr(VI) after 4, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 110, and 120 years of elapsed model simulation time.
2. Maps of the simulated distribution for strontium-90 after 4, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, and 70 years of elapsed model simulation time.
3. Summary plots of concentration statistics (that is, maximum and 90th percentile) for each alternative and COC.
4. Graphs of affected shoreline length over time for each alternative and COC.
5. Tabulated estimated cleanup times based on the calculated concentration statistics and the corresponding applicable standard.

Statistical calculations were based on the simulated spatial COC distribution in each layer as calculated by the model and mapped by post-processing the model outputs. COC concentrations were considered in the calculations based on values at all model cells within a geographically defined area encompassing the 100-BC-5 OU and all COC initial and predicted plume distributions. The extent of the COC spatial distribution was determined at each simulation time step, considering all model cells with concentration values above a selected lower limit (threshold). This lower limit was defined as 10 percent of the corresponding PRG or, in the case of Cr(VI), the AWQS of 10 µg/L. This was done to ensure that a realistic representation of the COC plume extents and corresponding concentration statistics are calculated at each time step and that the performance metrics are consistent and directly comparable for each alternative and COC.

Calculation of concentration statistics at the shoreline were based on the chain of model cells corresponding to the most extreme high river stage observed during the flow model simulation. Concentration statistics were calculated and included the maximum and 90th percentile of simulated concentrations per model layer.

The applicable standard for each COC and the corresponding threshold for the calculation of concentration statistics are listed in Table 6-1:

Table 6-1. COC Concentration Statistics – Applicable Standards and Thresholds

COC	Applicable Standard	Cut-Off Limit
Cr(VI)	10 µg/L (AWQS)	1 µg/L
Strontium-90	8 pCi/L (PRG)	0.8 pCi/L

Influent concentrations reflect mixing of the extracted water from each well, resulting in a blended concentration that passes through the treatment system. The calculated influent concentration during each stress period is equal to the product of the wellhead concentration at each extraction well (i.e., the COC

concentration at the model cell representing the particular well) and the corresponding pumped water volume during that period, divided by the total volume of water extracted at the wells over the same time frame.

The model results and corresponding plots and graphs are grouped per COC and type in the following sequence:

1. For each COC:
    a. Simulated COC distribution after 4, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 110, and 120 years for Cr(VI) or up to 70 years for strontium-90, for each alternative. Model results for Alternatives 1 and 2 are identical, as the simulated conditions are equivalent from a modeling standpoint
    b. Summary concentration statistics in the aquifer and along the shoreline
    c. Impacted shoreline length above clean-up standard
    d. Tabulated estimated cleanup times based on the calculated concentration statistics and the corresponding applicable standard

Strontium-90 is recirculated in the aquifer without in situ or ex situ treatment for the proposed alternative designs with a P&T system implemented for Cr(VI). To ensure that strontium-90 concentrations in the reinjected water do not exceed the PRG of 8 pCi/L, concentrations at the extraction wells are calculated for strontium-90 in Alternatives 3 and 4, where a P&T system is implemented for Cr(VI). If extracted concentrations do not exceed the strontium-90 PRG, then concentration at each of the injection wells, which is equal to the blended effluent concentration from the treatment plant, is also below the PRG.

7 Results and Conclusions

Calculation results and conclusions are provided in the following subsections.

7.1 Simulated Contaminant Distributions – Concentration Statistics

Simulated contaminant distributions and associated concentration statistics are provided in the following subsections.

7.1.1 Simulated Contaminant Distributions and Concentration Statistics: Cr(VI)

Model results for Cr(VI) are grouped in the following sets of figures:

1. Figures 7-1 to 7-18: simulated concentration distribution for no further action or MNA after 4, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 110, and 120 years, respectively
2. Figures 7-19 to 7-36: simulated concentration distribution for P&T after 4, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 110, and 120 years, respectively
3. Figures 7-37 to 7-54: simulated concentration distribution for P&T with Cr(VI) Source Treatment after 4, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 110, and 120 years, respectively
4. Figures 7-55 to 7-57: maximum and 90th percentile concentration time series for each model layer for no further action or MNA; P&T; and P&T with Cr(VI) Source Treatment
5. Figures 7-58 to 7-60: impacted shoreline length time series for each model layer above the drinking water standard (DWS, 48 µg/L), 40 µg/L, 20 µg/L, and ambient water quality standard (AWQS, 10 µg/L), for no further action or MNA; P&T; and P&T with Cr(VI) source treatment.

Estimated cleanup times, reflecting time frames for concentrations reaching levels below the Cr(VI) DWS and AWQS, in the aquifer and along the shoreline are summarized in Tables 7-1 and 7-2, respectively. These estimated cleanup times are based on the maximum and 90th percentile of the calculated concentration distribution in the aquifer and along the shoreline.

Table 7-1. Model Predicted Time (Years) for Maximum Concentration to Achieve Cr(VI) Groundwater PRGs

Groundwater PRG (Units)	No Further Action or MNA		P&T only		P&T with Source Treatment	
	Aquifer	Shoreline	Aquifer	Shoreline	Aquifer	Shoreline
Cr(VI) Drinking Water Standard (48 µg/L)	15	ABS	5	ABS	5	ABS
Cr(VI) AWQC (10 µg/L)	n/a	60	n/a	15	n/a	15

Notes:

- = The remediation time presented represents the range to achieve PRGs based on the maximum concentration (Cmax).

ABS = always below standard

n/a = time-to-PRGs are listed only for the appropriate standard in the aquifer or the shoreline.

Table 7-2. Model Predicted Time (Years) for Concentration 90th Percentile to Achieve Cr(VI) Groundwater PRGs

Groundwater PRG (Units)	No Further Action or MNA		P&T only		P&T with Source Treatment	
	Aquifer	Shoreline	Aquifer	Shoreline	Aquifer	Shoreline
Cr(VI) drinking water standard (48 µg/L)	5	ABS	5	ABS	5	ABS
Cr(VI) AWQC (10 µg/L)	n/a	30	n/a	15	n/a	15

Note:

- = The remediation time presented represents the range to achieve PRGs based on the 90th percentile of concentrations above 10% of PRG (C90).

ABS = always below standard

n/a = time-to-PRGs are listed only for the appropriate standard in the aquifer or the shoreline.

7.1.2 Simulated Contaminant Distributions and Concentration Statistics: Strontium-90

Model results for strontium-90 are grouped in the following sets of figures:

1. Figures 7-61 to 7-73: simulated concentration distribution for no further action or MNA after 4, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, and 70 years, respectively
2. Figures 7-74 to 7-86: simulated concentration distribution for P&T after 4, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, and 70 years, respectively
3. Figures 7-87 to 7-99: simulated concentration distribution for P&T with Cr(VI) Source Treatment after 4, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, and 70 years, respectively
4. Figures 7-100 to 7-102: maximum and 90th percentile concentration time series for each model layer for no further action or MNA; P&T; and P&T with Cr(VI) Source Treatment
5. Figures 7-103 to -7-105: impacted shoreline length time series for each model layer above the drinking water standard (DWS, 48 µg/L), 40 µg/L, 20 µg/L, and ambient water quality standard (AWQS, 10 µg/L), for no further action or MNA; P&T; and P&T with Cr(VI) source treatment

Estimated cleanup times, reflecting time frames for concentrations reaching levels below the strontium-90 PRG of 8 pCi/L, in the aquifer and along the shoreline are summarized in Tables 7-3 and 7-4, respectively. These estimated cleanup times are based on the maximum and 90th percentile of the calculated concentration distribution in the aquifer and along the shoreline.

Concentrations at the extraction wells are calculated for strontium-90 in Alternatives 3 and 4, where a P&T system is implemented for Cr(VI). As indicated in Figures 7-106 and 7-107, extracted concentrations do not exceed the strontium-90 PRG of 8 pCi/L and, therefore, strontium-90 concentration at each of the injection wells, which is equal to the blended effluent concentration from the treatment plant, is also below the PRG.

Table 7-3. Model Predicted Time (Years) for Maximum Concentration to Achieve Strontium-90 Groundwater PRGs

Groundwater PRG (units)	No Further Action or MNA		P&T		P&T with Cr(VI) Source Treatment	
	Aquifer	Shoreline	Aquifer	Shoreline	Aquifer	Shoreline
Strontium-90 MCL (8 pCi/L)	70	15	70	10	70	10

Note: The remediation time presented represents the range to achieve PRGs based on the maximum concentration (Cmax).

Table 7-4. Model Predicted Time (Years) for Concentration 90th Percentile to Achieve Strontium-90 Groundwater PRGs

Groundwater PRG (units)	No Further Action or MNA		P&T		P&T with Cr(VI) Source Treatment	
	Aquifer	Shoreline	Aquifer	Shoreline	Aquifer	Shoreline
Strontium-90 MCL (8 pCi/L)	60	15	60	10	60	10

Note: The remediation time presented represents the range to achieve PRGs based on the 90th percentile of concentrations above 10% of PRG (C90).

7.2 Conclusions

100-BC groundwater alternatives were developed for the Cr(VI) and strontium-90 plumes. The groundwater remedial action alternatives present a range of estimated time frames for each alternative to achieve PRGs:

- The lower end of the remediation time frame range is defined by the time required for the EPC (estimated using the 90th percentile) to decline to the PRG. The C90 concentration, which corresponds to the lower end of the remediation time frame, provides a reasonable estimate for the cleanup time frame that could be achieved with rigorous monitoring and remedial process optimization.
- The upper end of the range is defined by the time required for the maximum concentration to decline to the PRG. The Cmax concentration, which corresponds to upper end of the remediation time frame, provides a conservative estimate corresponding to potentially isolated point-concentrations.

Under Alternatives 1 and 2, significant Cr(VI) reduction occurs through natural flushing. The model suggests that a small aquifer area will have Cr(VI) concentrations above the DWS (48 µg/L) for 15 years. The model also suggests that small areas of the site will have Cr(VI) concentrations above the AWQC (10 µg/L) at the end of 60 years. The 100-BC plume extent continues to diminish until Cr(VI) concentrations are below 10 µg/L everywhere by about 2135 (120-year simulation time). However, as indicated in Figures 7-108 and 7-109, although persistent high concentrations extend remediation time frames, these concentrations are confined within very small areas, as the 90th percentile values suggest that concentrations almost everywhere in the aquifer are below the DWS within five years or less, even when no active remediation is implemented.

Finally, the model suggests the Cr(VI) groundwater plume continues to discharge to the river at concentrations above the 10 µg/L PRG for about 60 years in the shallow aquifer and about 20 years in the deeper zone of the aquifer. However, the associated impacted shoreline length, which is about one mile long at the beginning of the simulation, reduces to about half a mile within five years, and is contained within less than 200 meters in fewer than 15 years. The impacted shoreline length continues reducing in the following years and it is eliminated in fewer than 60 years. Comparison to model results for Alternatives 3 and 4 (Figures 7-110 and 7-111 for the shallow and dep aquifer zones, respectively) suggests that, although the corresponding remedial designs are more effective in containing discharges to the river within a short time frame, these time frames are not significantly shorter than Alternatives 1 and 2, especially in the deep aquifer zone.

Strontium-90 recovery appears to be relatively insensitive to the choice of remedial action (Figure 7-112). This is largely due to adsorption and, more importantly, significant half-life, which impede its migration in the aquifer. As a result, concentration reduction follows a pattern consistent with its half-life, even when P&T remediation is implemented. In addition, the diffusive nature of the strontium-90 continuing sources in the vadose zone and PRZ results in maintaining a dissolved plume with significant areal extent that is essentially infeasible to expedite recovery via P&T or source-reduction methods.

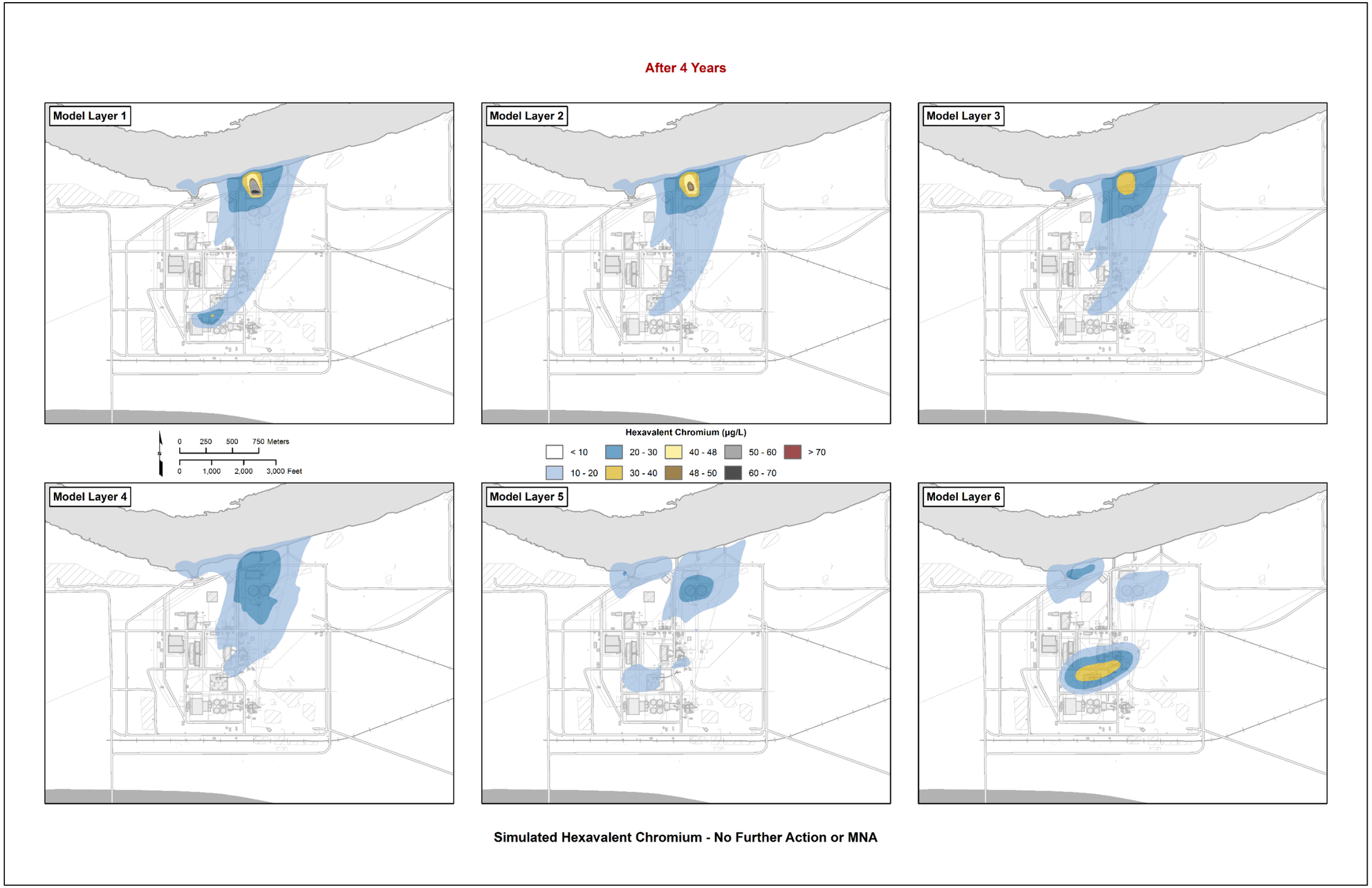


Figure 7-1. Simulated Distribution of Cr(VI) After 4 Years – No Further Action or MNA

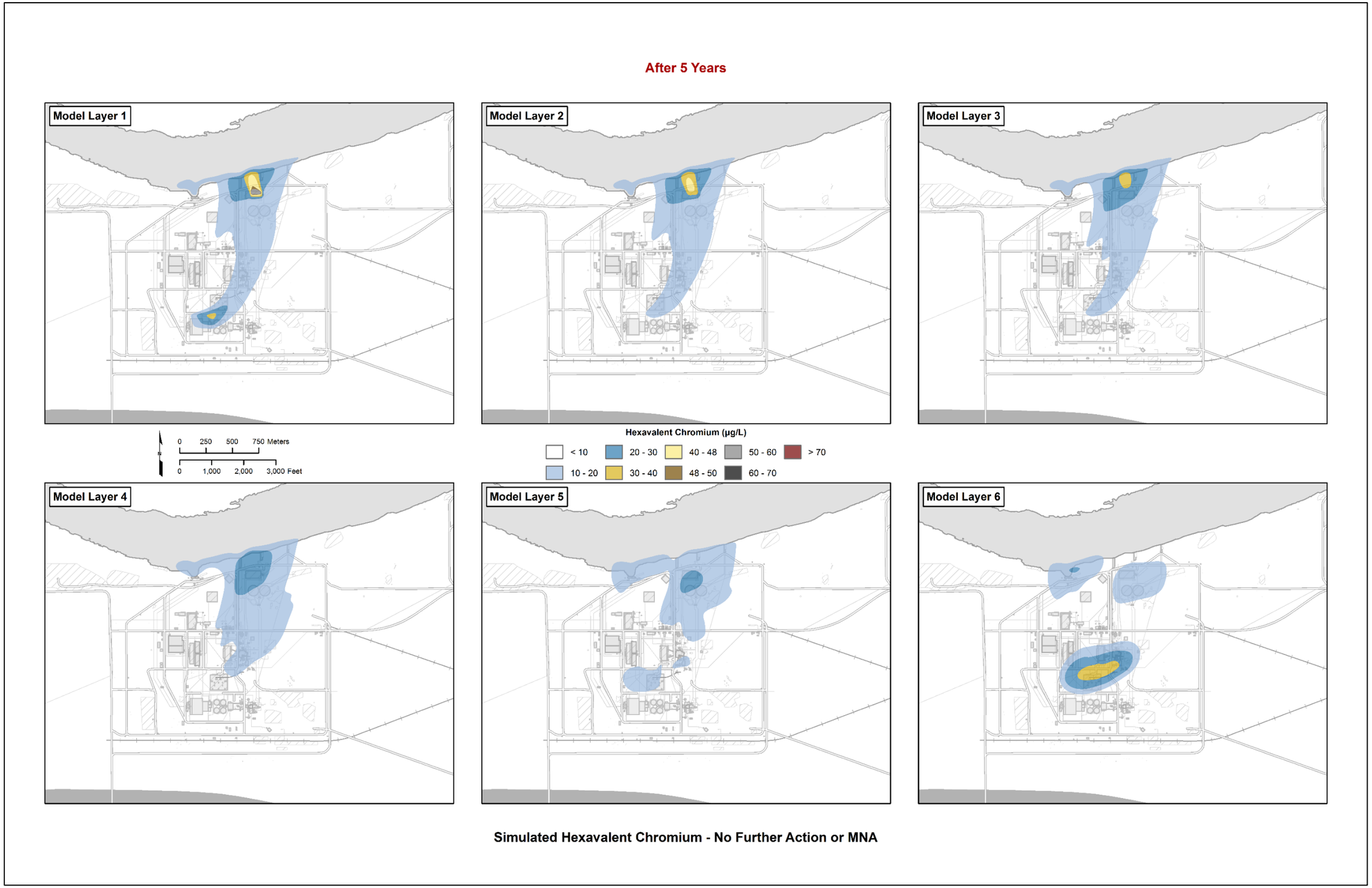


Figure 7-2. Simulated Distribution of Cr(VI) After 5 Years - No Further Action or MNA

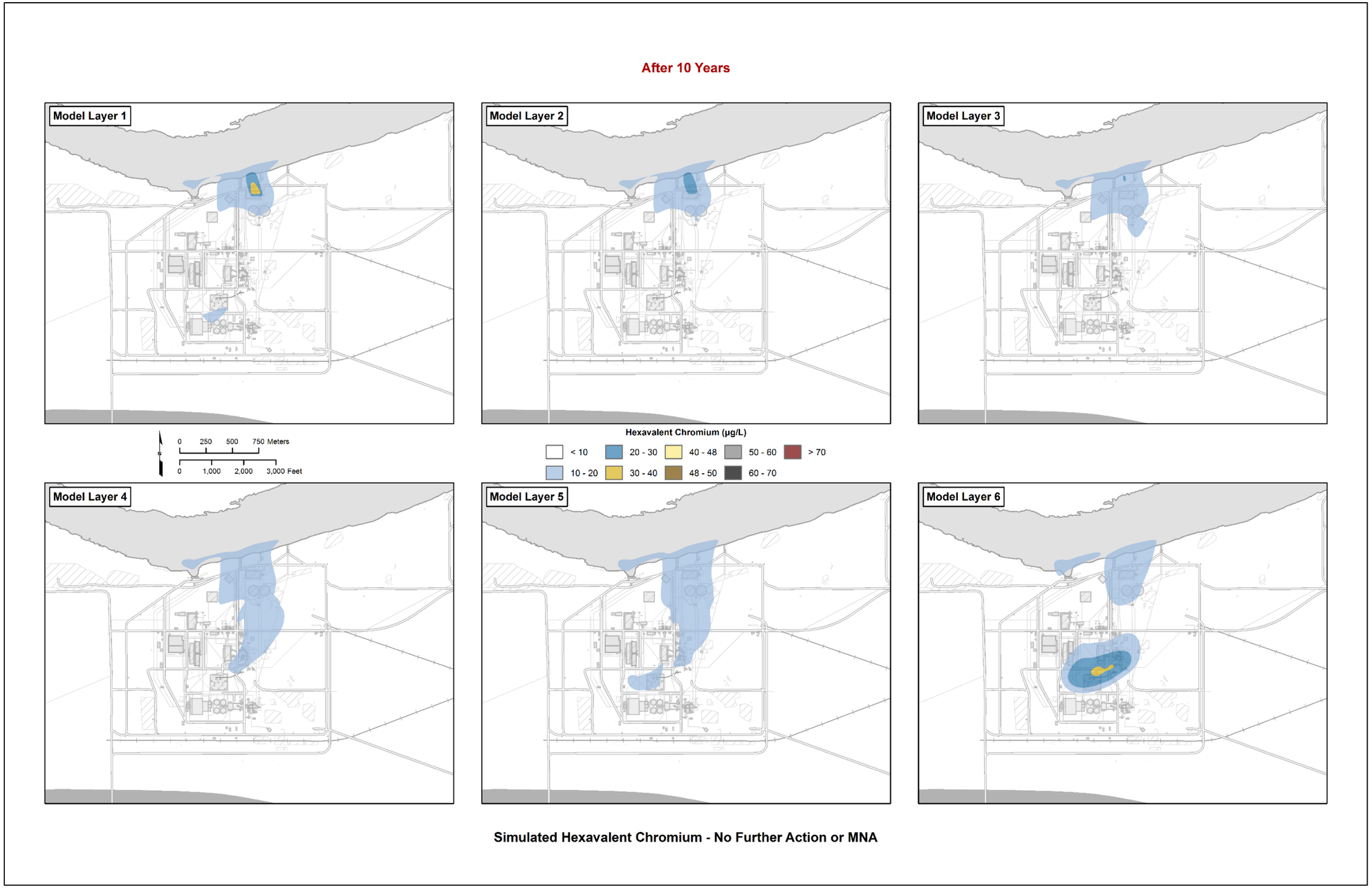


Figure 7-3. Simulated Distribution of Cr(VI) After 10 Years - No Further Action or MNA

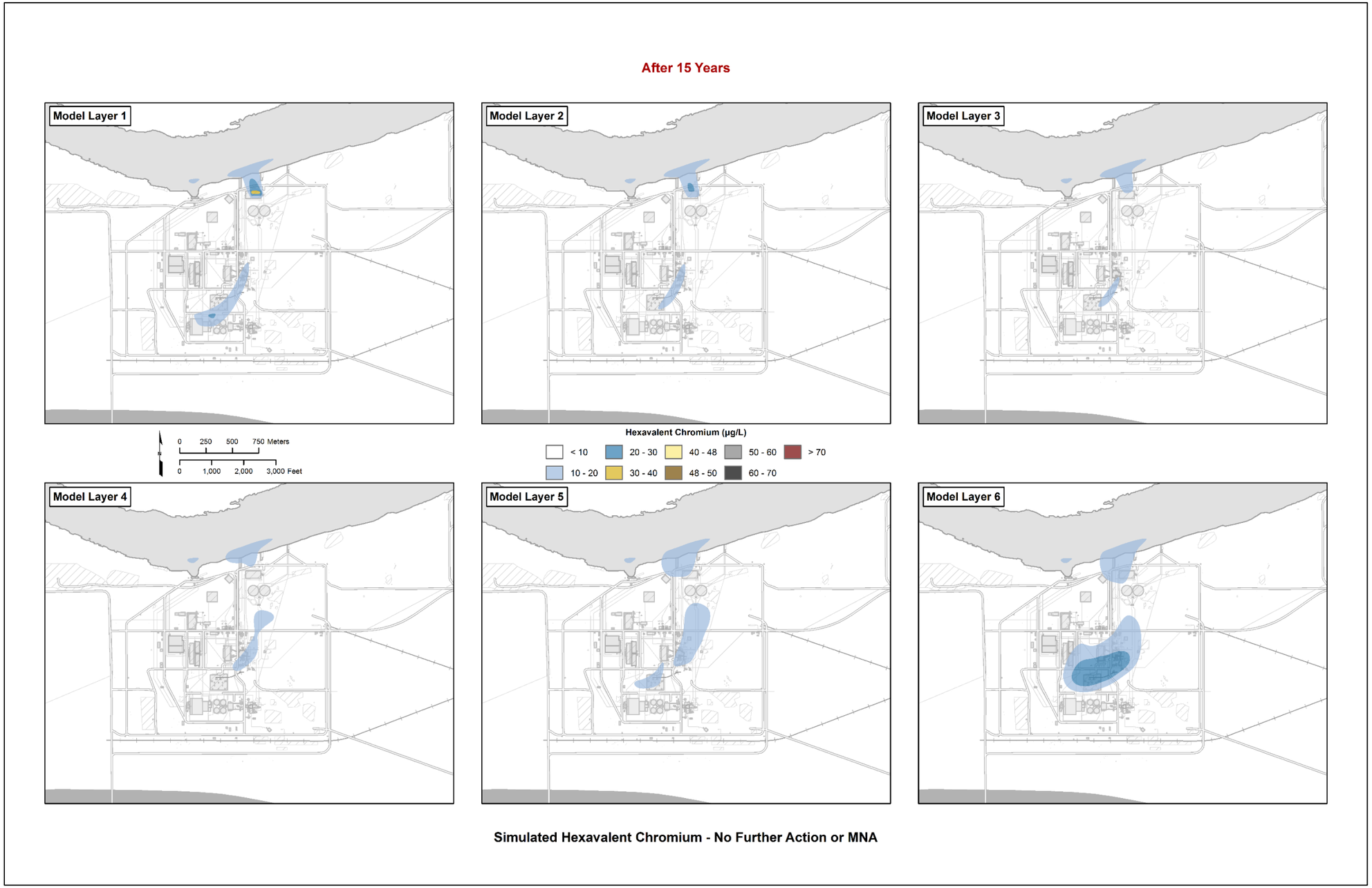


Figure 7-4. Simulated Distribution of Cr(VI) After 15 Years - No Further Action or MNA

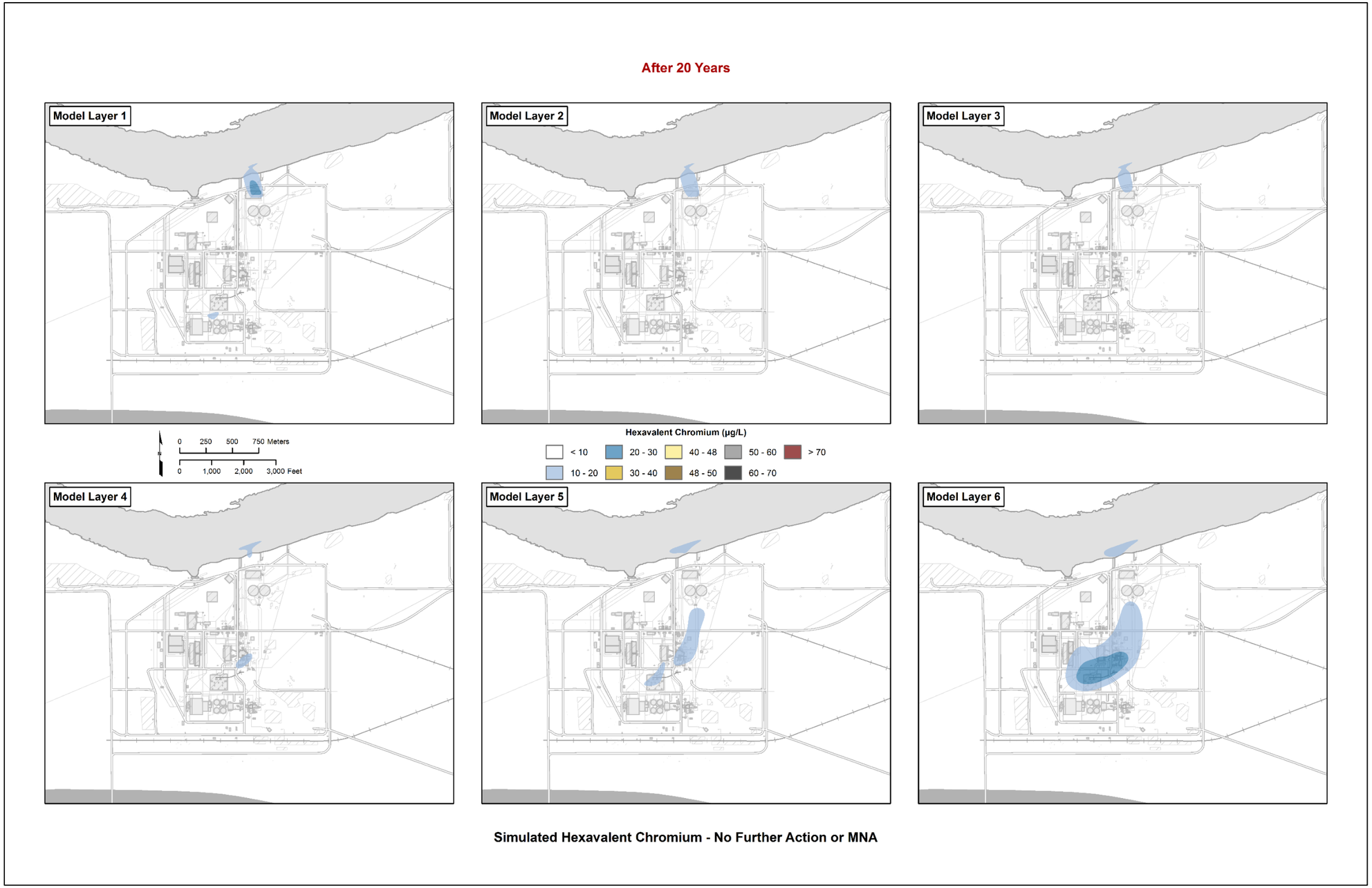


Figure 7-5. Simulated Distribution of Cr(VI) After 20 Years - No Further Action or MNA

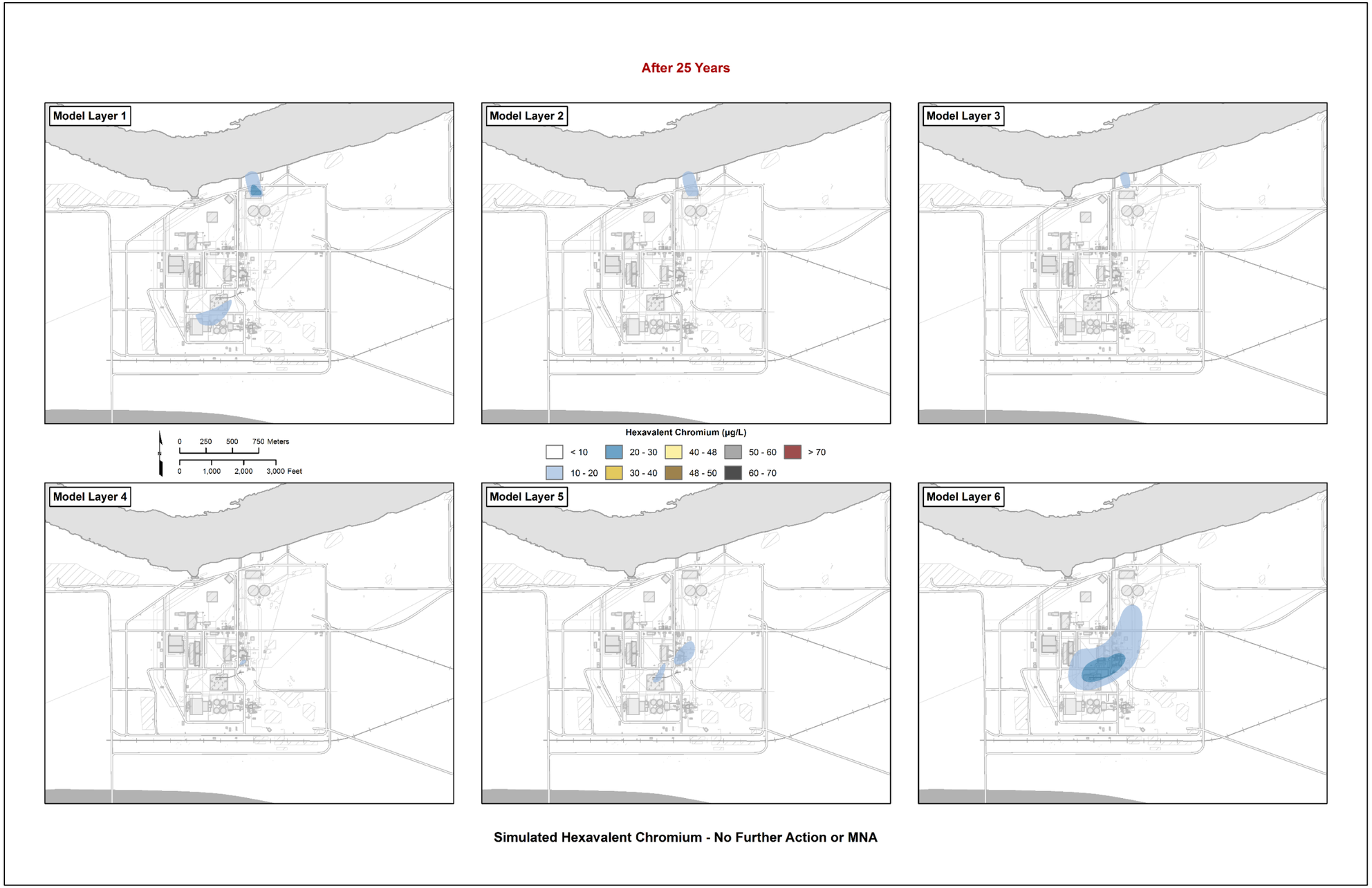


Figure 7-6. Simulated Distribution of Cr(VI) After 25 Years - No Further Action or MNA

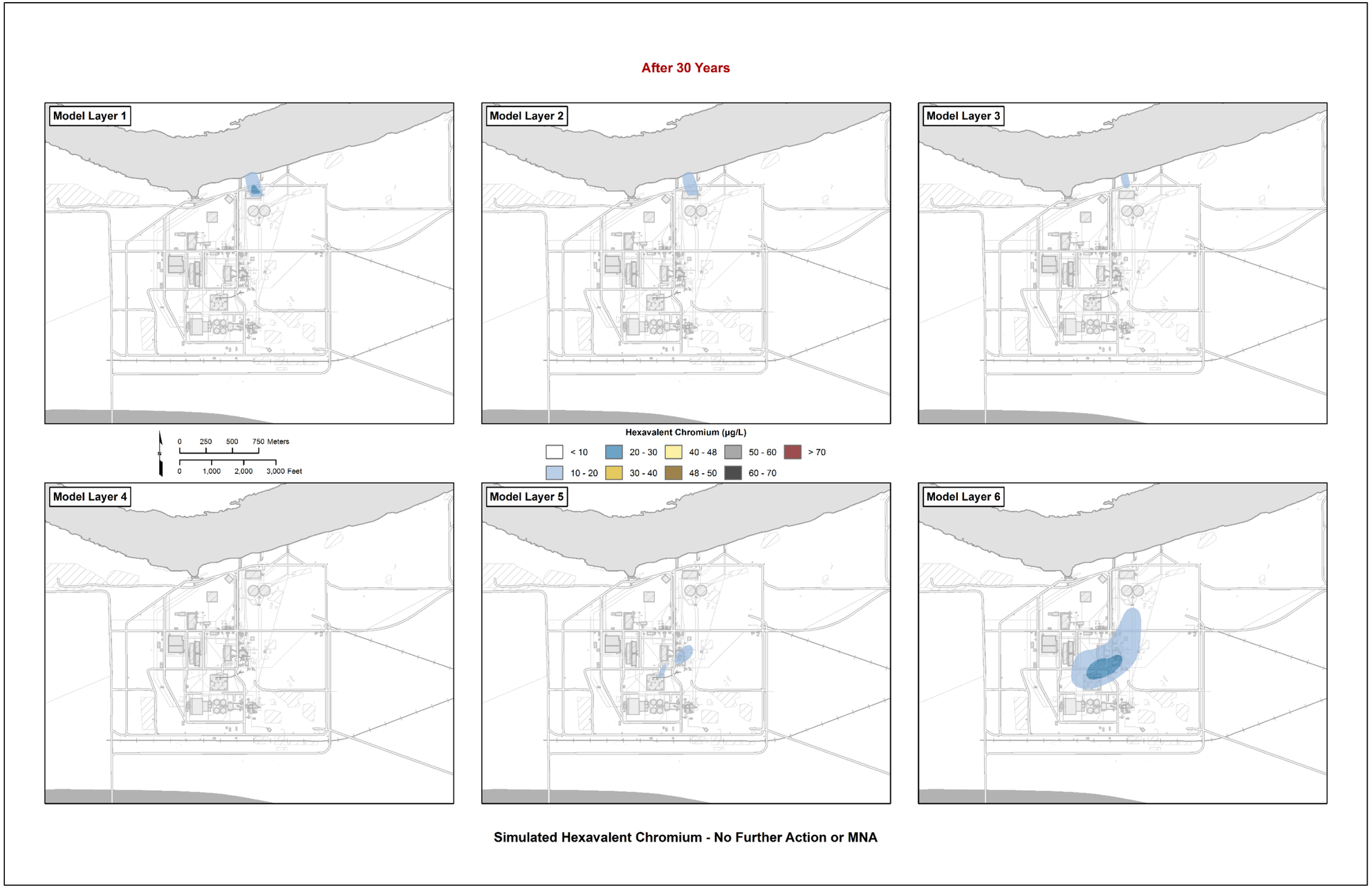


Figure 7-7. Simulated Distribution of Cr(VI) After 30 Years - No Further Action or MNA

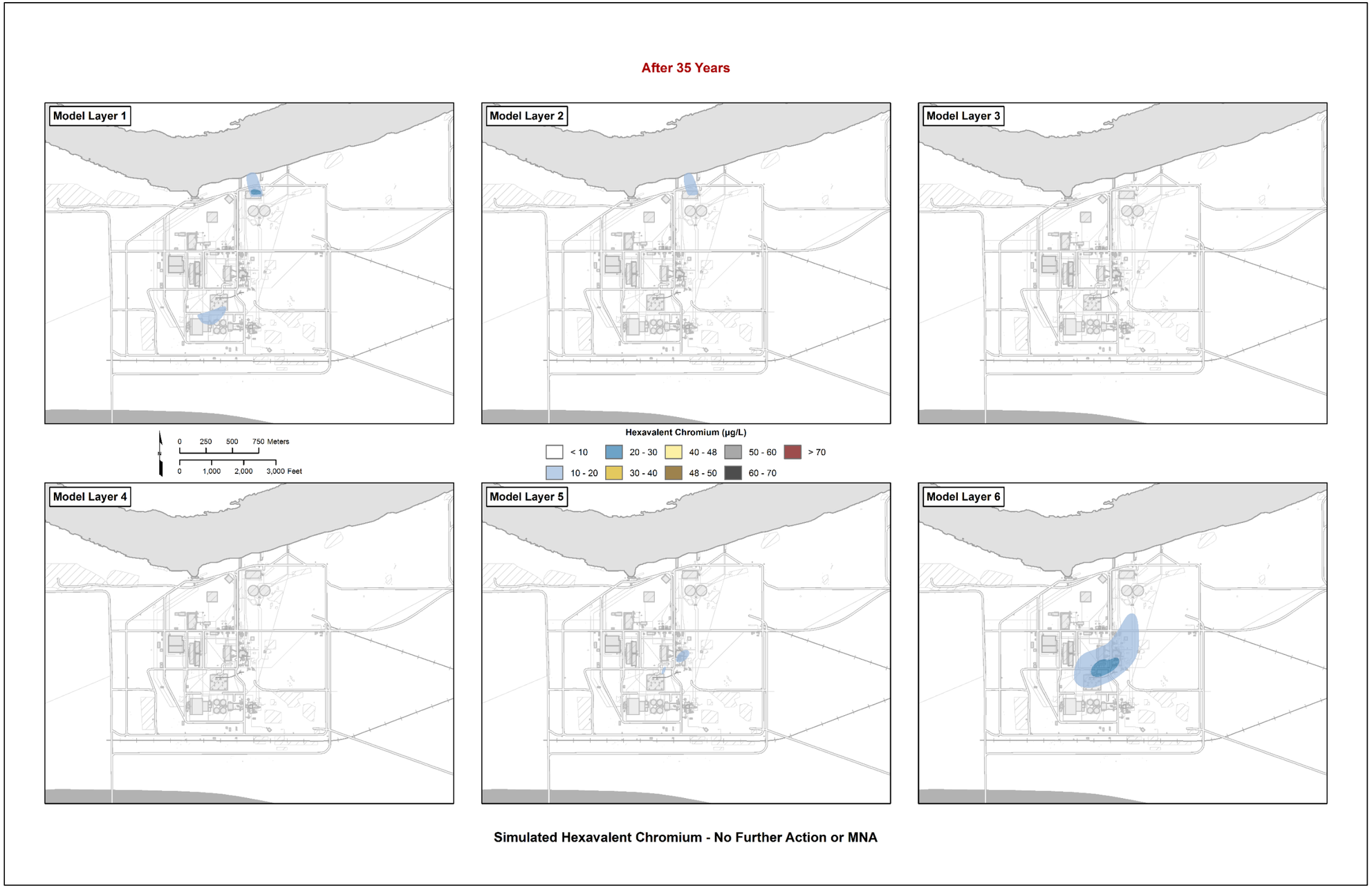


Figure 7-8. Simulated Distribution of Cr(VI) After 35 Years - No Further Action or MNA

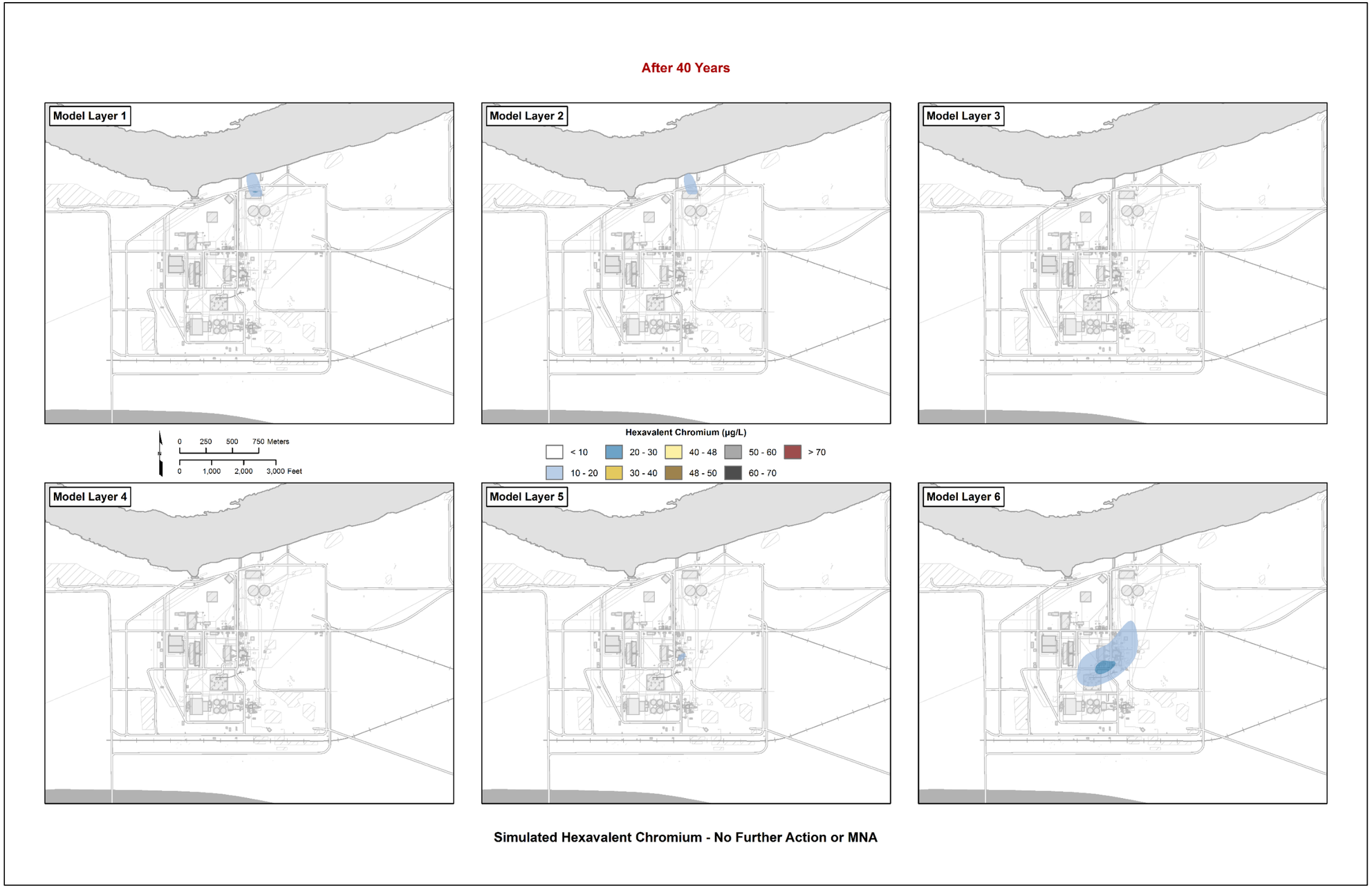


Figure 7-9. Simulated Distribution of Cr(VI) After 40 Years - No Further Action or MNA

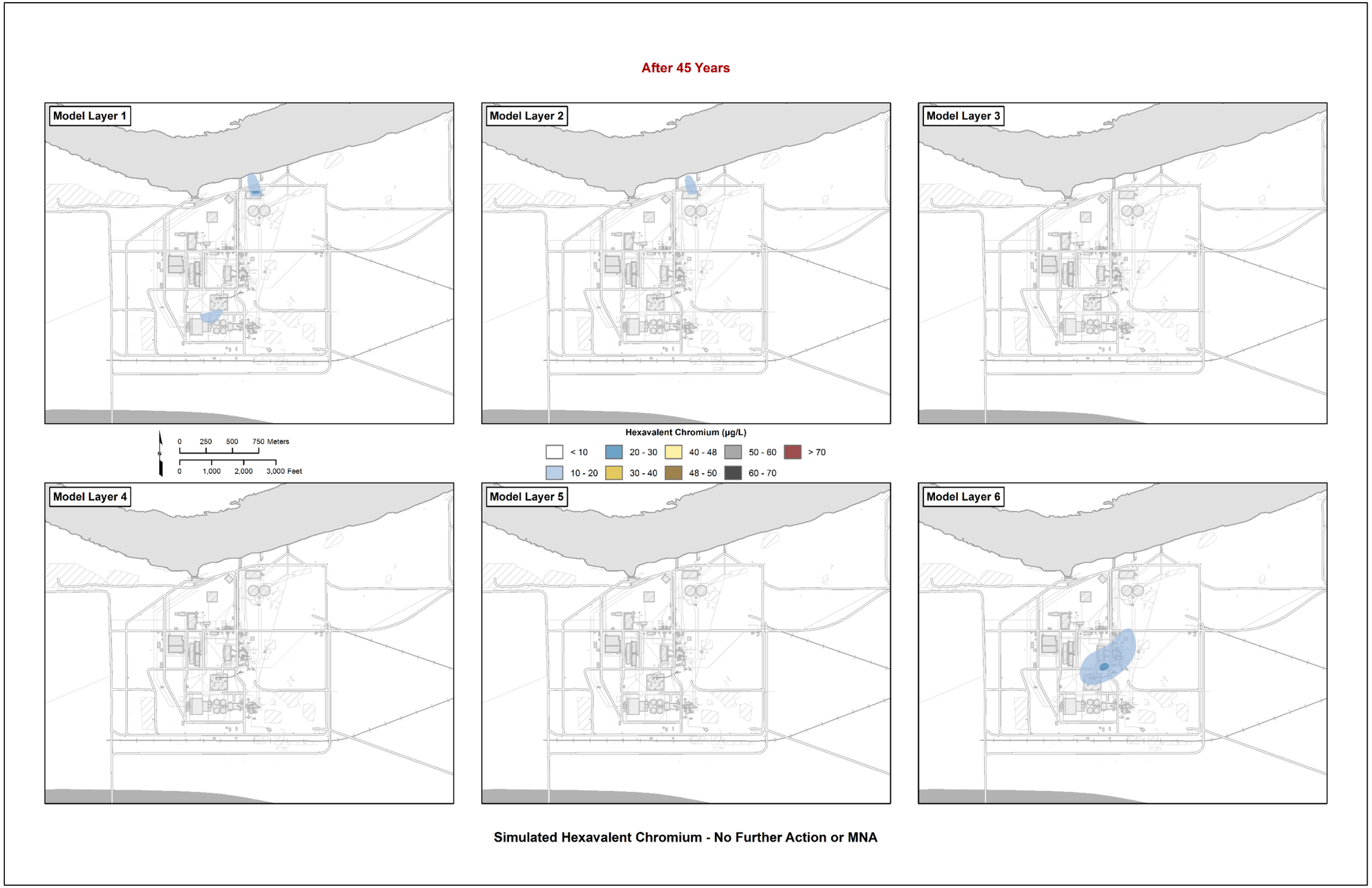


Figure 7-10. Simulated Distribution of Cr(VI) After 45 Years - No Further Action or MNA

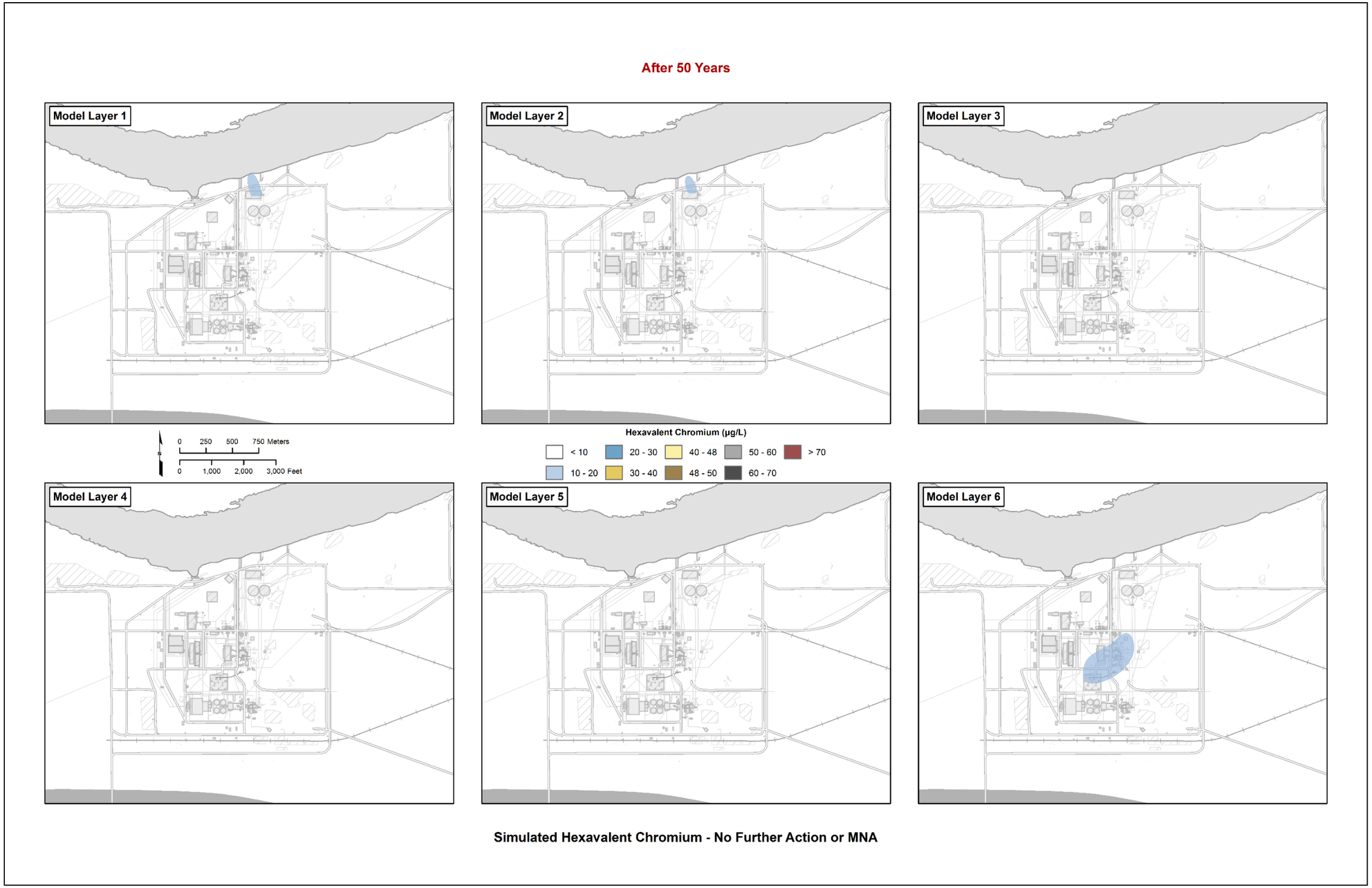


Figure 7-11. Simulated Distribution of Cr(VI) After 50 Years - No Further Action or MNA

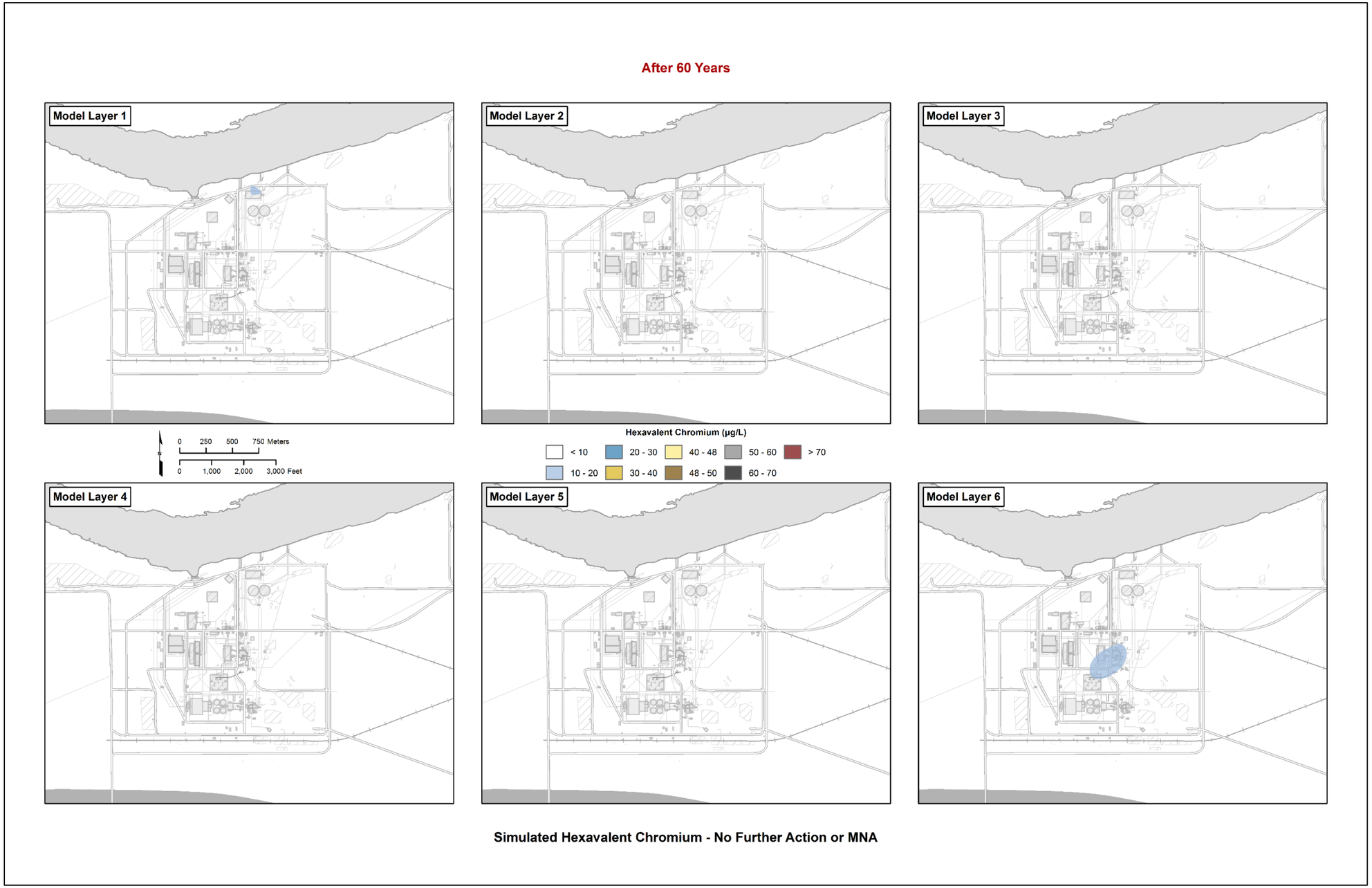


Figure 7-12. Simulated Distribution of Cr(VI) After 60 Years - No Further Action or MNA

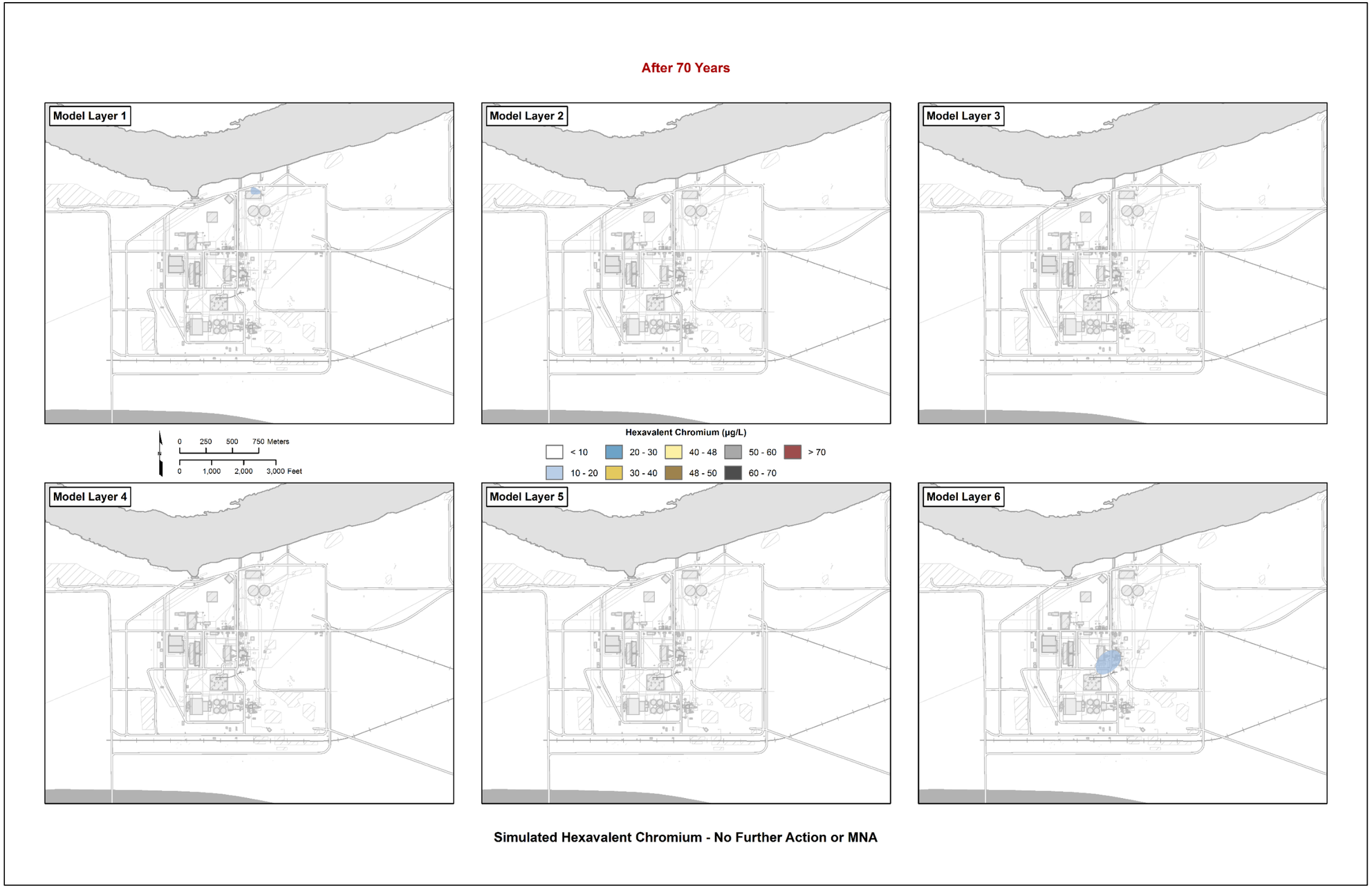


Figure 7-13. Simulated Distribution of Cr(VI) After 70 Years - No Further Action or MNA

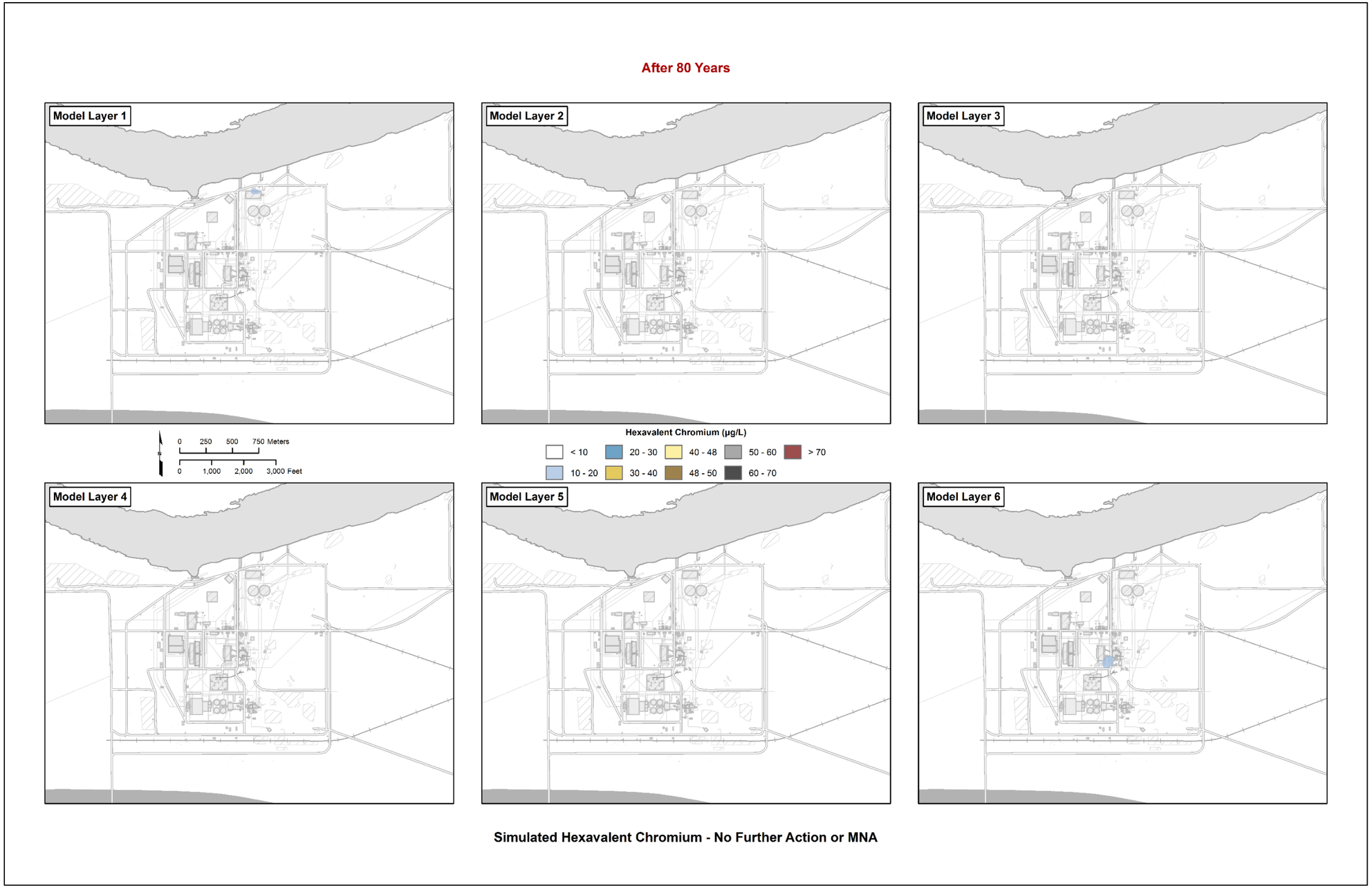


Figure 7-14. Simulated Distribution of Cr(VI) After 80 Years - No Further Action or MNA

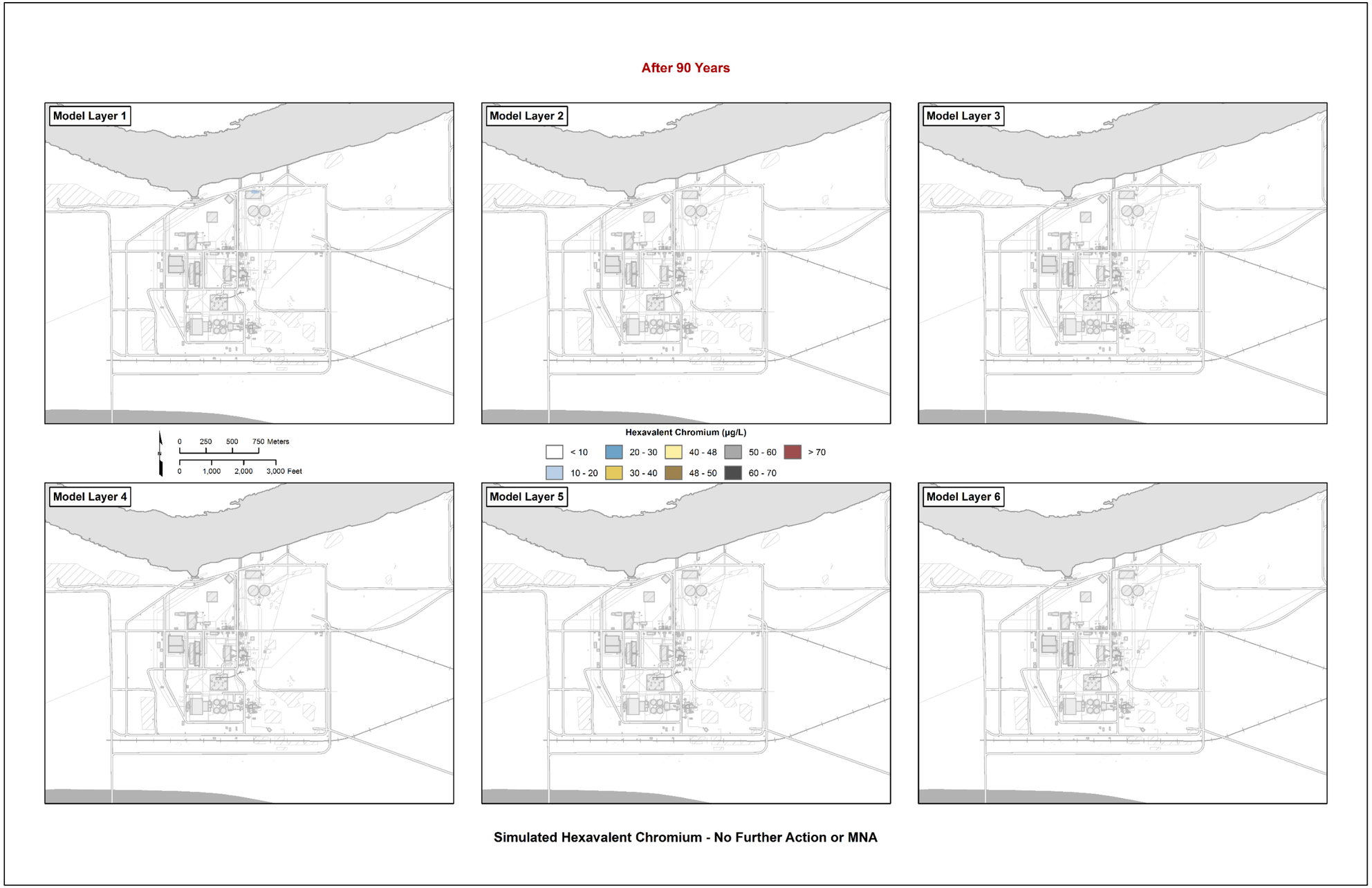


Figure 7-15. Simulated Distribution of Cr(VI) After 90 Years - No Further Action or MNA

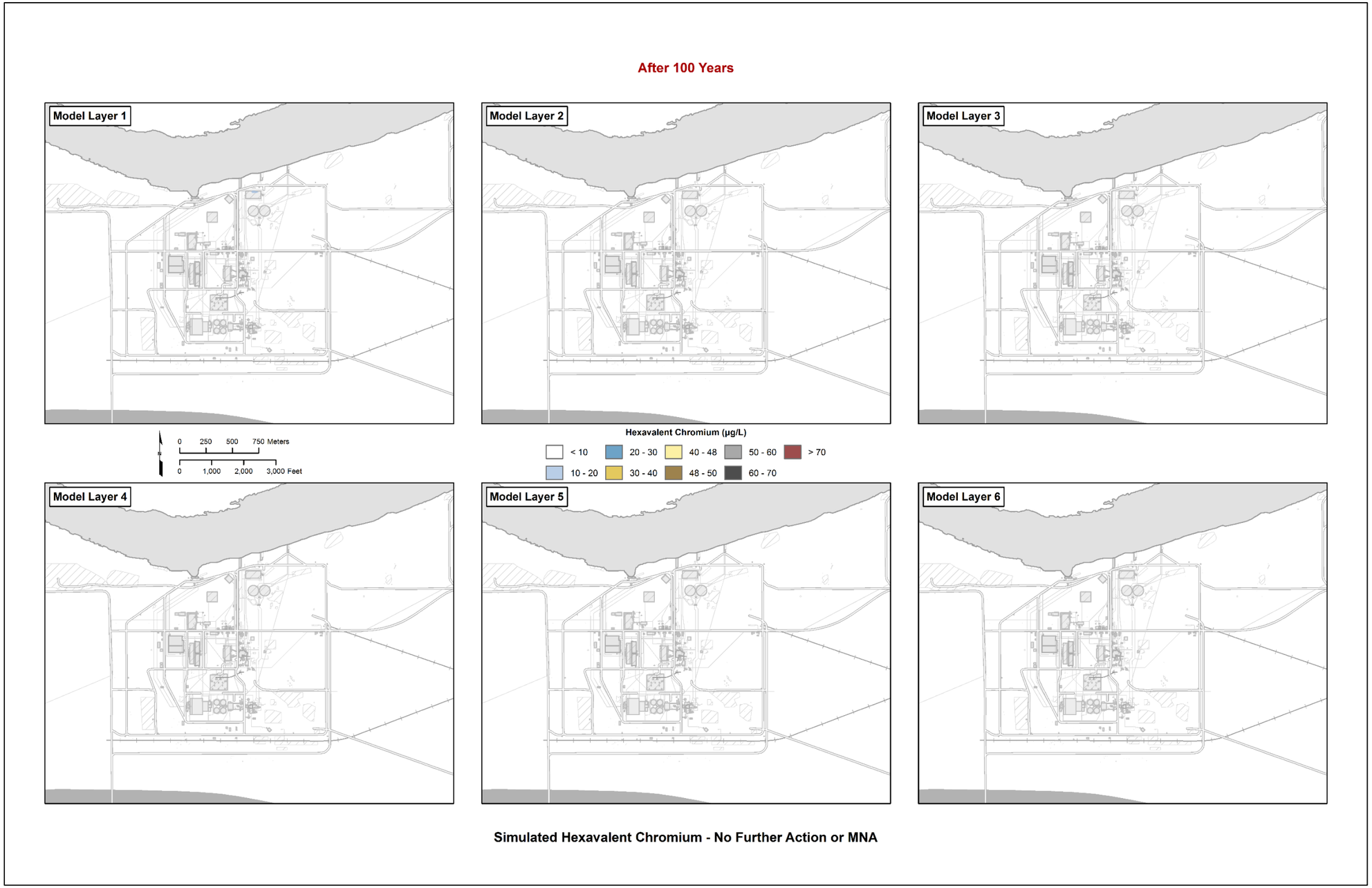


Figure 7-16. Simulated Distribution of Cr(VI) After 100 Years - No Further Action or MNA

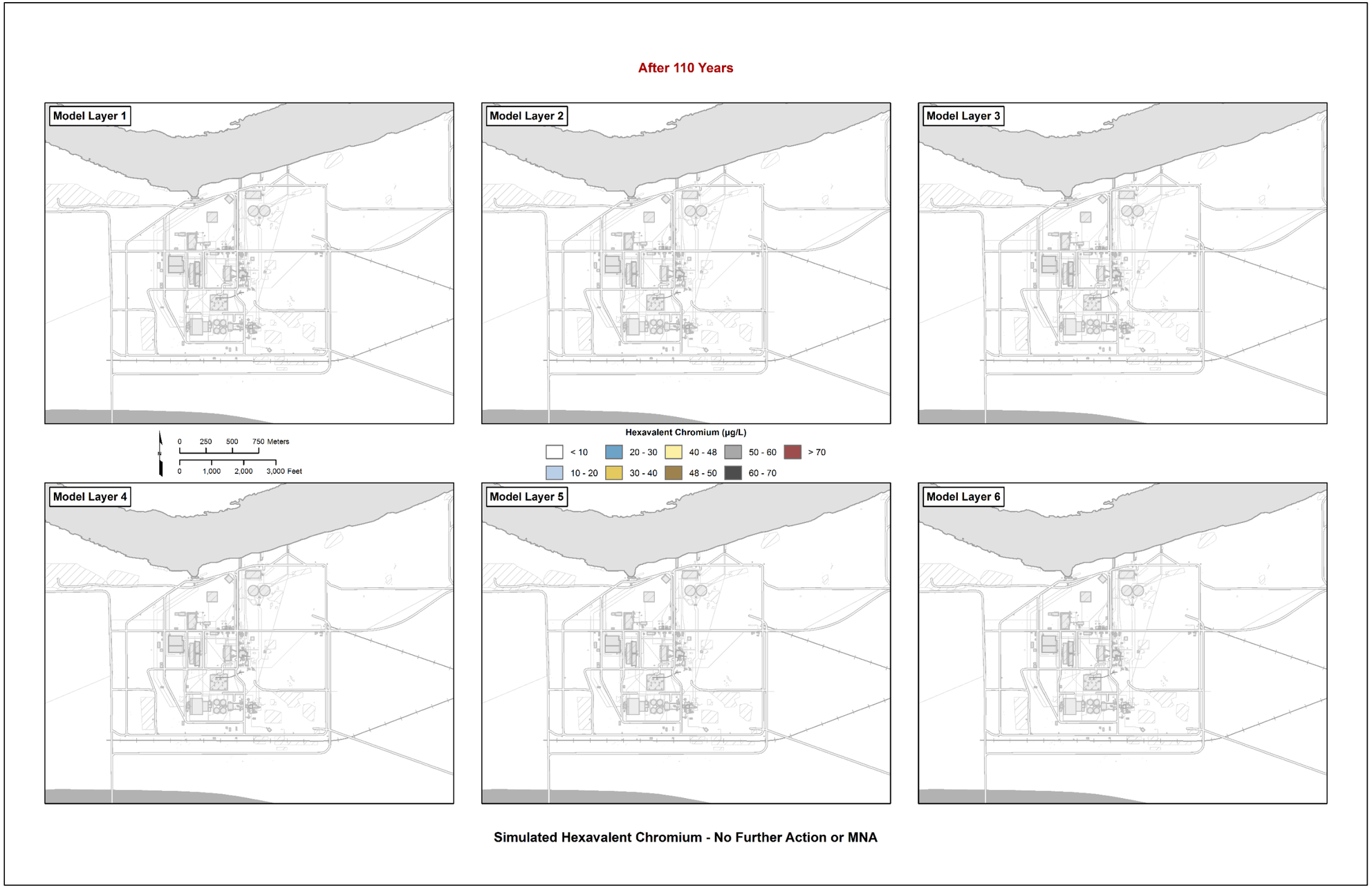


Figure 7-17. Simulated Distribution of Cr(VI) After 110 Years - No Further Action or MNA

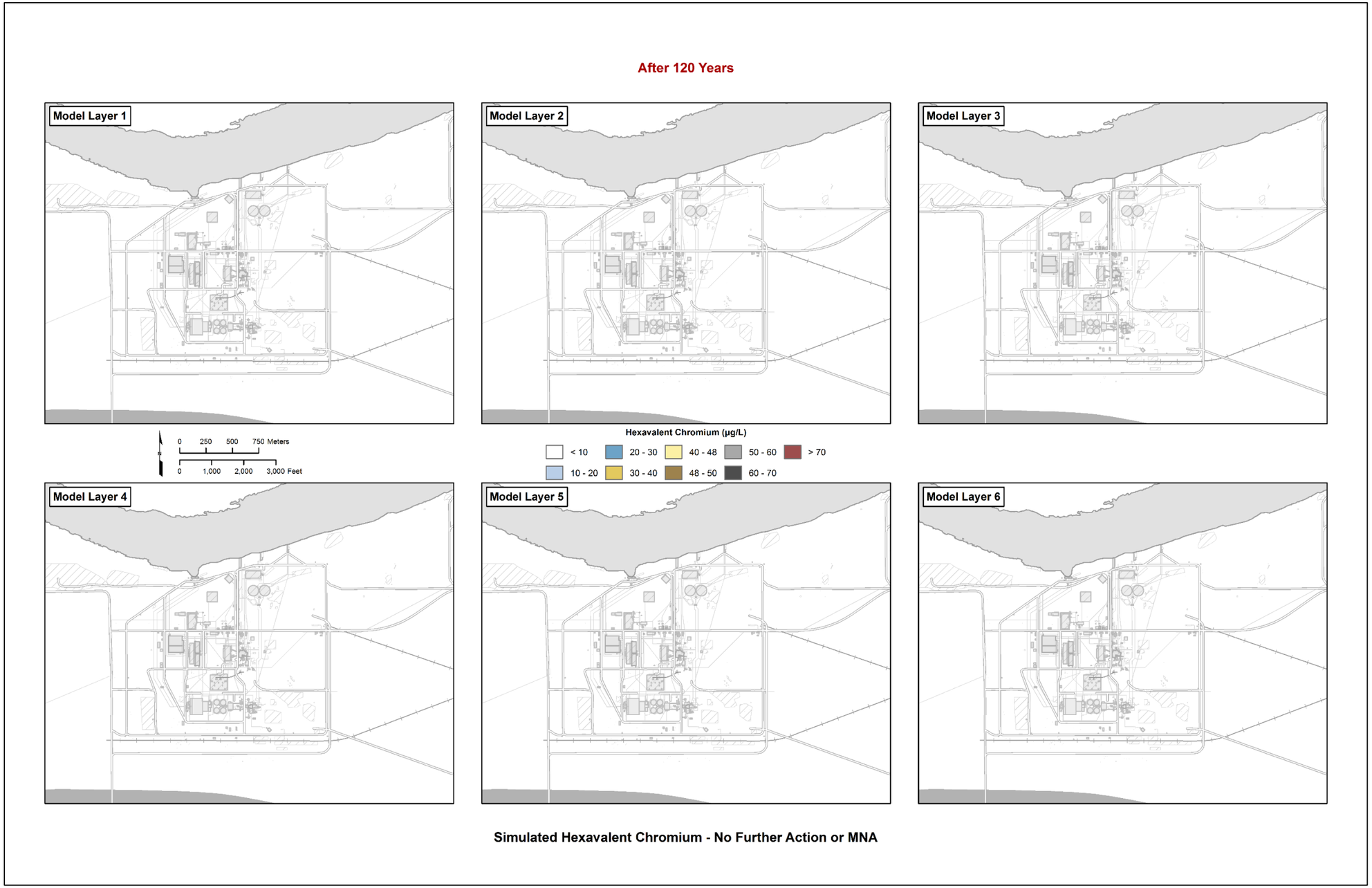


Figure 7-18. Simulated Distribution of Cr(VI) After 120 Years - No Further Action or MNA.

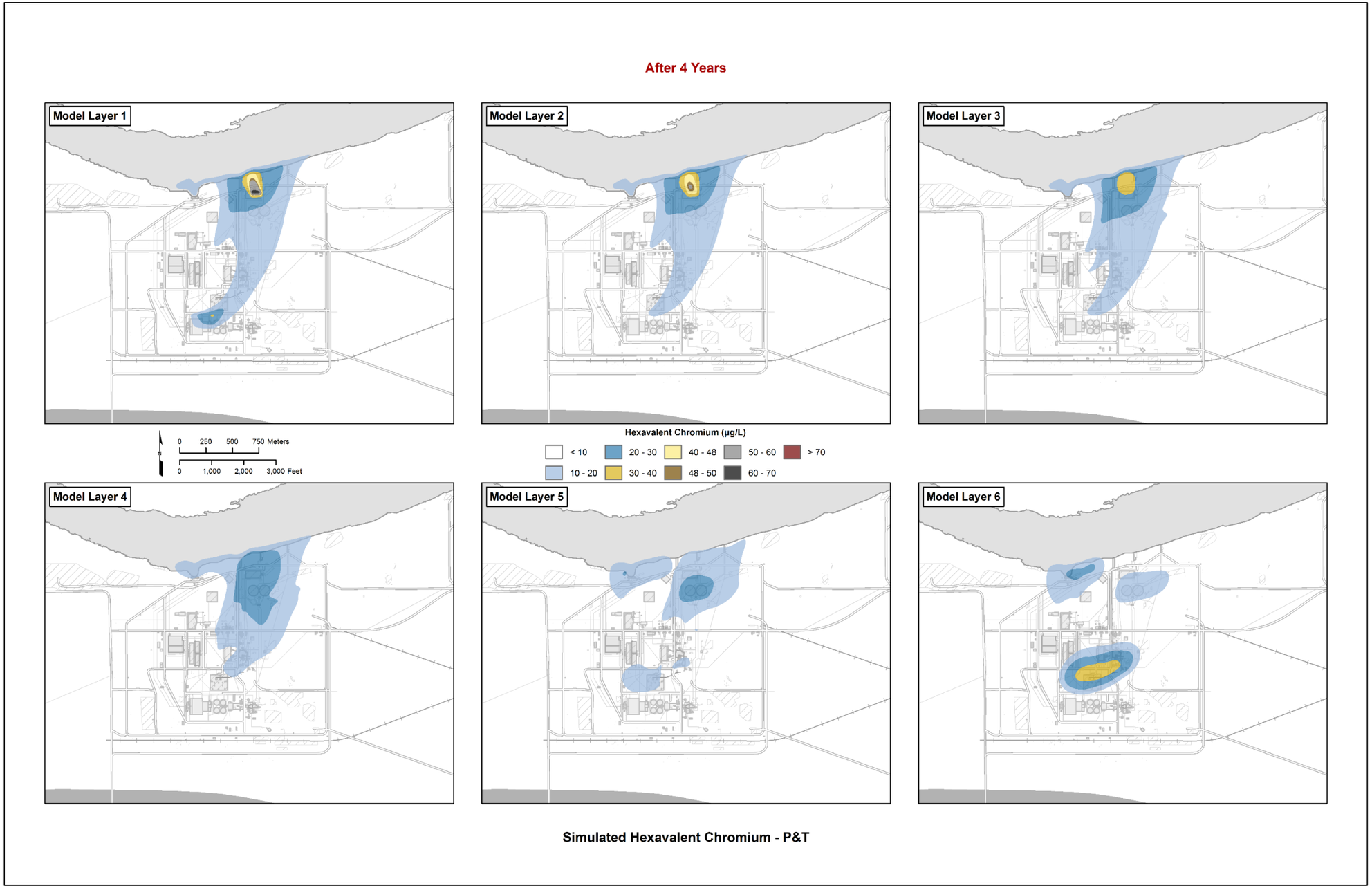


Figure 7-19. Simulated Distribution of Cr(VI) After 4 Years – P&T

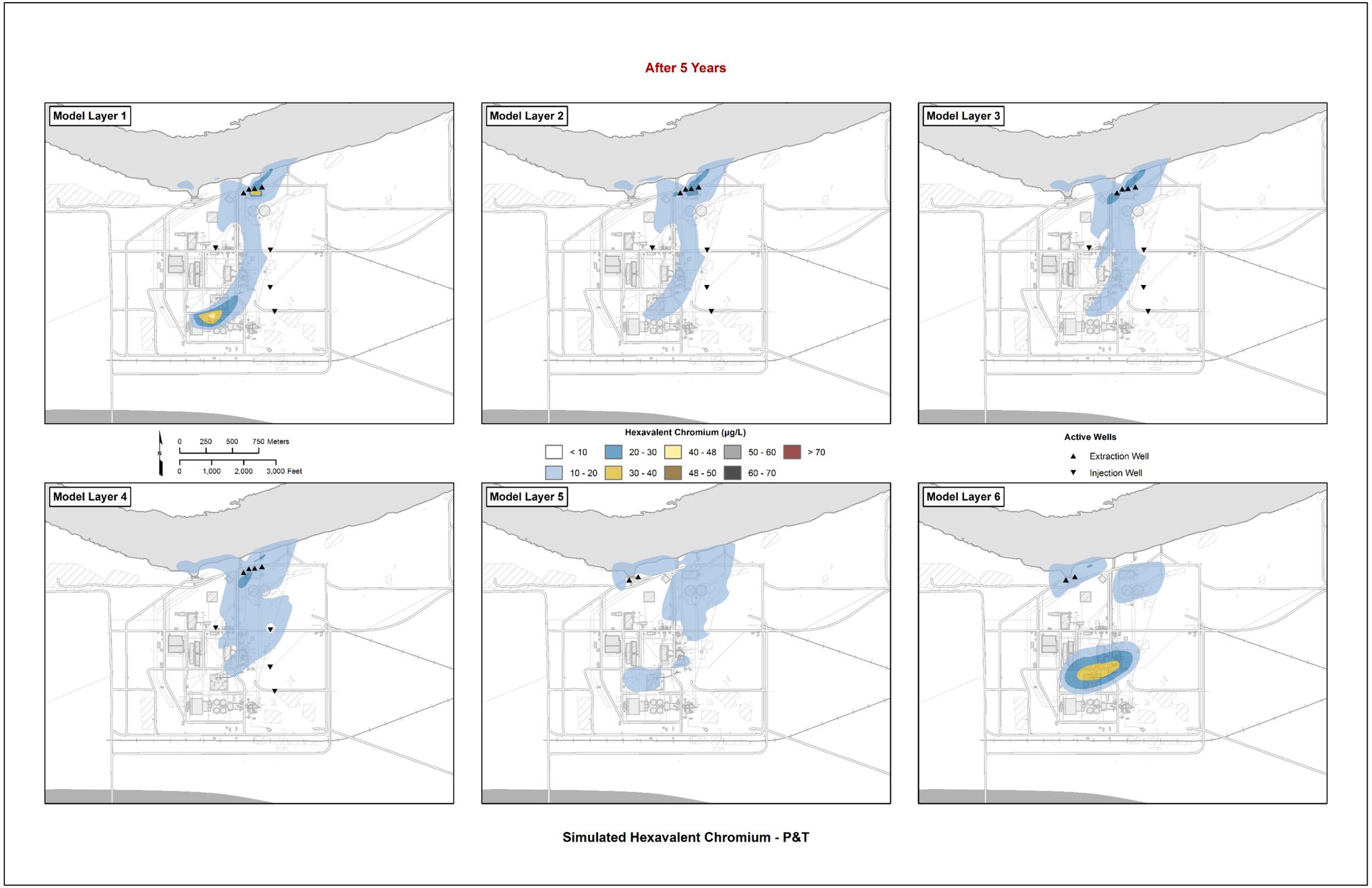


Figure 7-20. Simulated Distribution of Cr(VI) After 5 Years – P&T

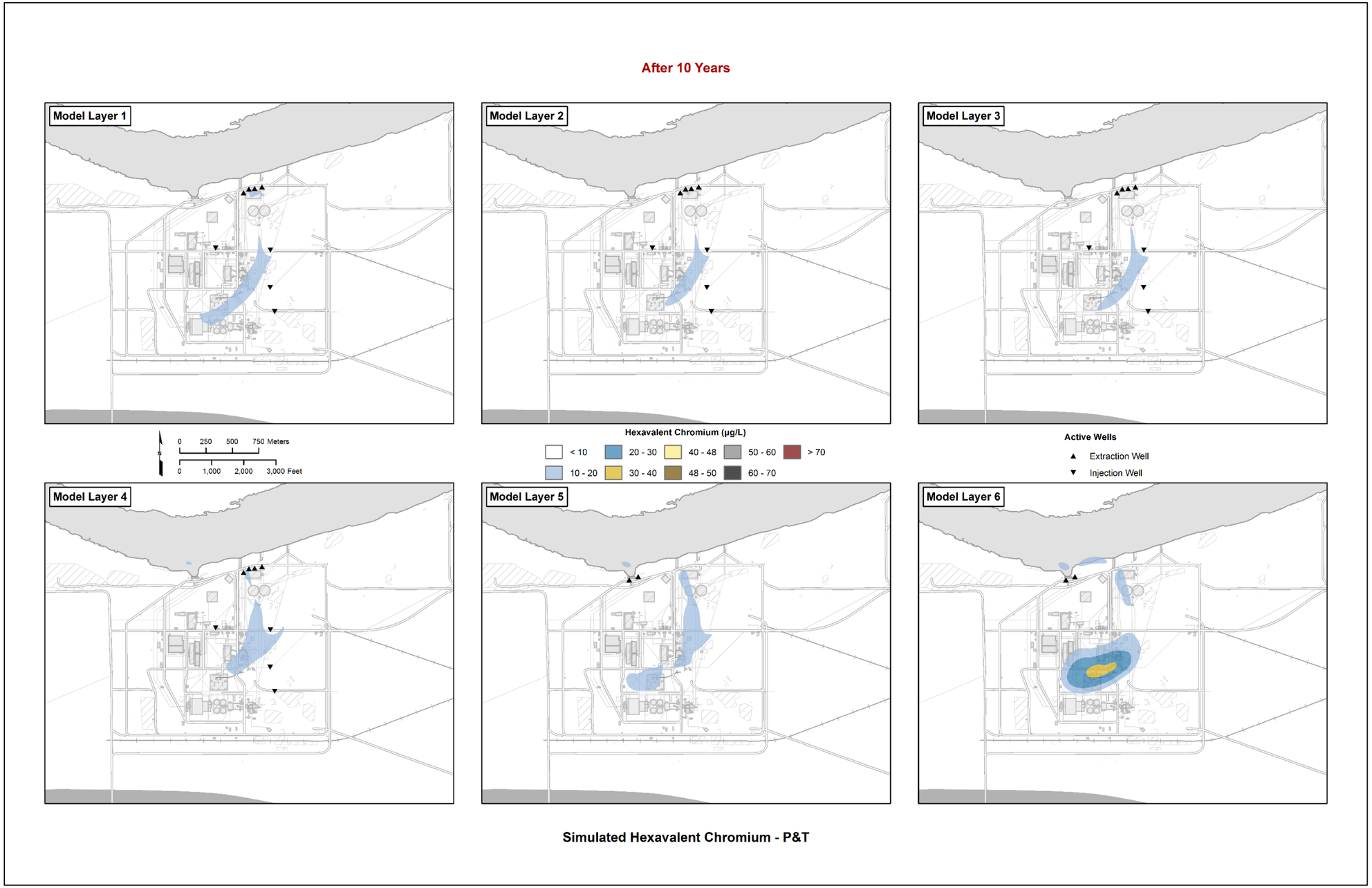


Figure 7-21. Simulated Distribution of Cr(VI) After 10 Years - P&T

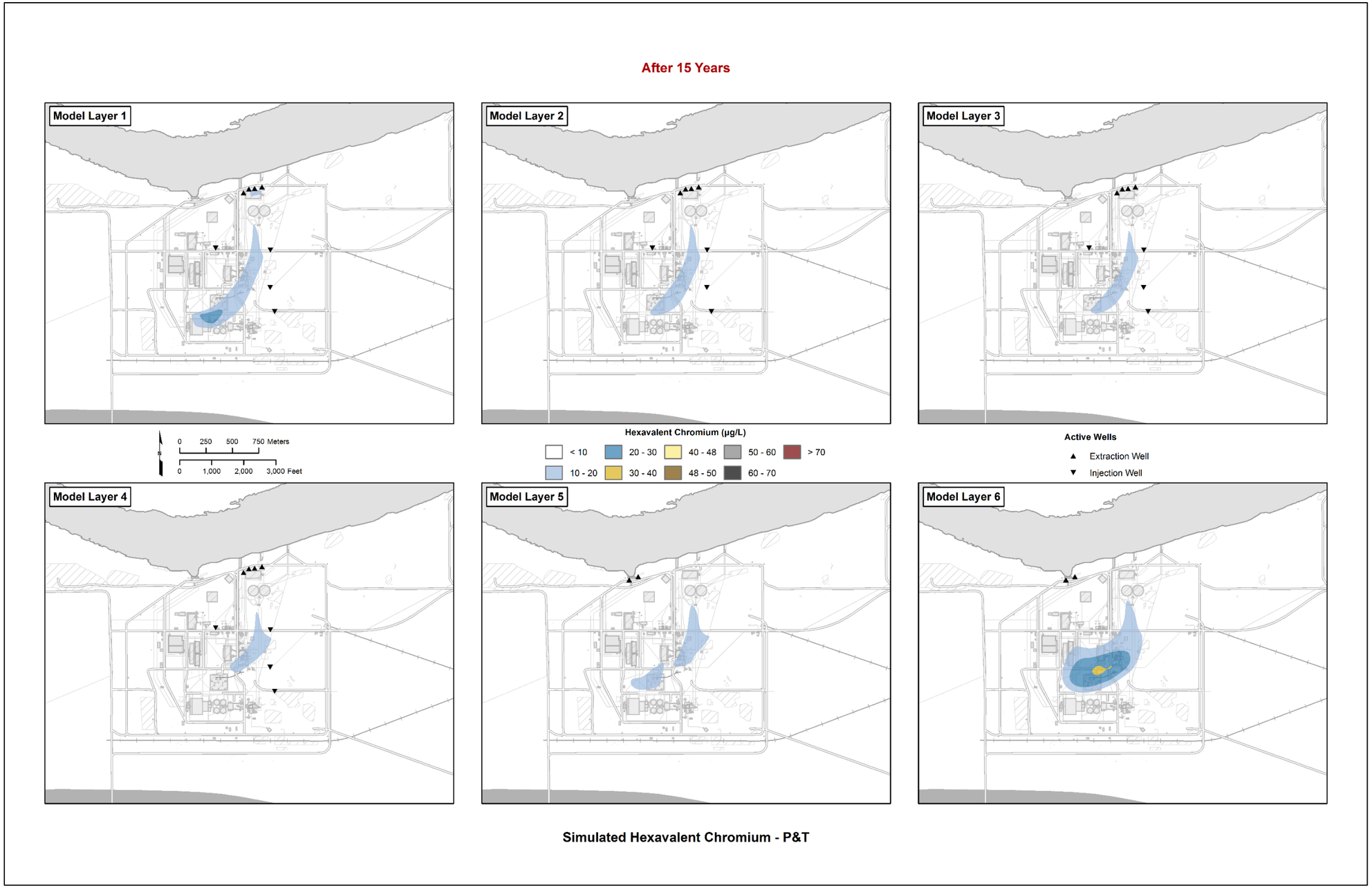


Figure 7-22. Simulated Distribution of Cr(VI) After 15 Years - P&T

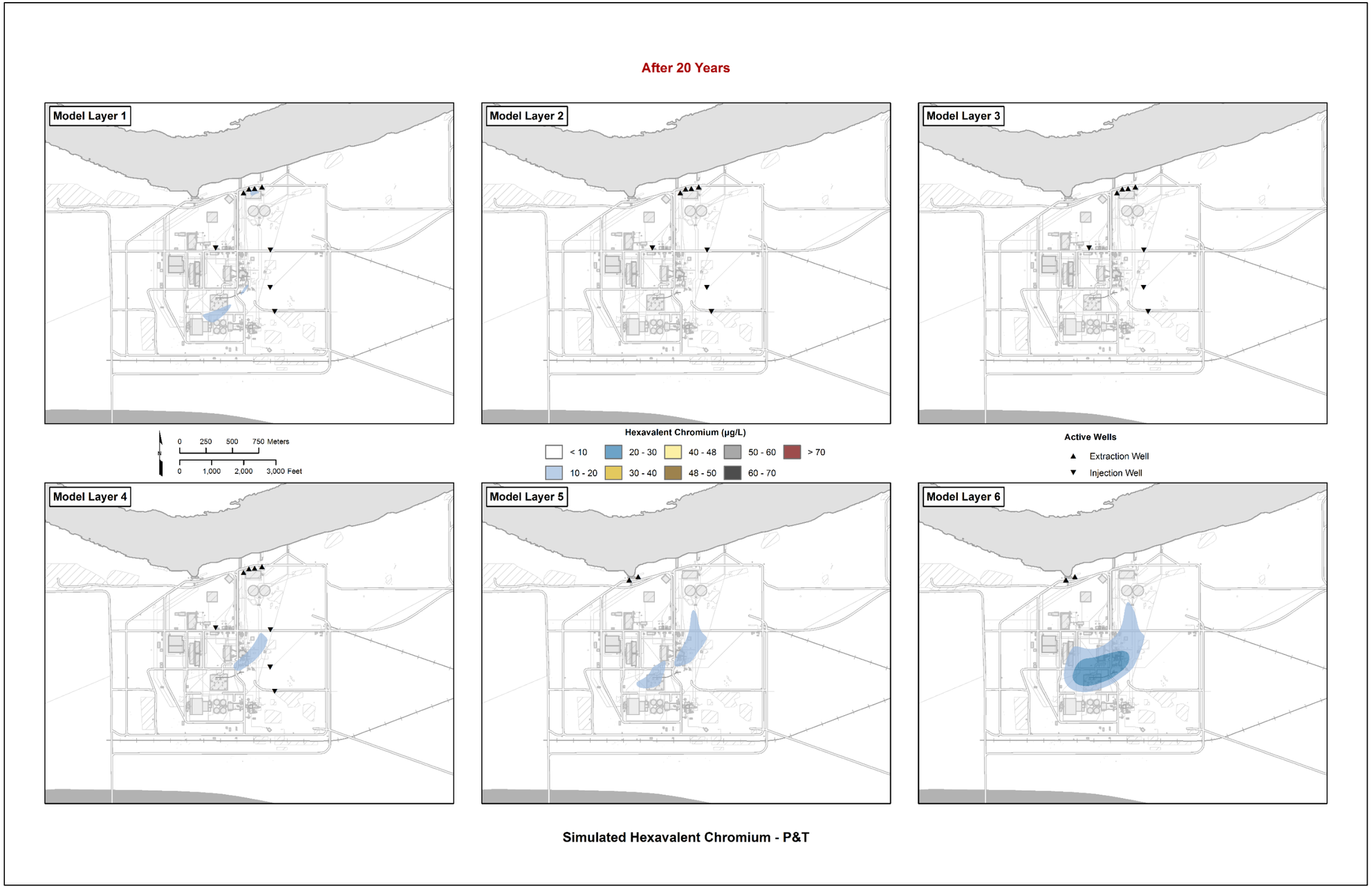


Figure 7-23. Simulated Distribution of Cr(VI) After 20 Years - P&T

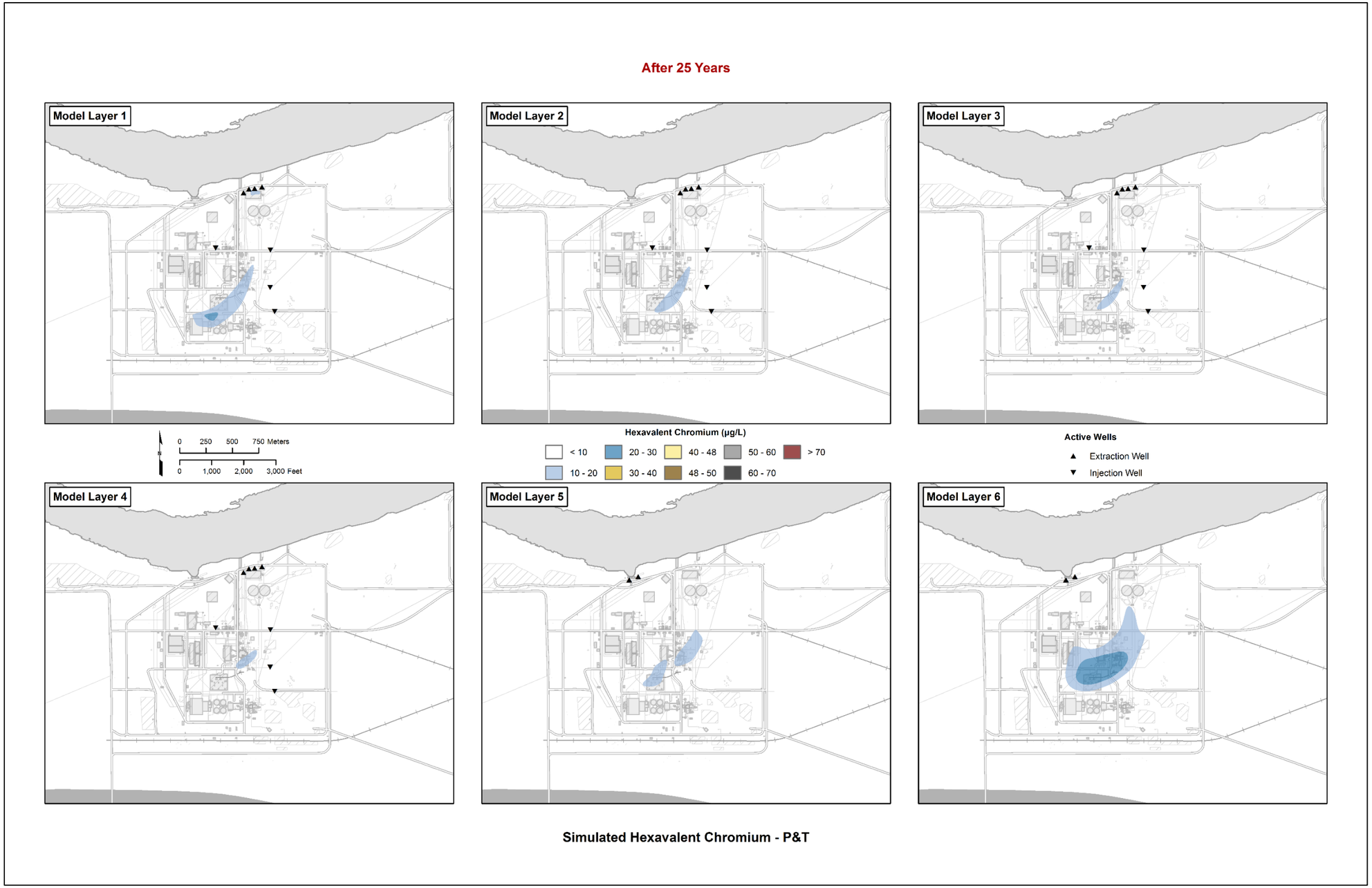


Figure 7-24. Simulated Distribution of Cr(VI) After 25 Years - P&T

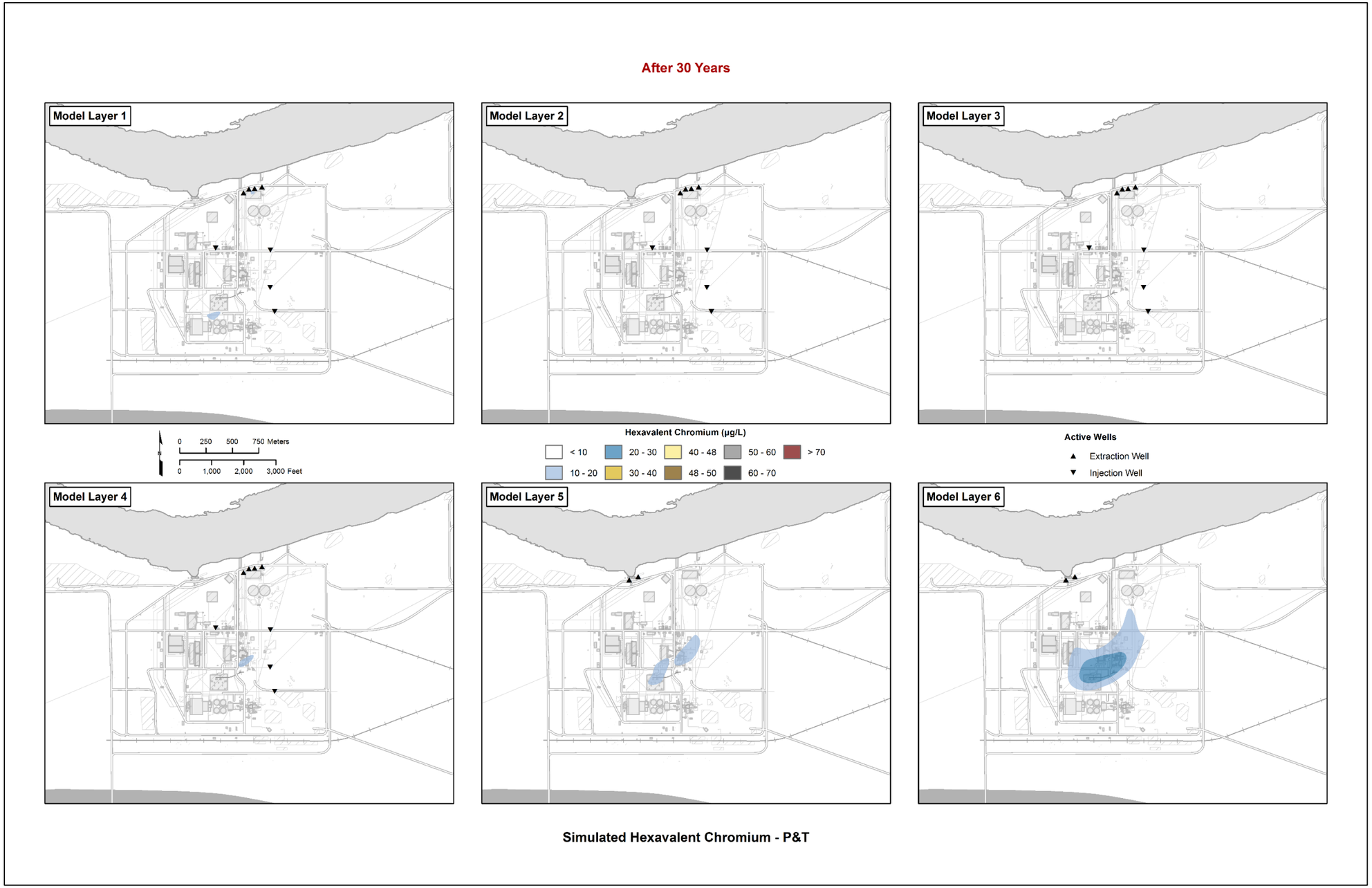


Figure 7-25. Simulated Distribution of Cr(VI) After 30 Years - P&T

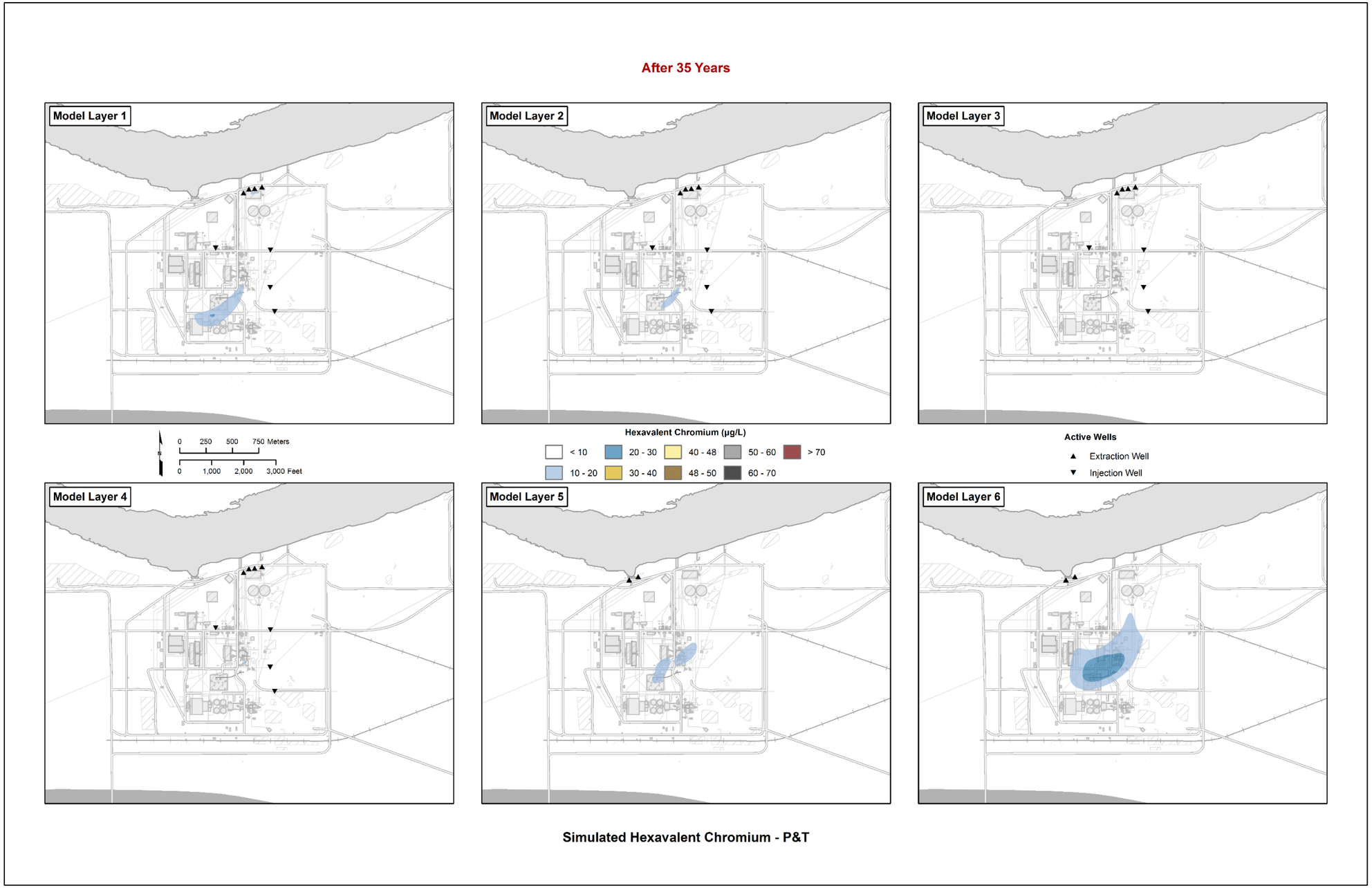


Figure 7-26. Simulated Distribution of Cr(VI) After 35 Years - P&T

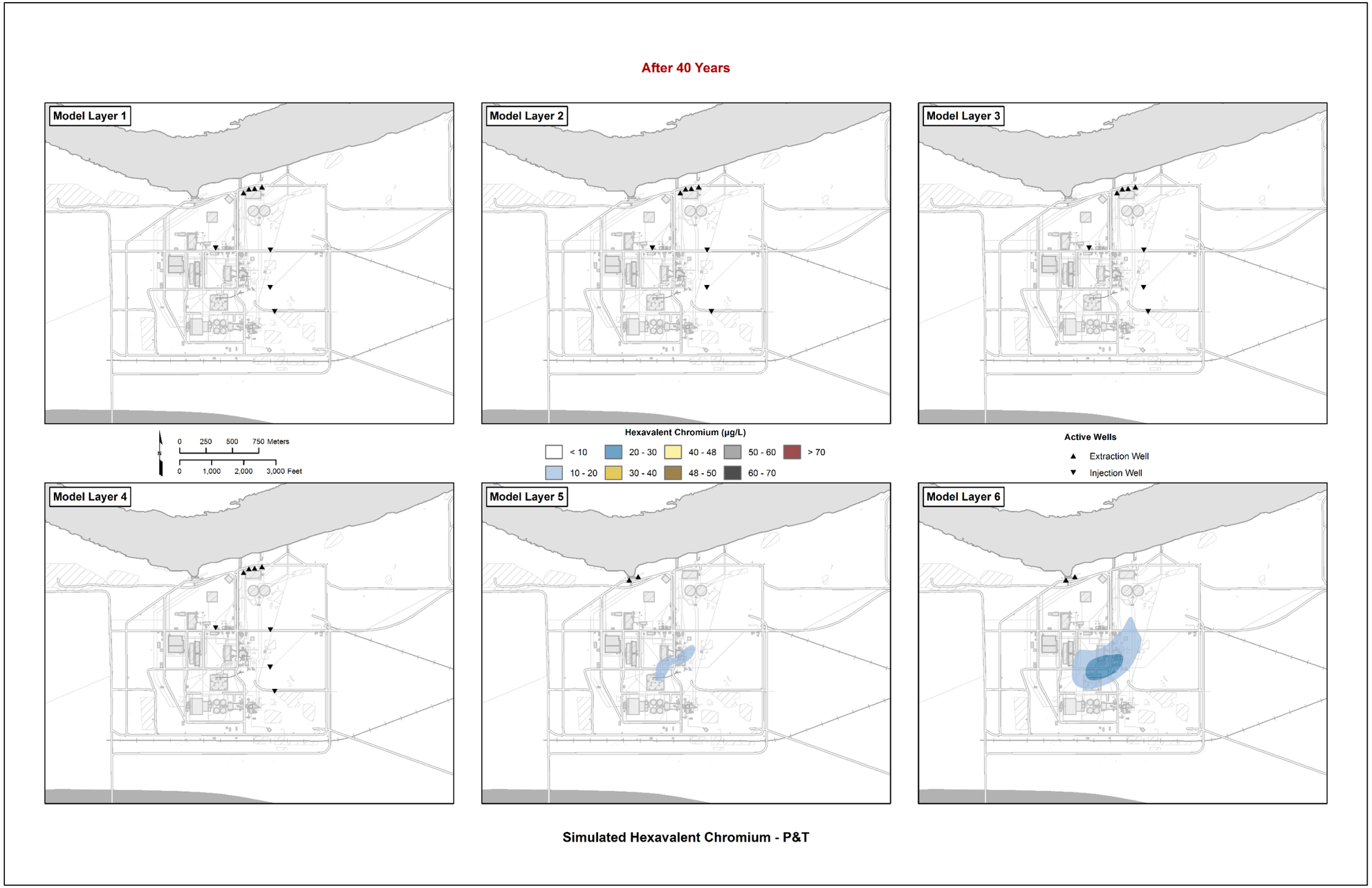


Figure 7-27. Simulated Distribution of Cr(VI) After 40 Years - P&T

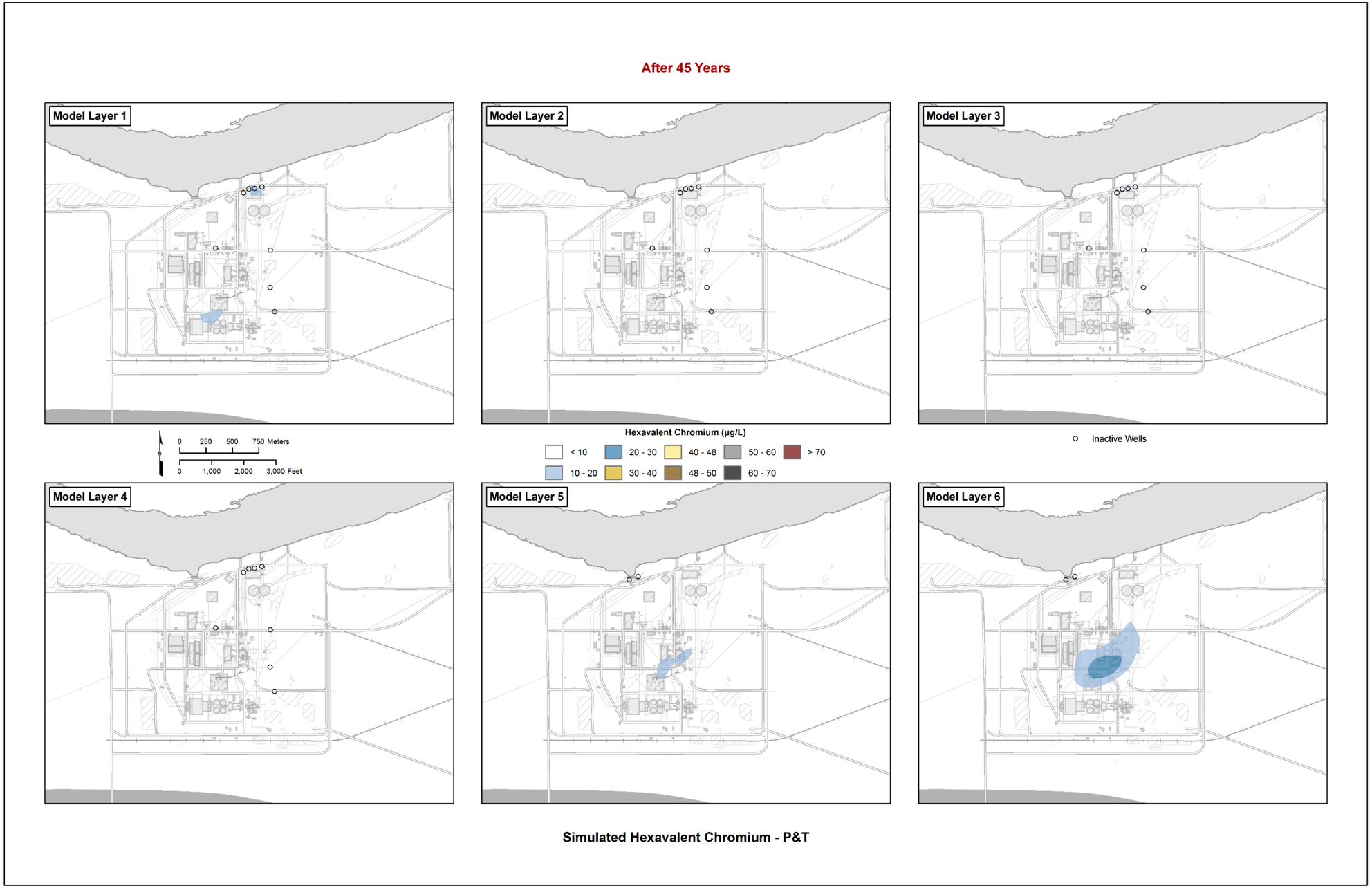


Figure 7-28. Simulated Distribution of Cr(VI) After 45 Years - P&T

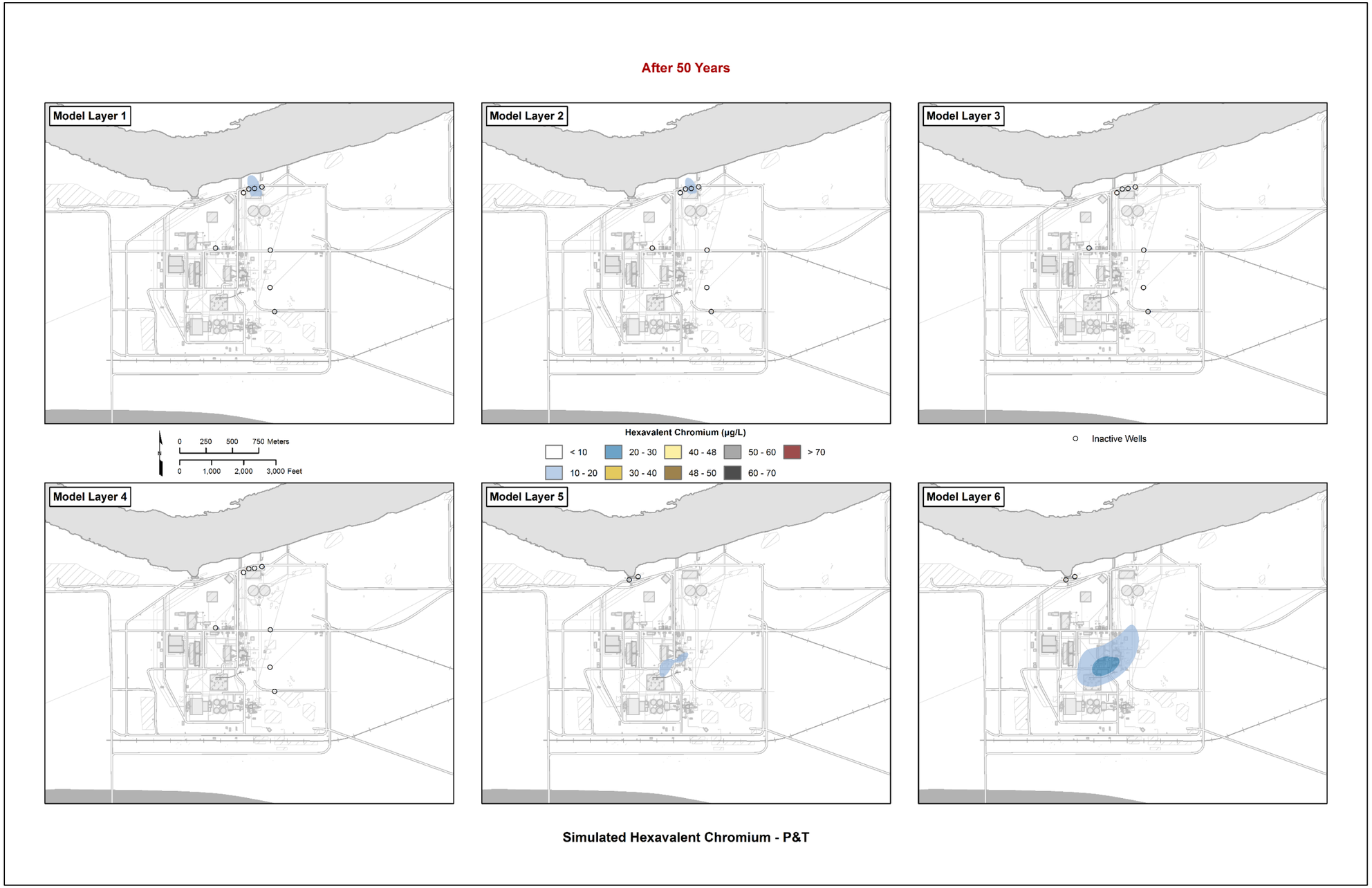


Figure 7-29. Simulated Distribution of Cr(VI) After 50 Years - P&T

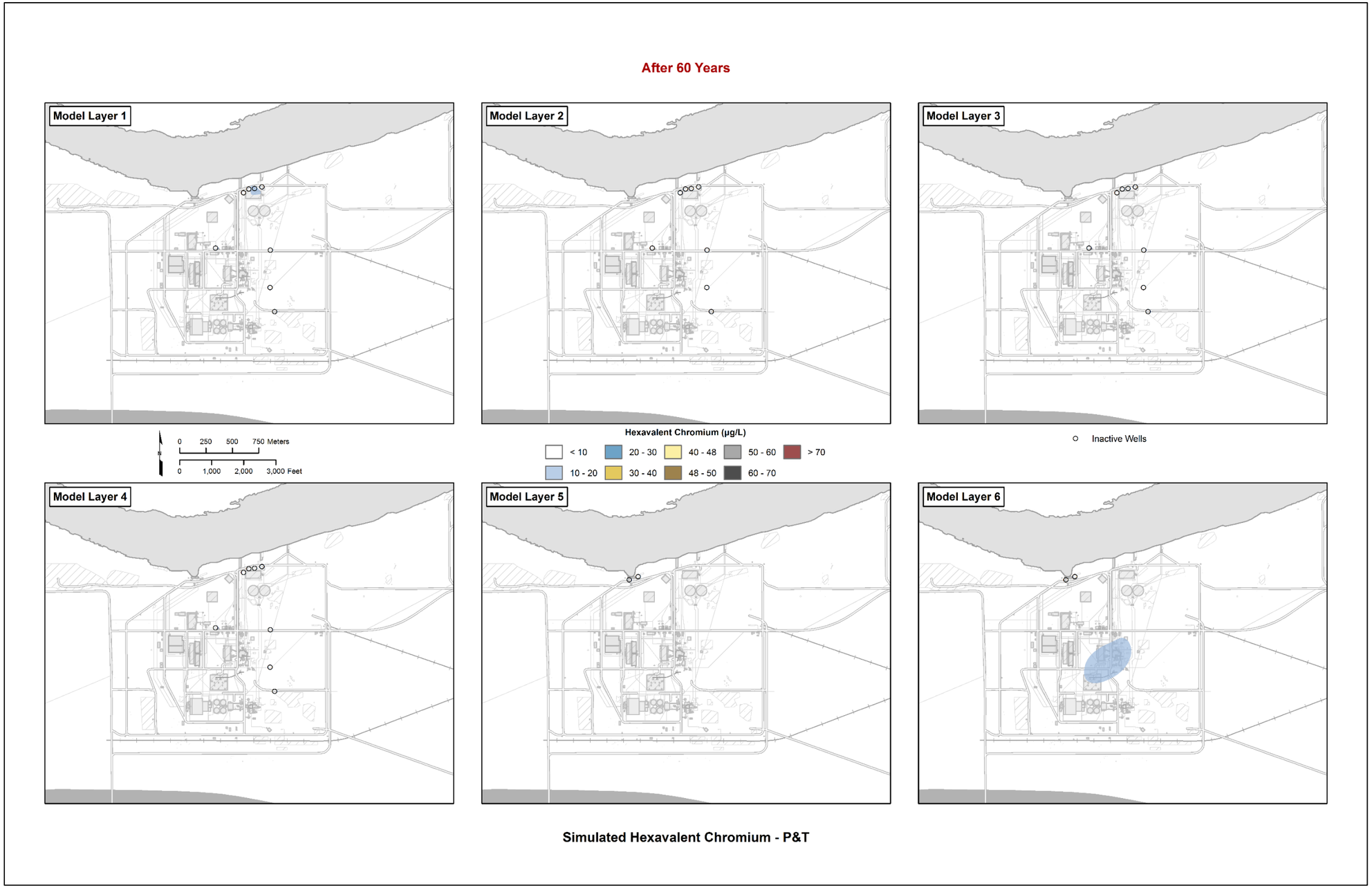


Figure 7-30. Simulated Distribution of Cr(VI) After 60 Years - P&T

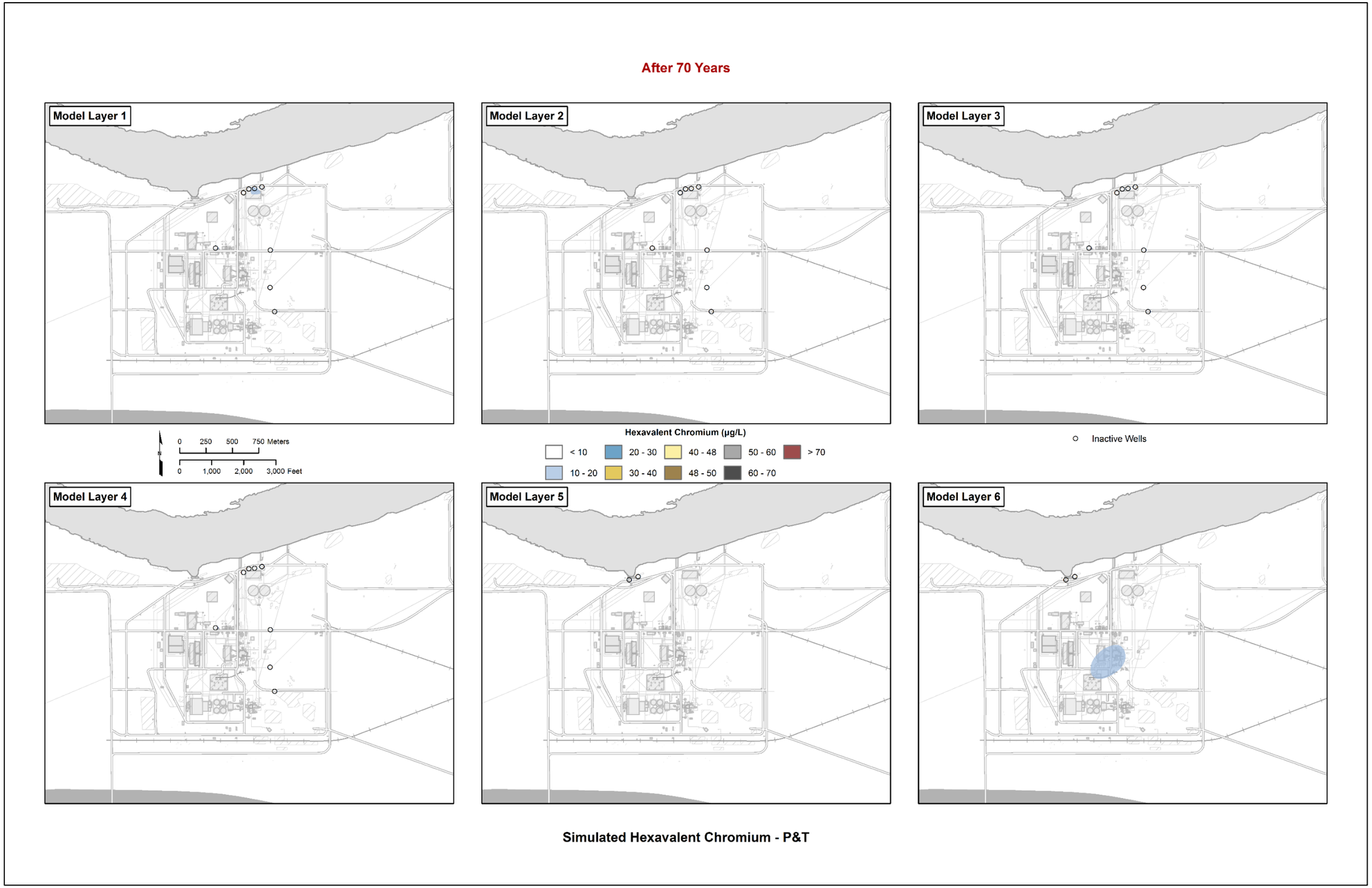


Figure 7-31. Simulated Distribution of Cr(VI) After 70 Years - P&T

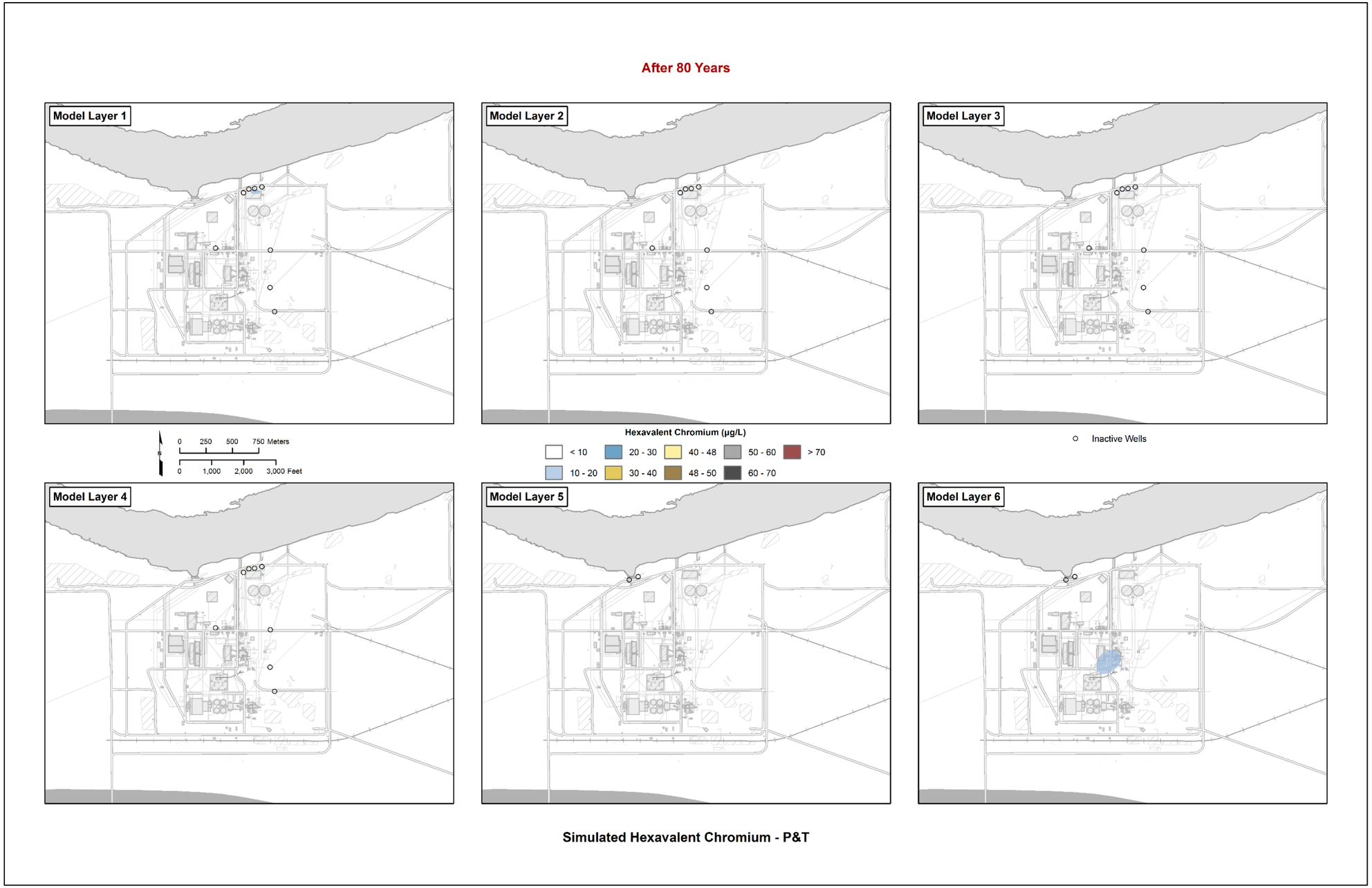


Figure 7-32. Simulated Distribution of Cr(VI) After 80 Years - P&T

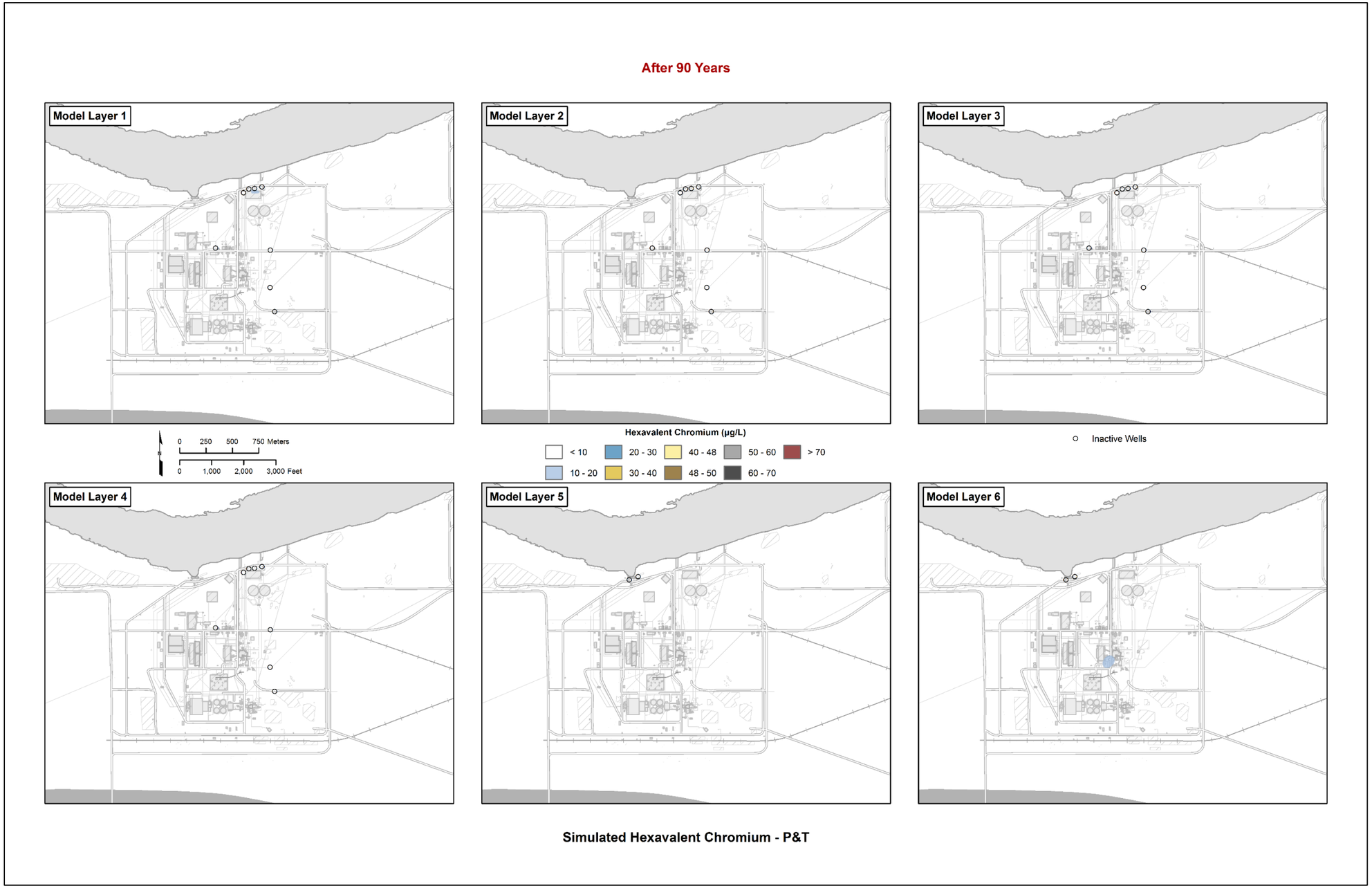


Figure 7-33. Simulated Distribution of Cr(VI) After 90 Years - P&T

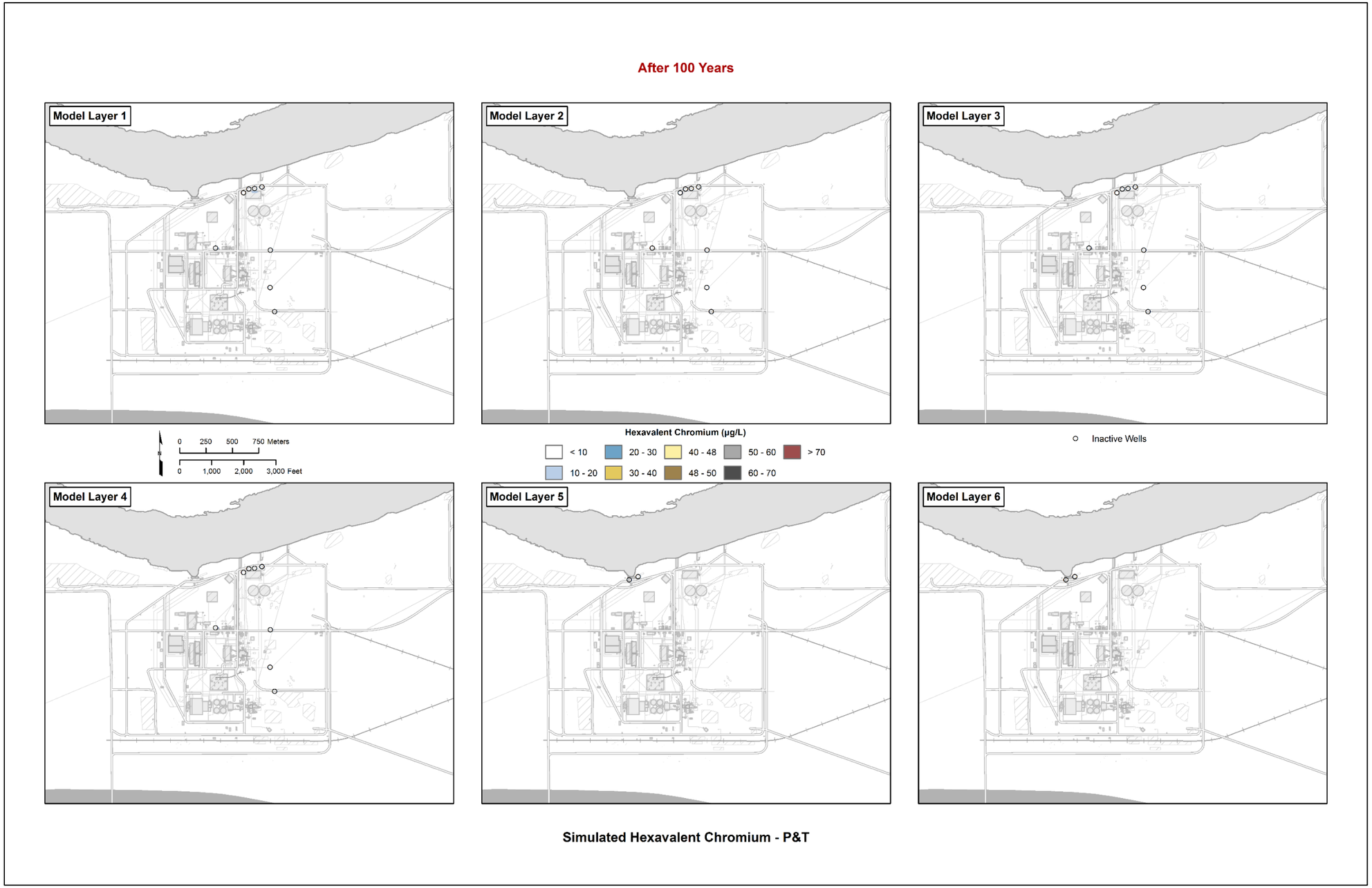


Figure 7-34. Simulated Distribution of Cr(VI) After 100 Years - P&T

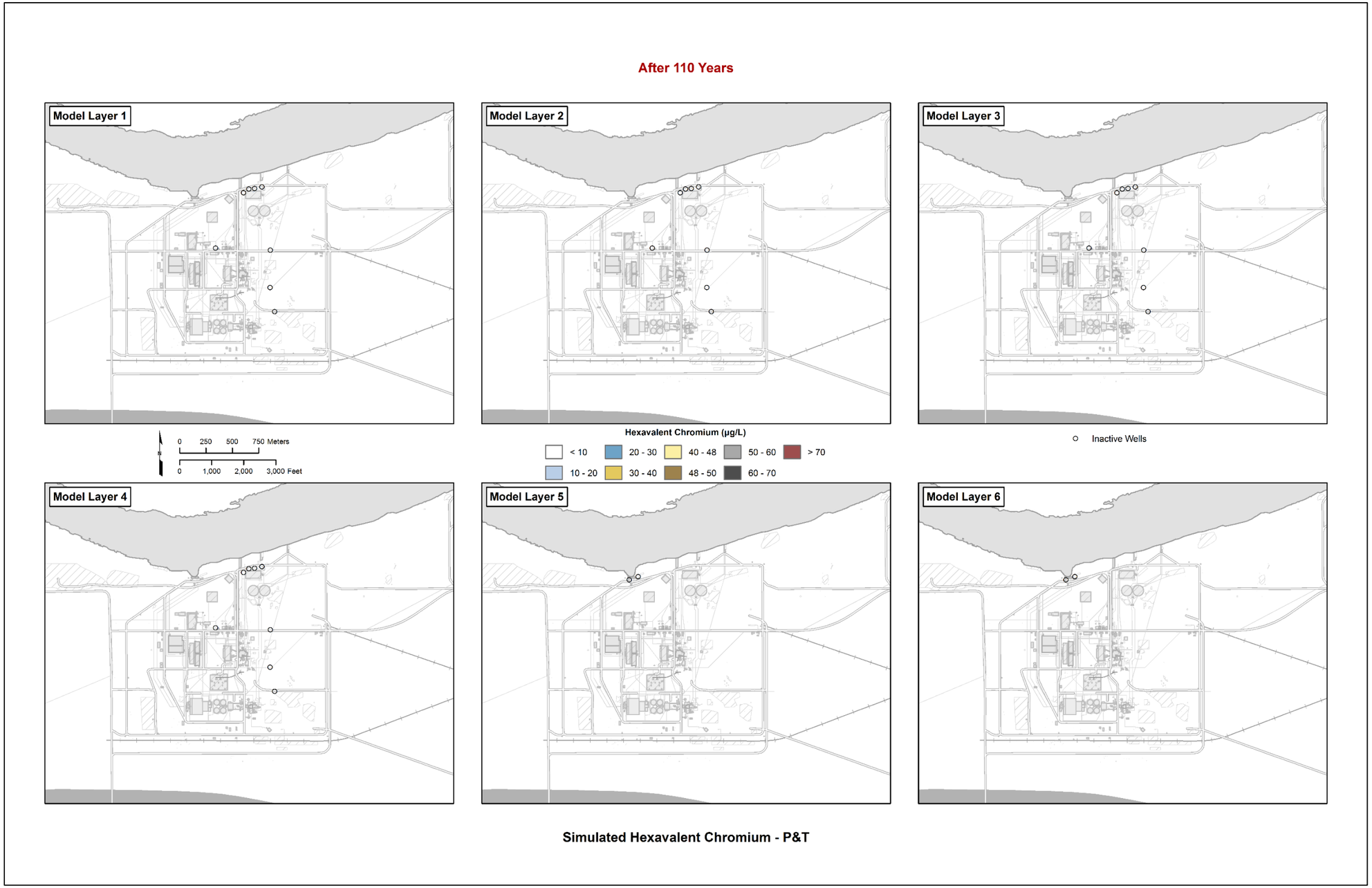


Figure 7-35. Simulated Distribution of Cr(VI) After 110 Years - P&T

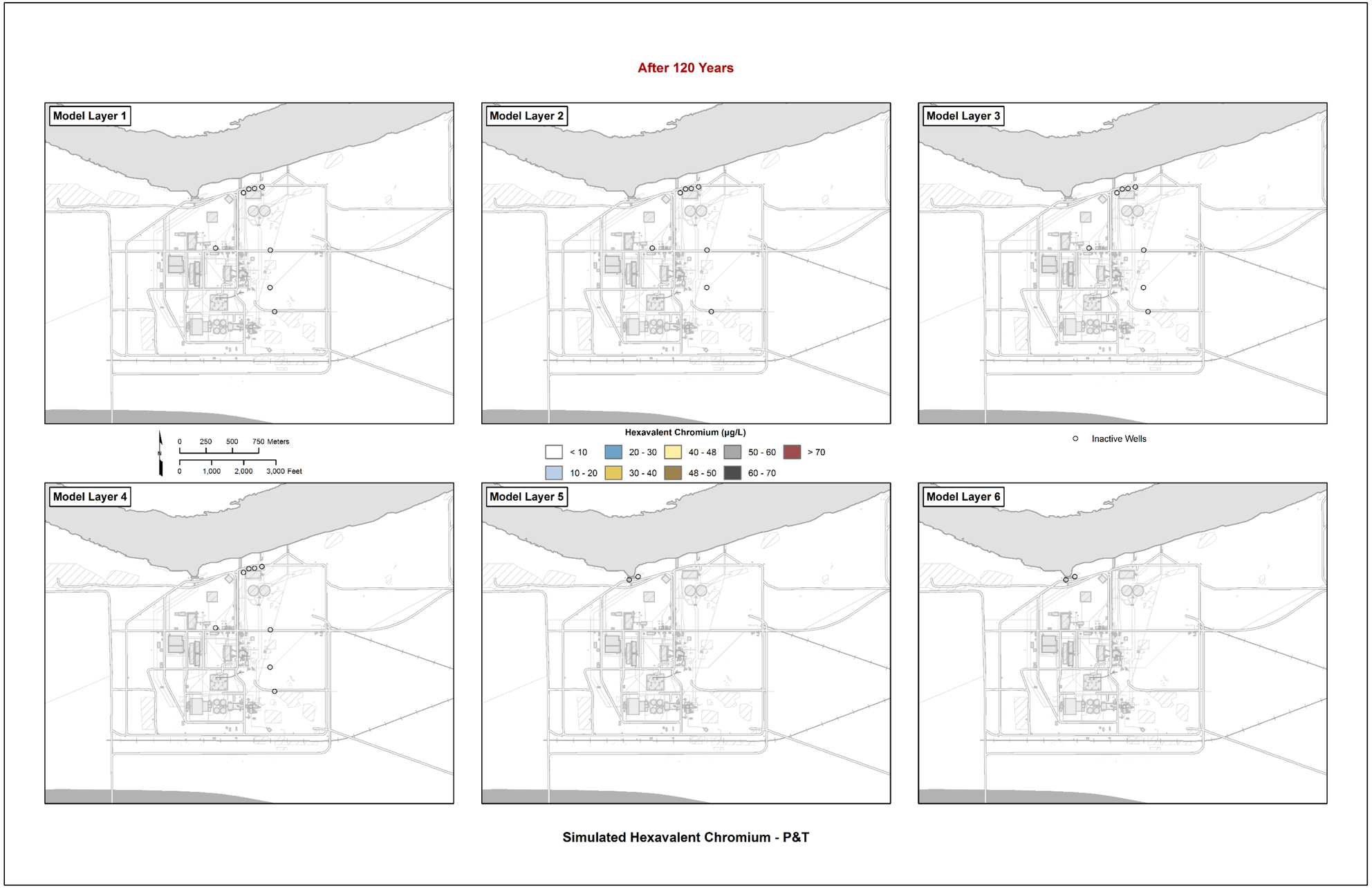


Figure 7-36. Simulated Distribution of Cr(VI) After 120 Years - P&T

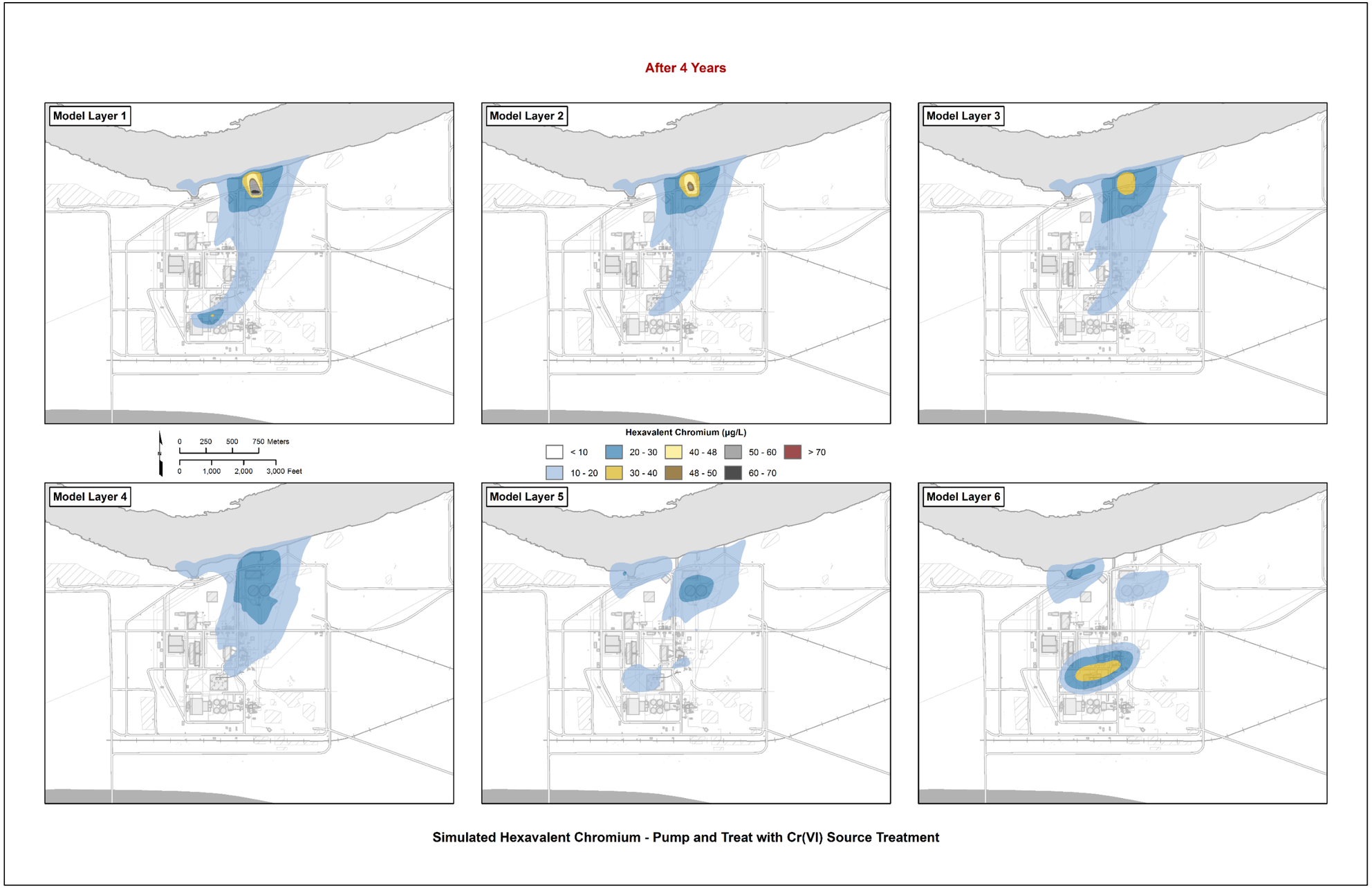


Figure 7-37. Simulated Distribution of Cr(VI) After 4 Years – P&T with Cr(VI) Source Treatment

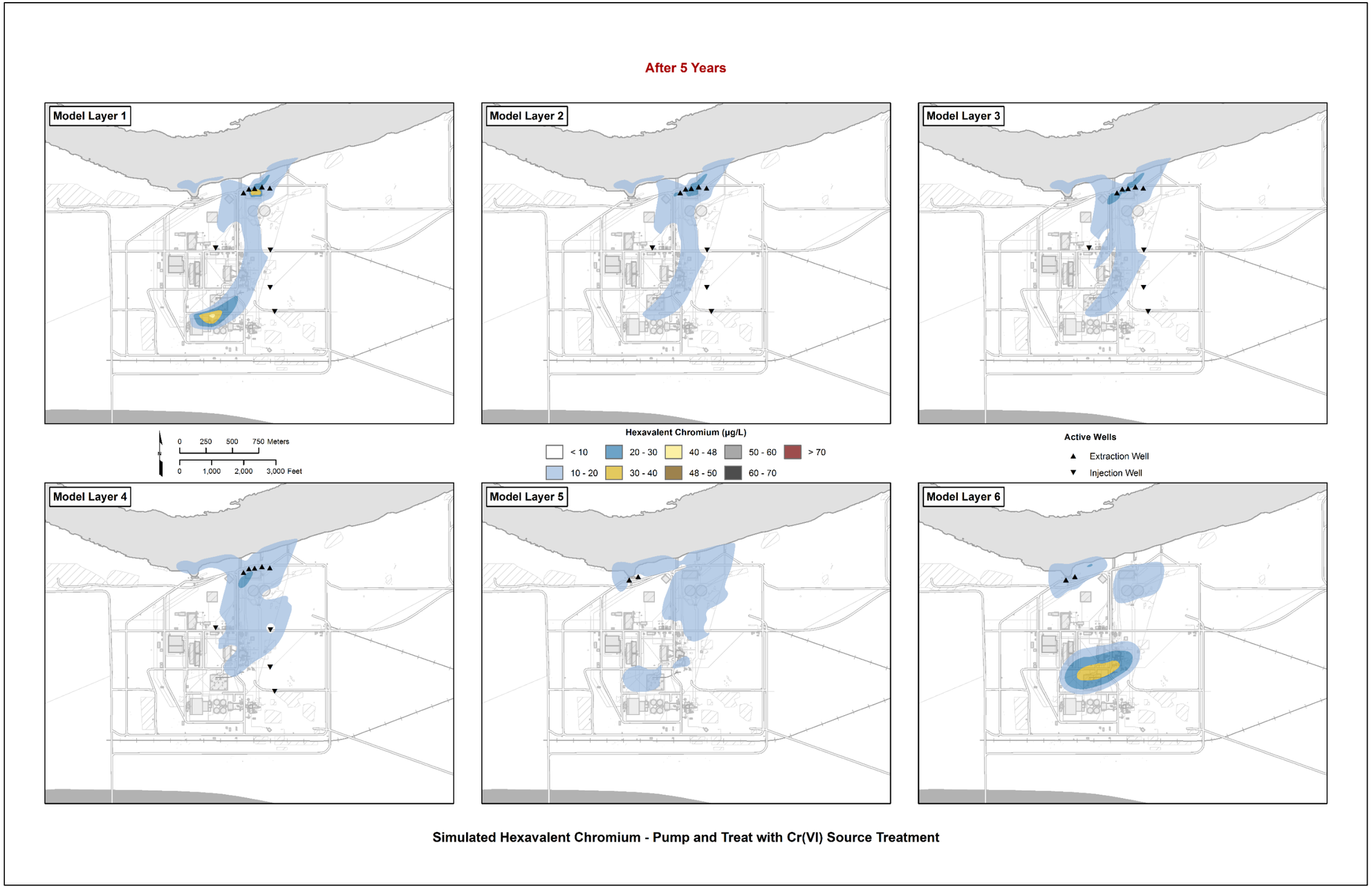


Figure 7-38. Simulated Distribution of Cr(VI) After 5 Years – P&T with Cr(VI) Source Treatment

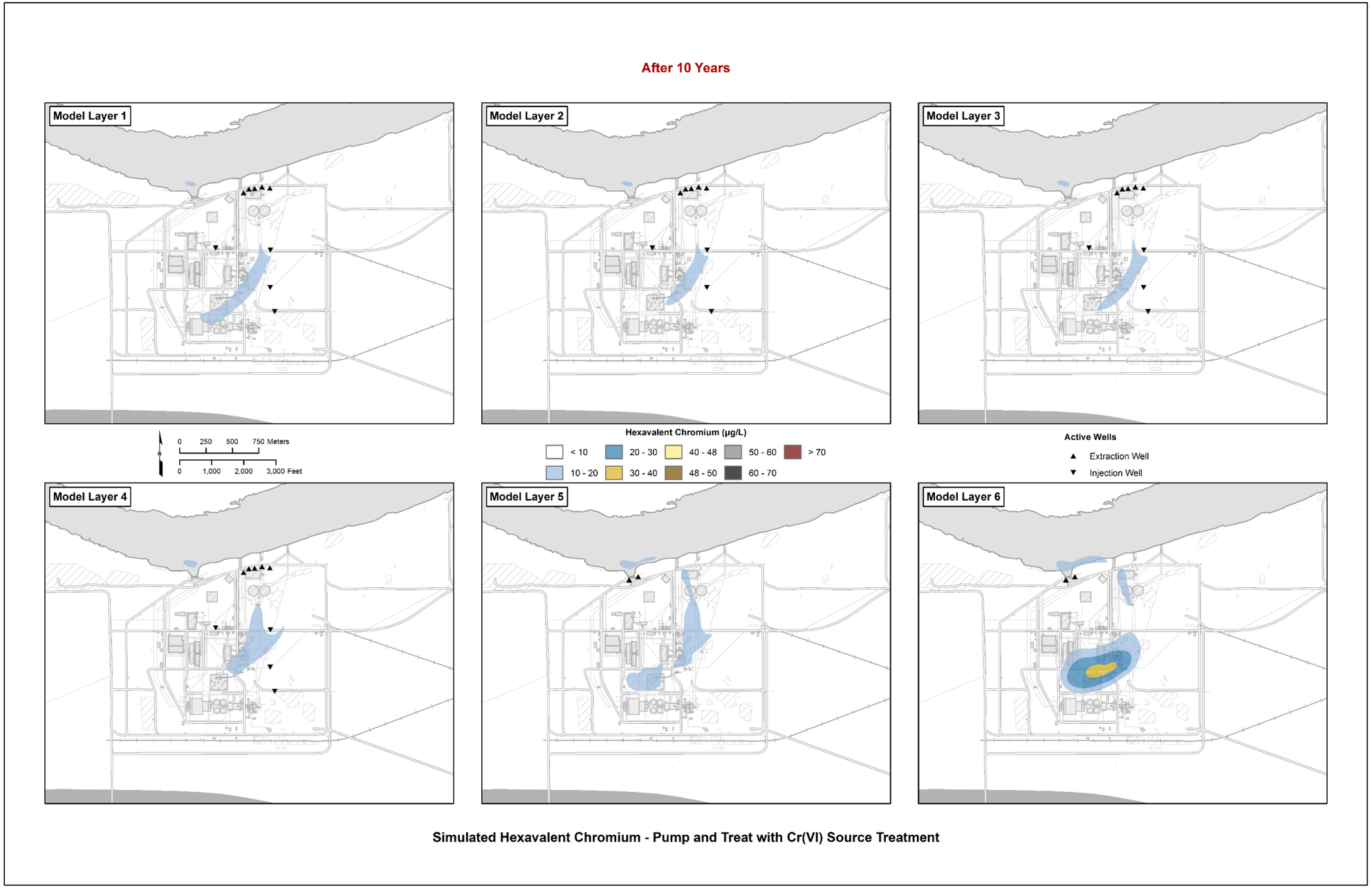


Figure 7-39. Simulated Distribution of Cr(VI) After 10 Years - P&T with Cr(VI) Source Treatment

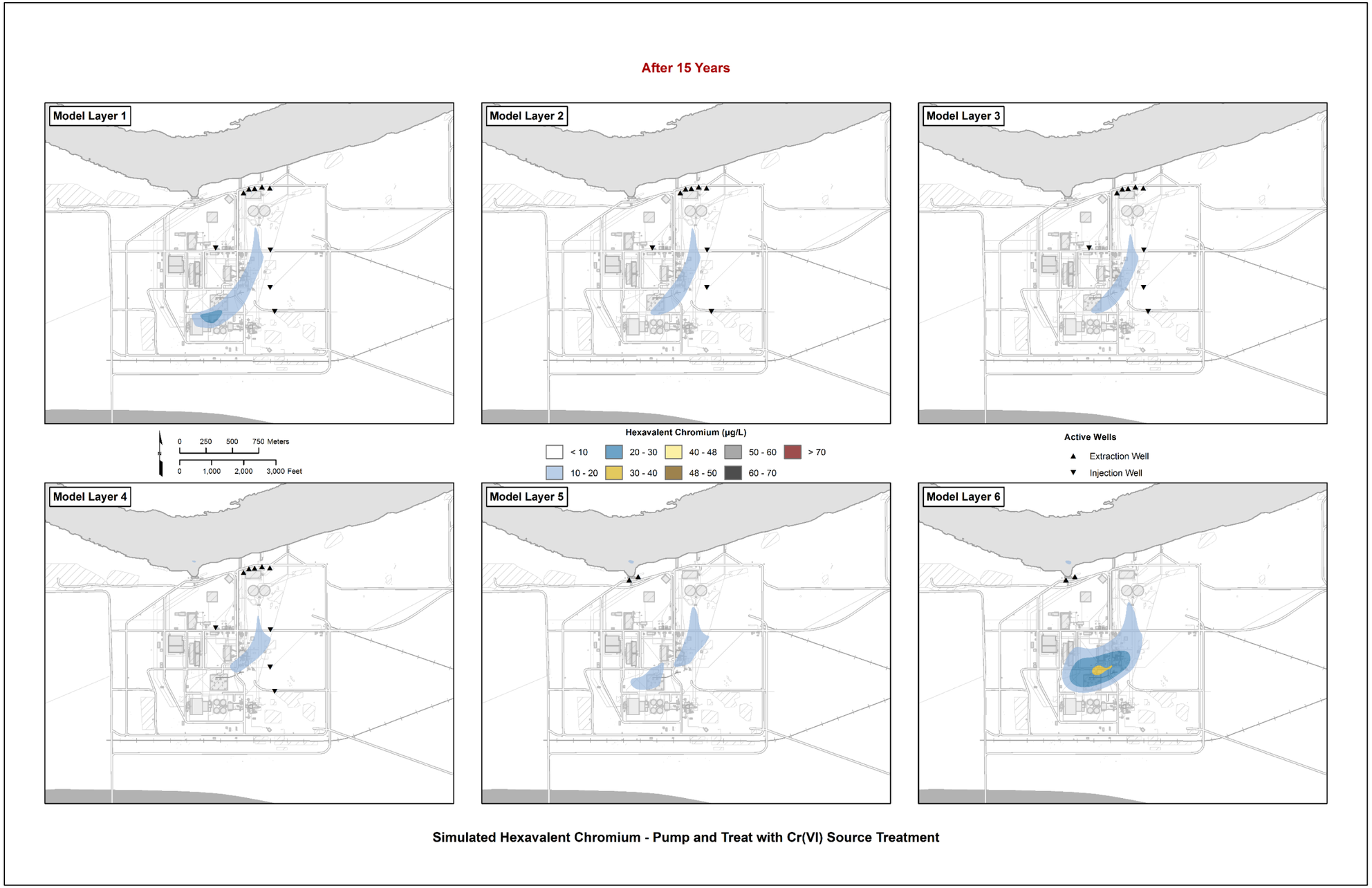


Figure 7-40. Simulated Distribution of Cr(VI) After 15 Years - P&T with Cr(VI) Source Treatment

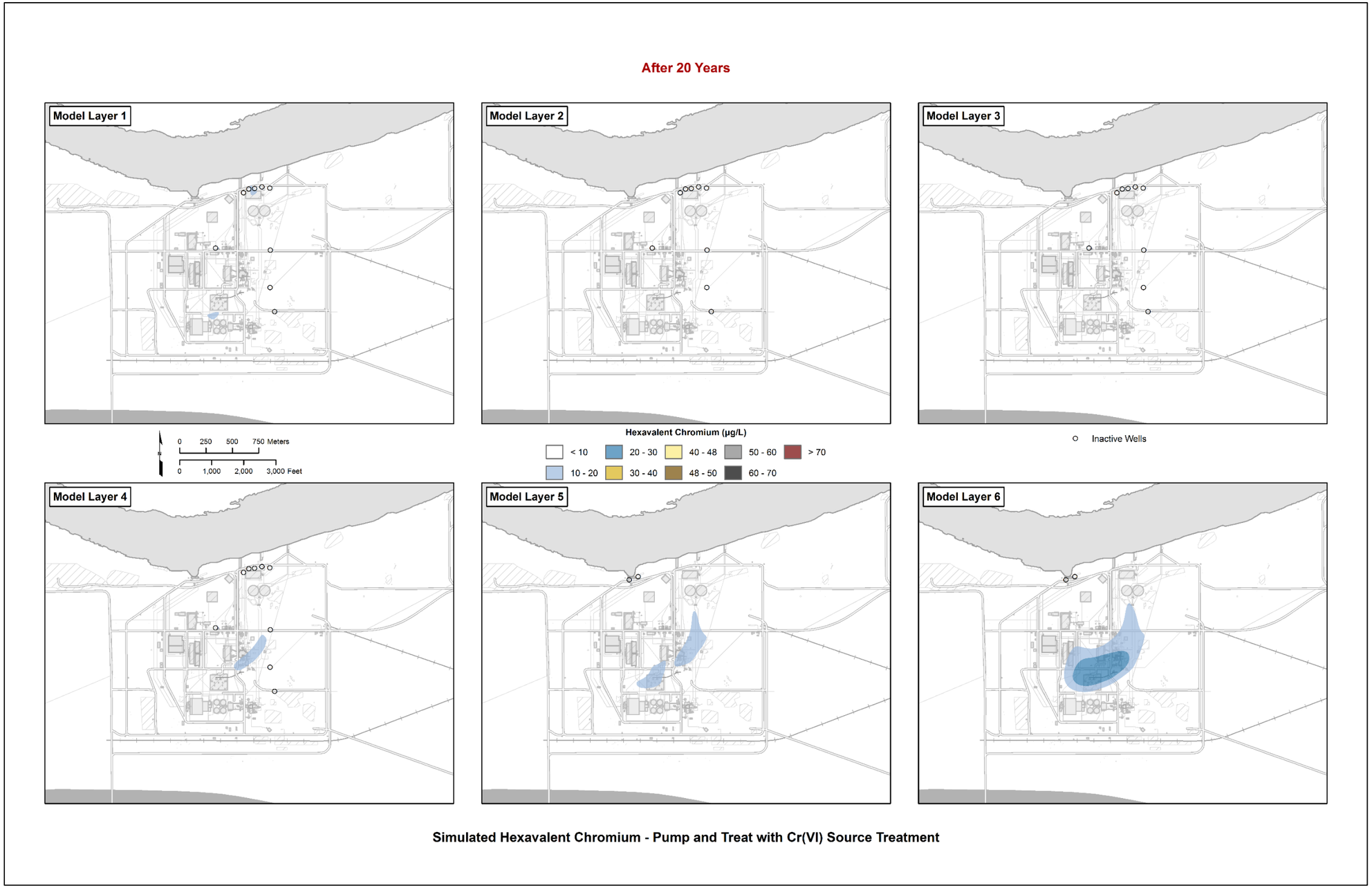


Figure 7-41. Simulated Distribution of Cr(VI) After 20 Years - P&T with Cr(VI) Source Treatment

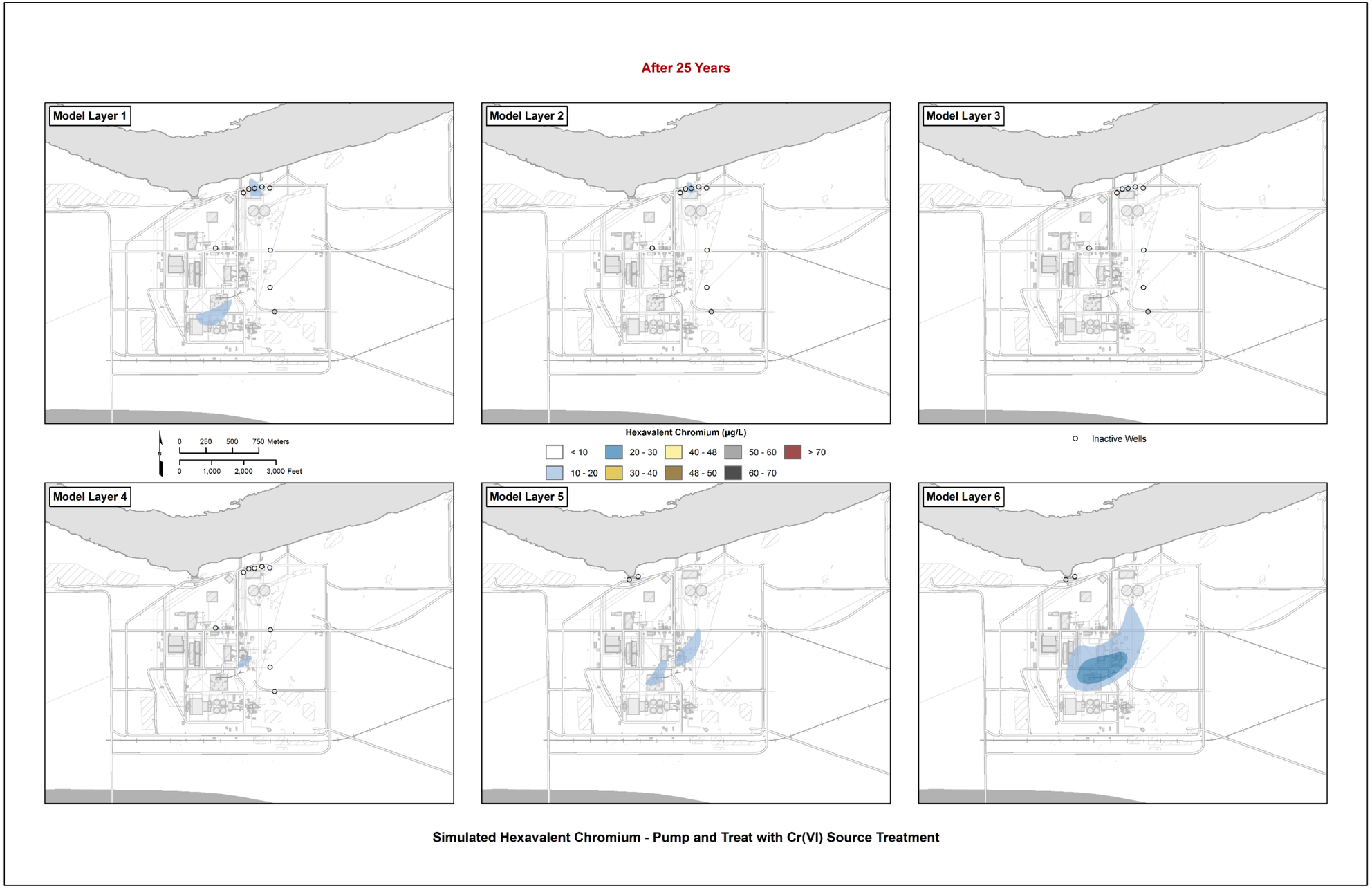


Figure 7-42. Simulated Distribution of Cr(VI) After 25 Years - P&T with Cr(VI) Source Treatment

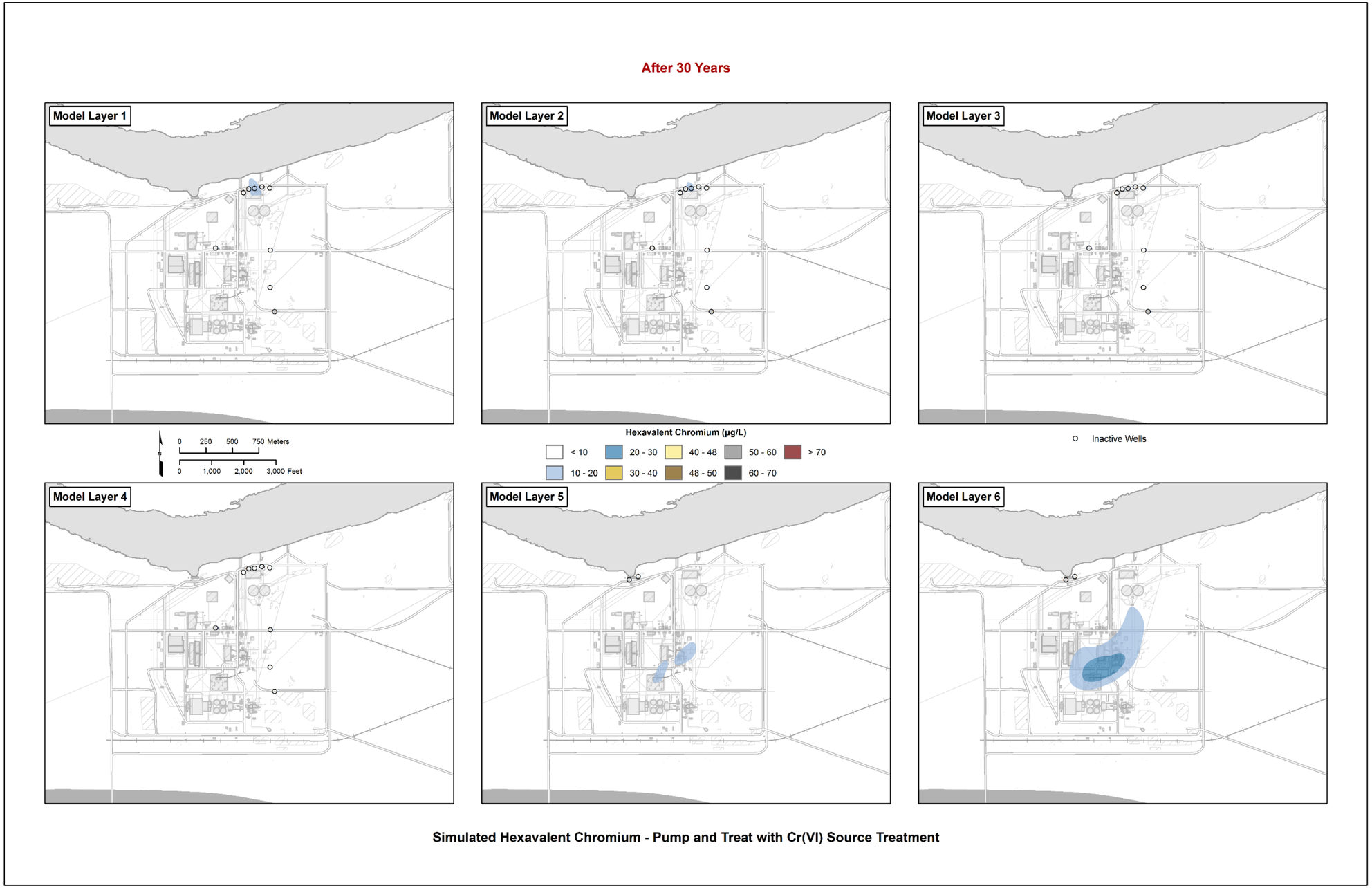


Figure 7-43. Simulated Distribution of Cr(VI) After 30 Years - P&T with Cr(VI) Source Treatment

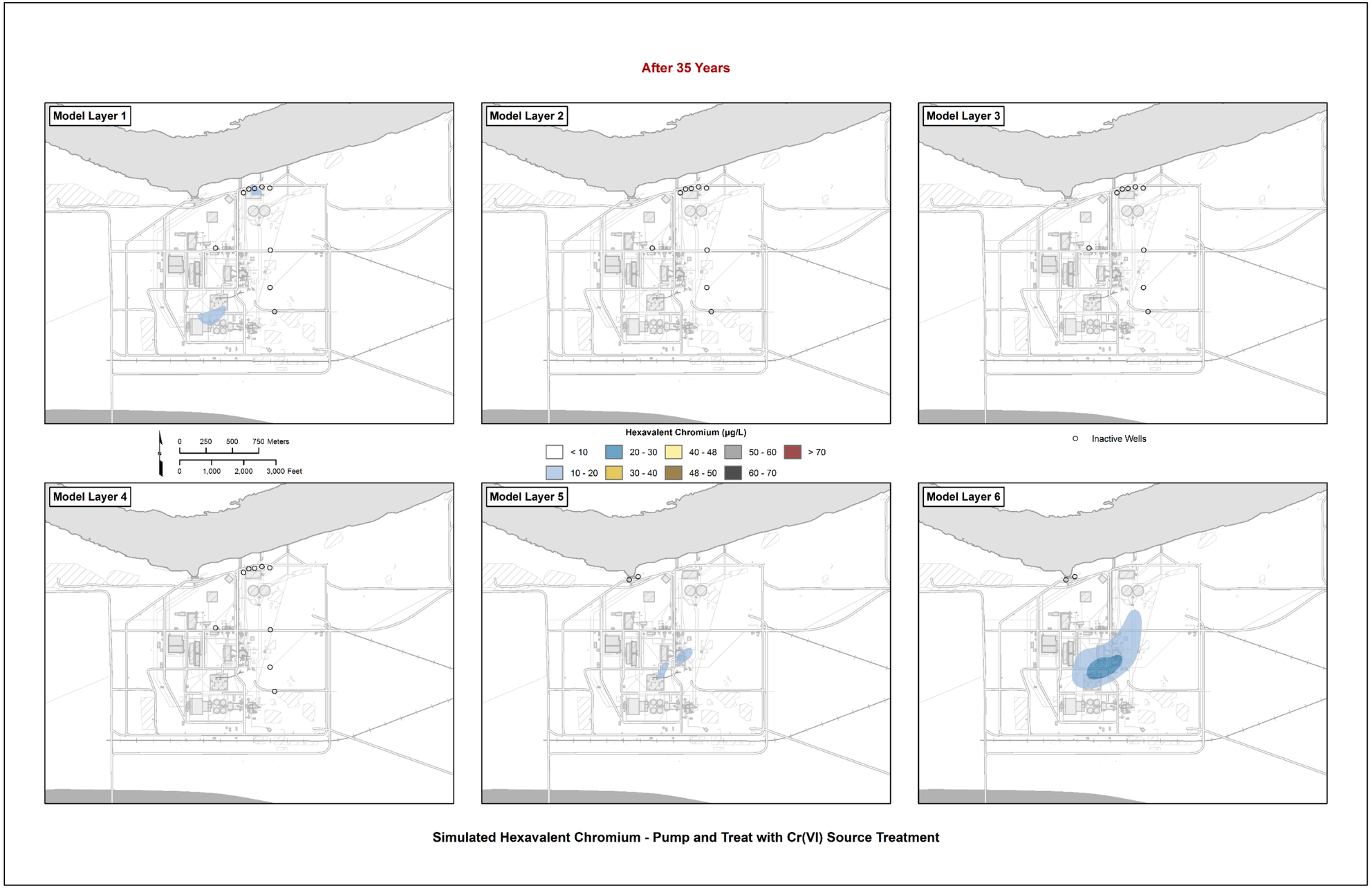


Figure 7-44. Simulated Distribution of Cr(VI) After 35 Years - P&T with Cr(VI) Source Treatment

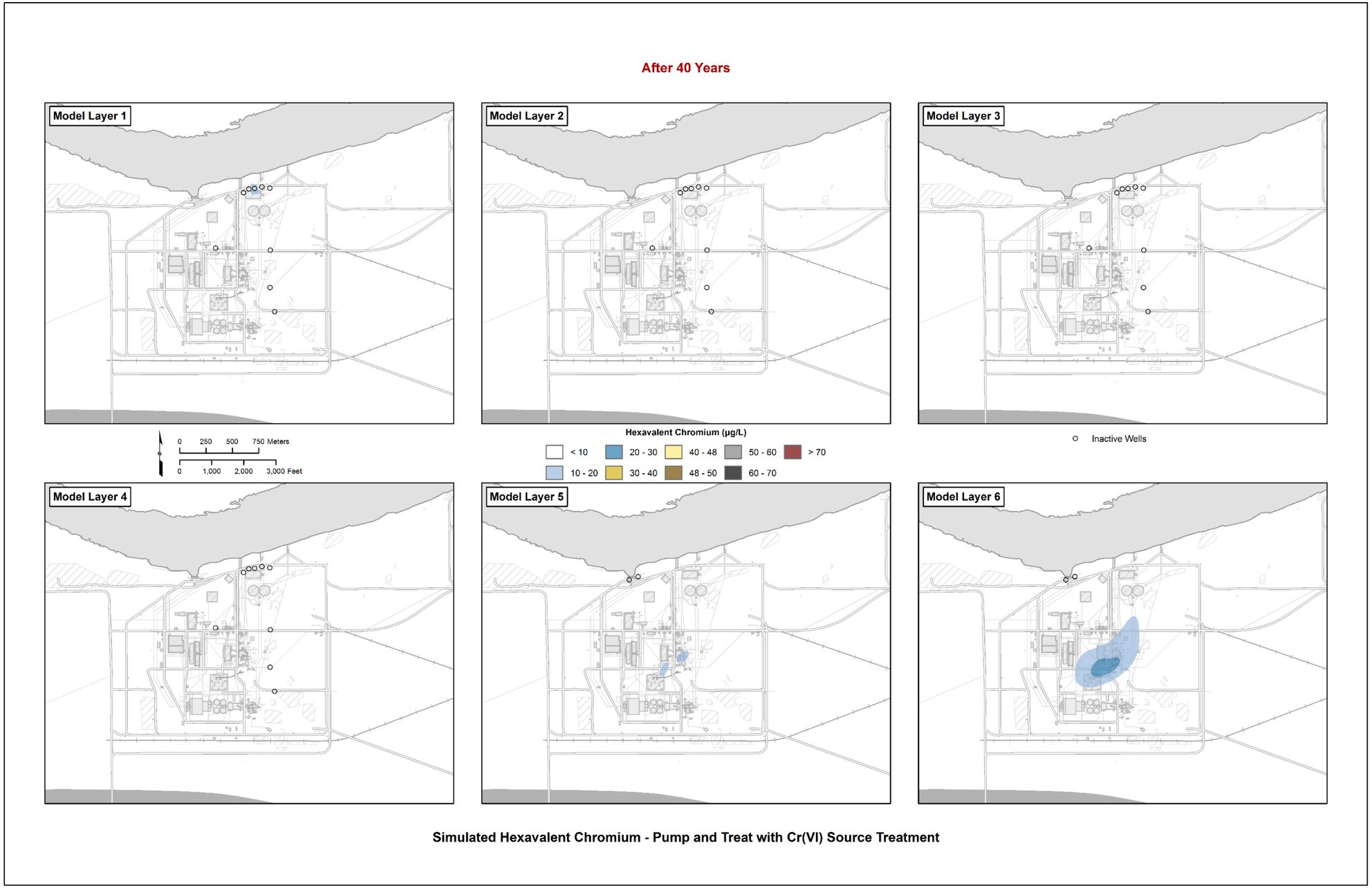


Figure 7-45. Simulated Distribution of Cr(VI) After 40 Years - P&T with Cr(VI) Source Treatment

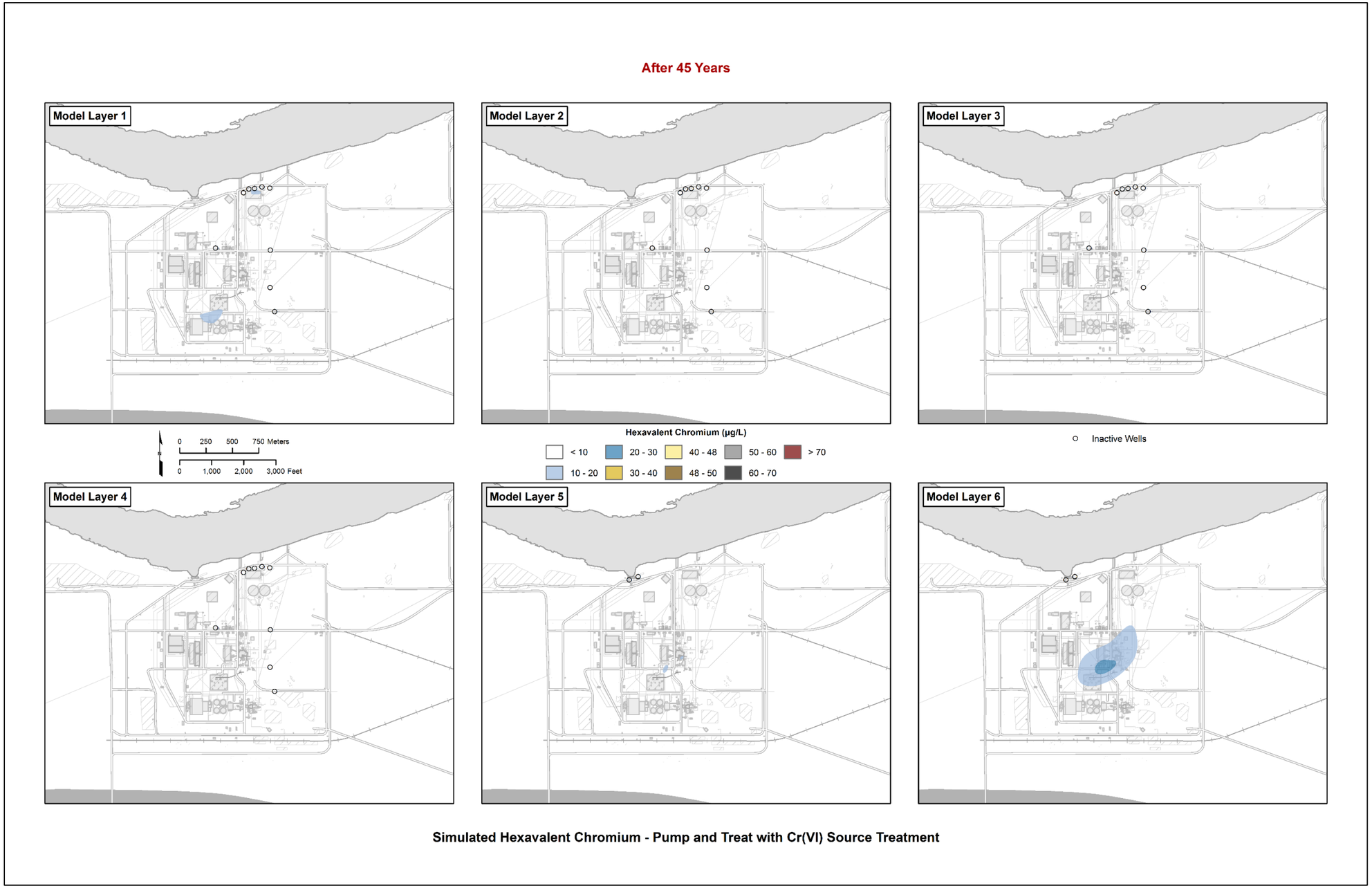


Figure 7-46. Simulated Distribution of Cr(VI) After 45 Years - P&T with Cr(VI) Source Treatment

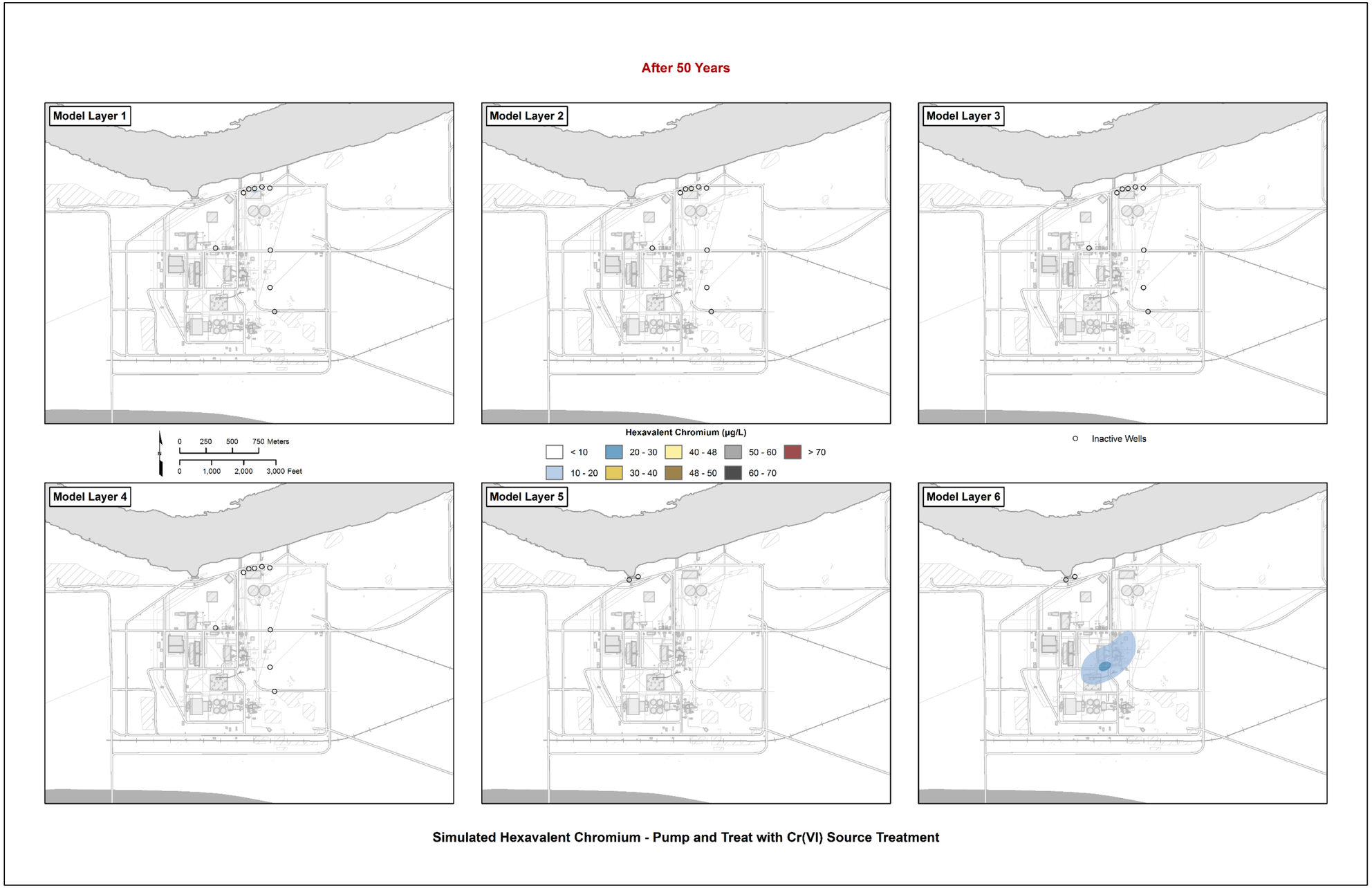


Figure 7-47. Simulated Distribution of Cr(VI) After 50 Years - P&T with Cr(VI) Source Treatment

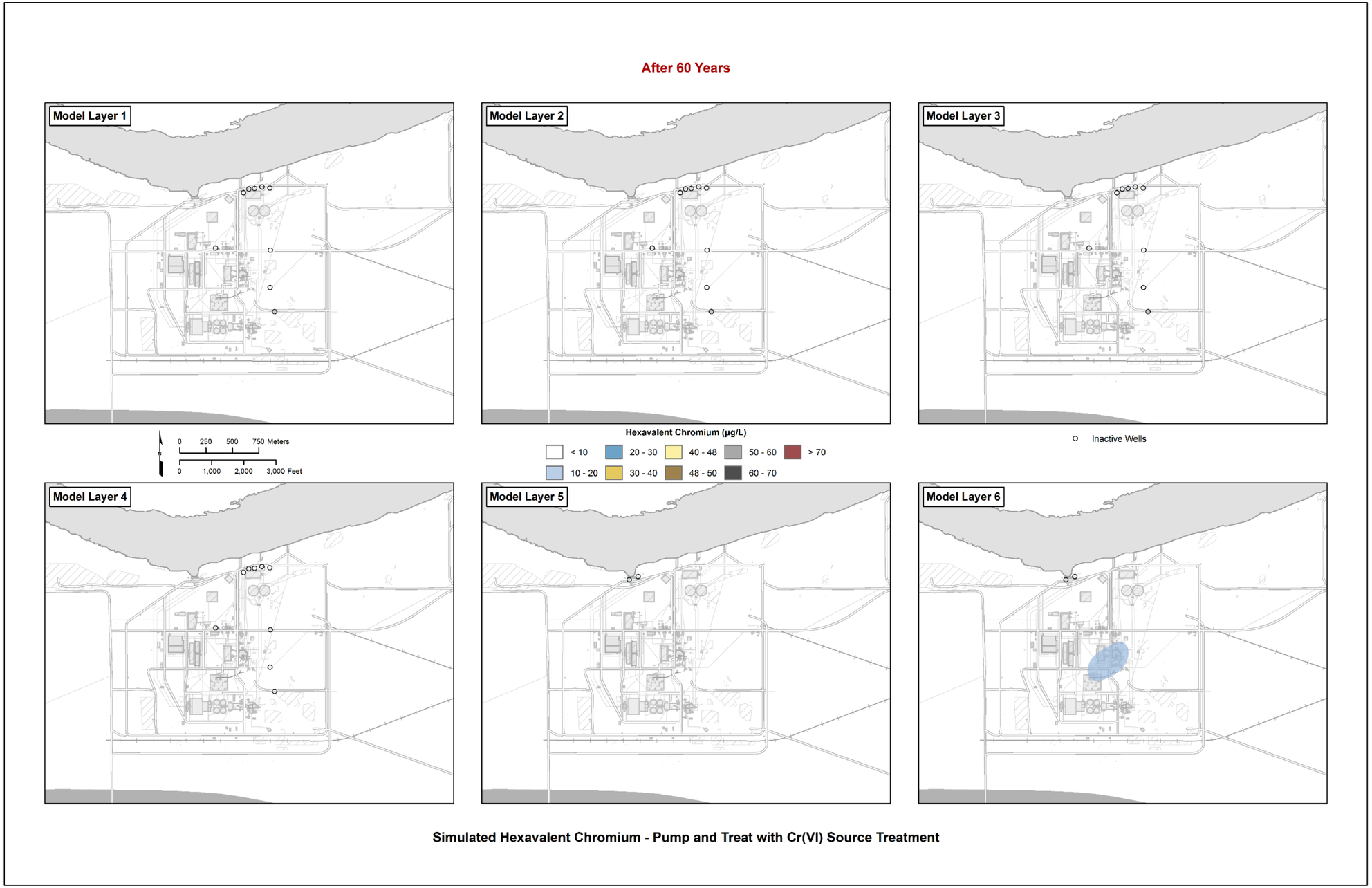


Figure 7-48. Simulated Distribution of Cr(VI) After 60 Years - P&T with Cr(VI) Source Treatment

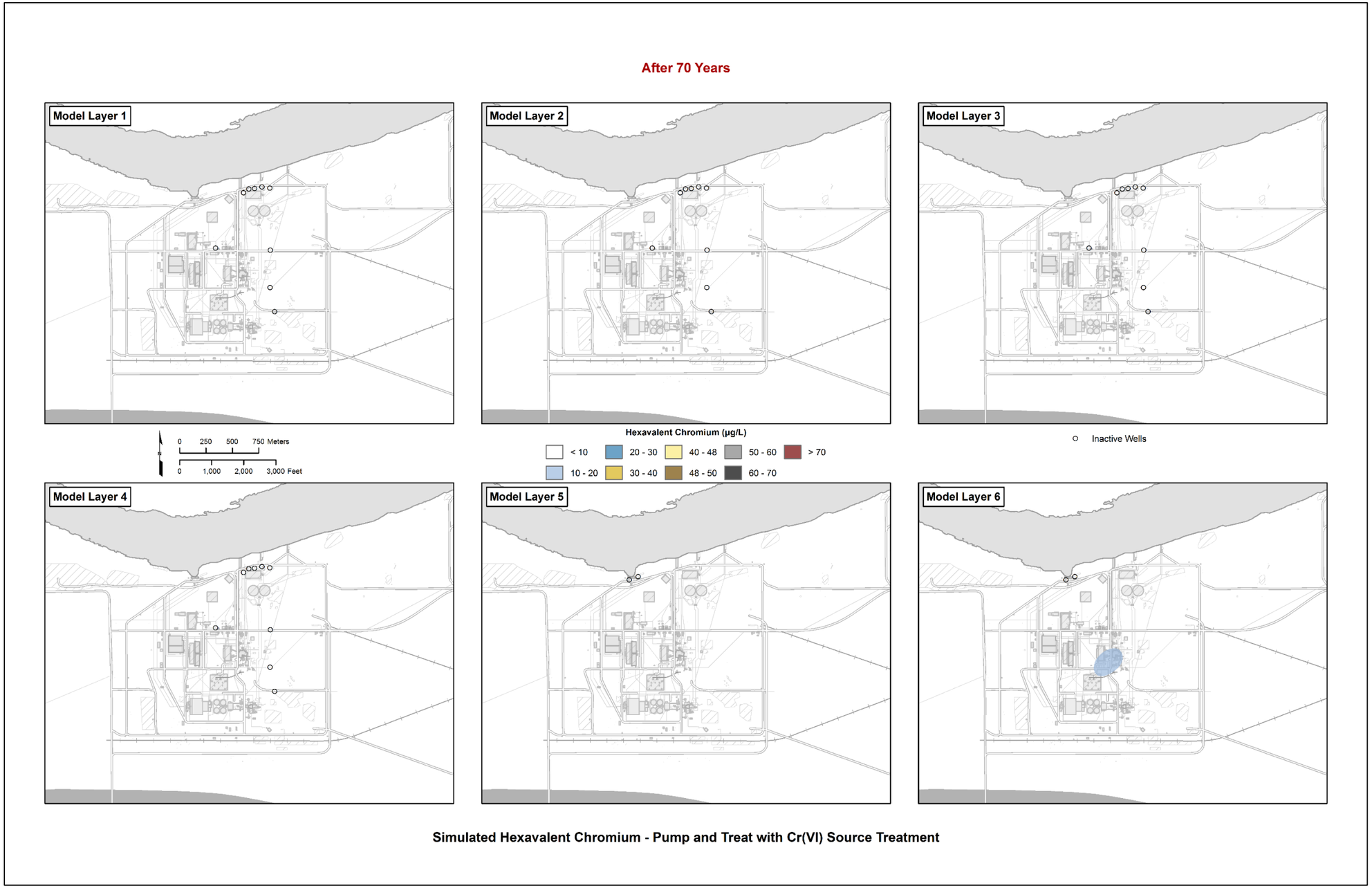


Figure 7-49. Simulated Distribution of Cr(VI) After 70 Years - P&T with Cr(VI) Source Treatment

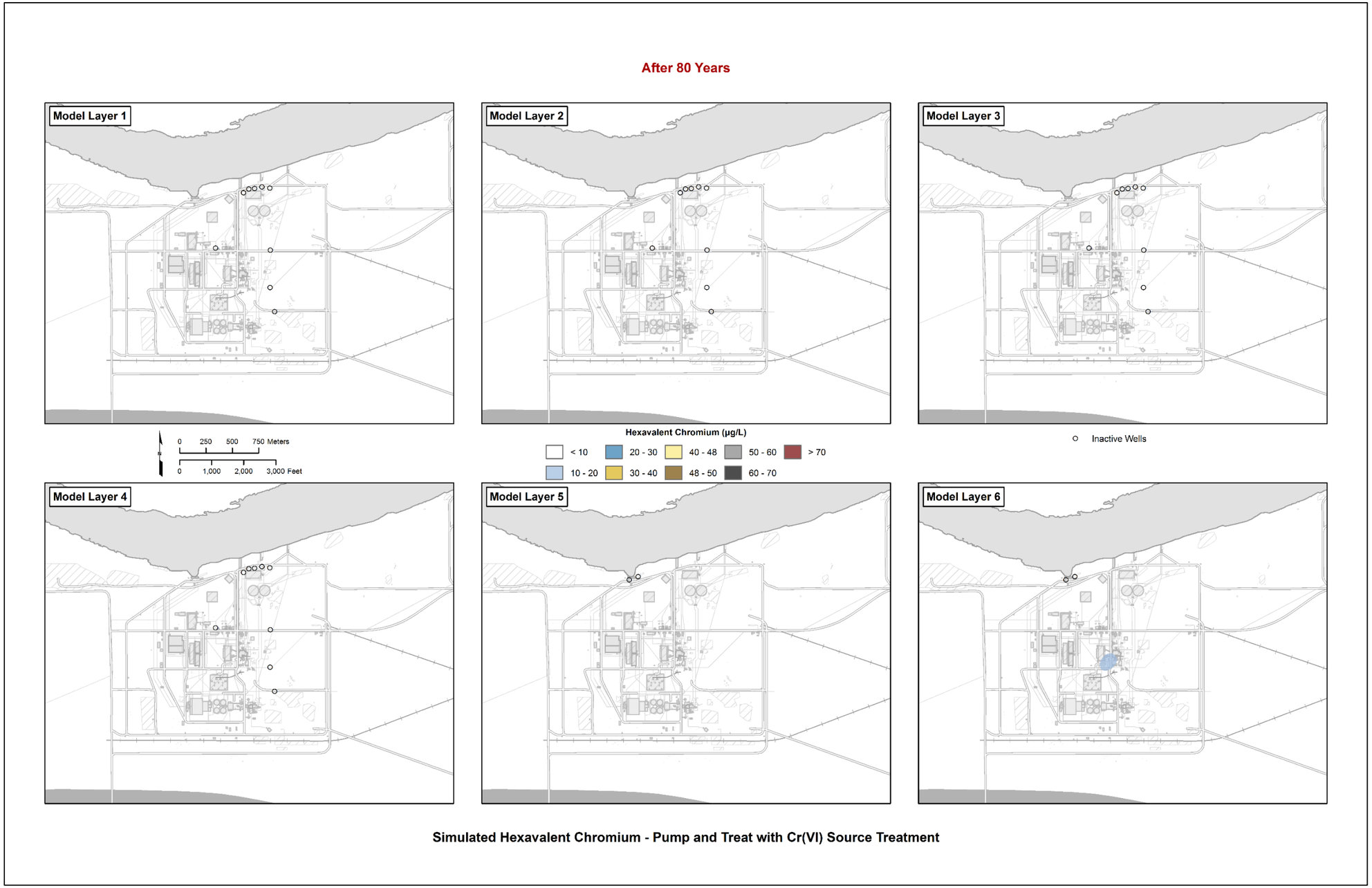


Figure 7-50. Simulated Distribution of Cr(VI) After 80 Years - P&T with Cr(VI) Source Treatment

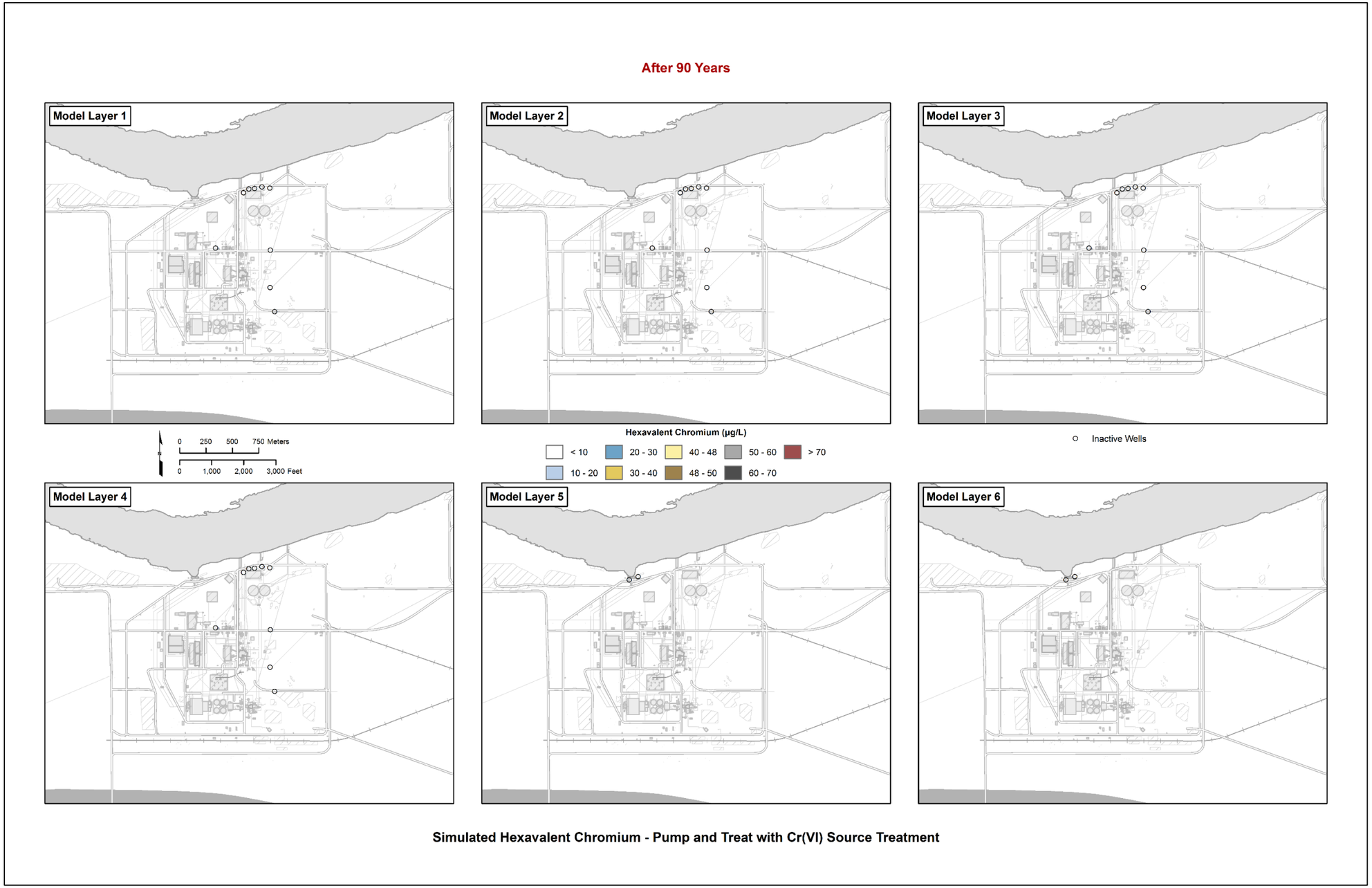


Figure 7-51. Simulated Distribution of Cr(VI) After 90 Years - P&T with Cr(VI) Source Treatment

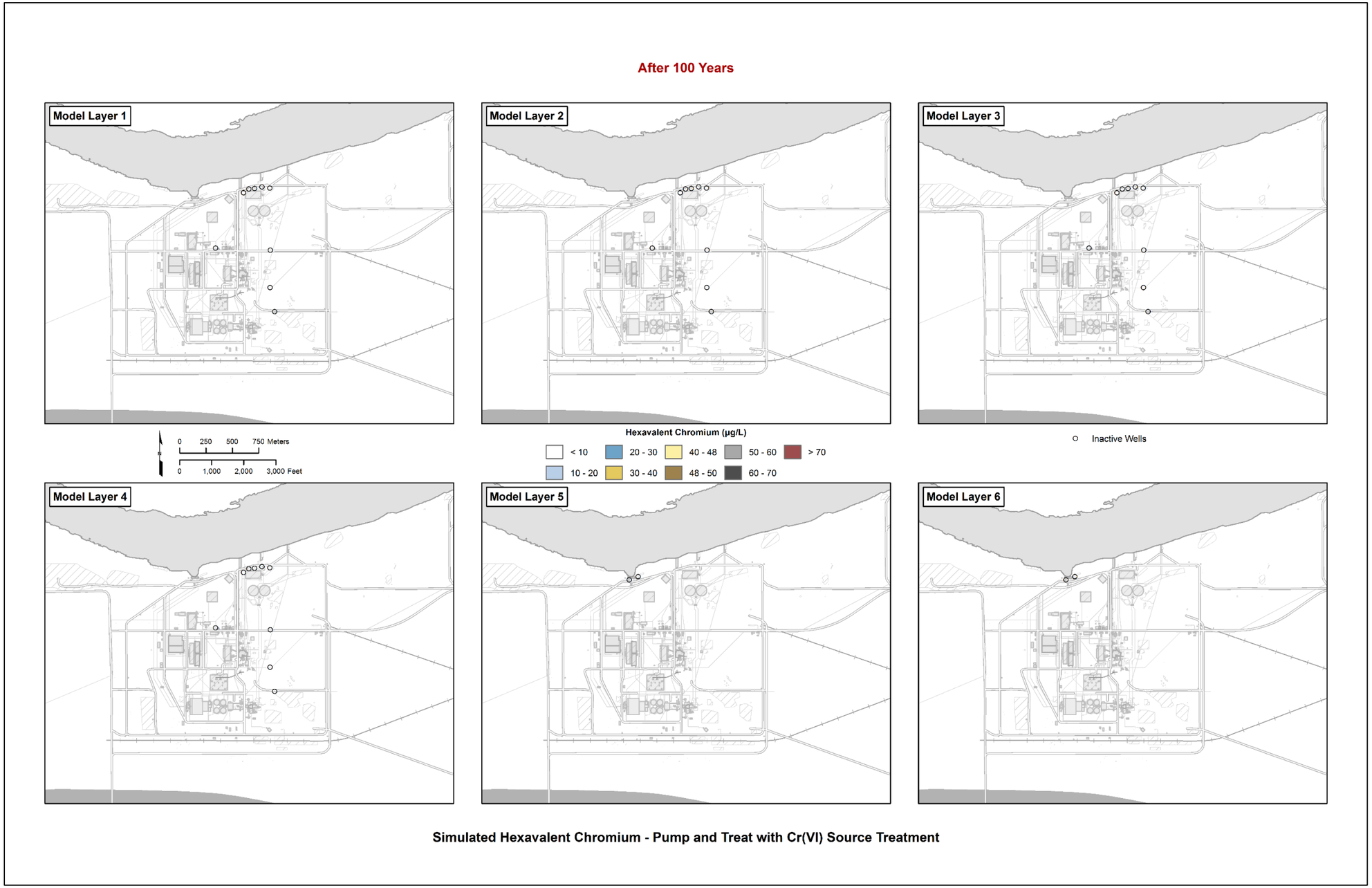


Figure 7-52. Simulated Distribution of Cr(VI) After 100 Years - P&T with Cr(VI) Source Treatment

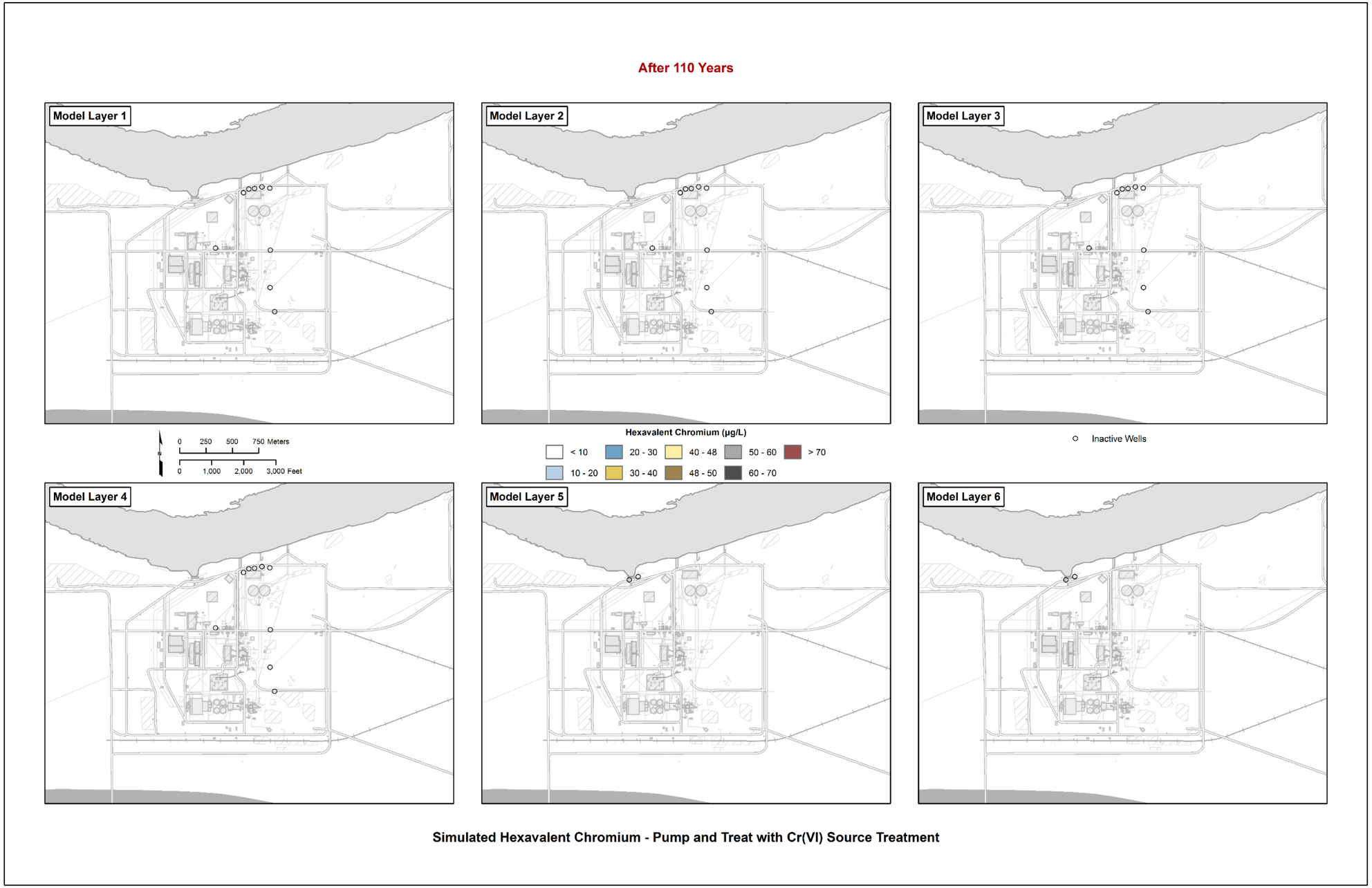


Figure 7-53. Simulated Distribution of Cr(VI) After 110 Years - P&T with Cr(VI) Source Treatment

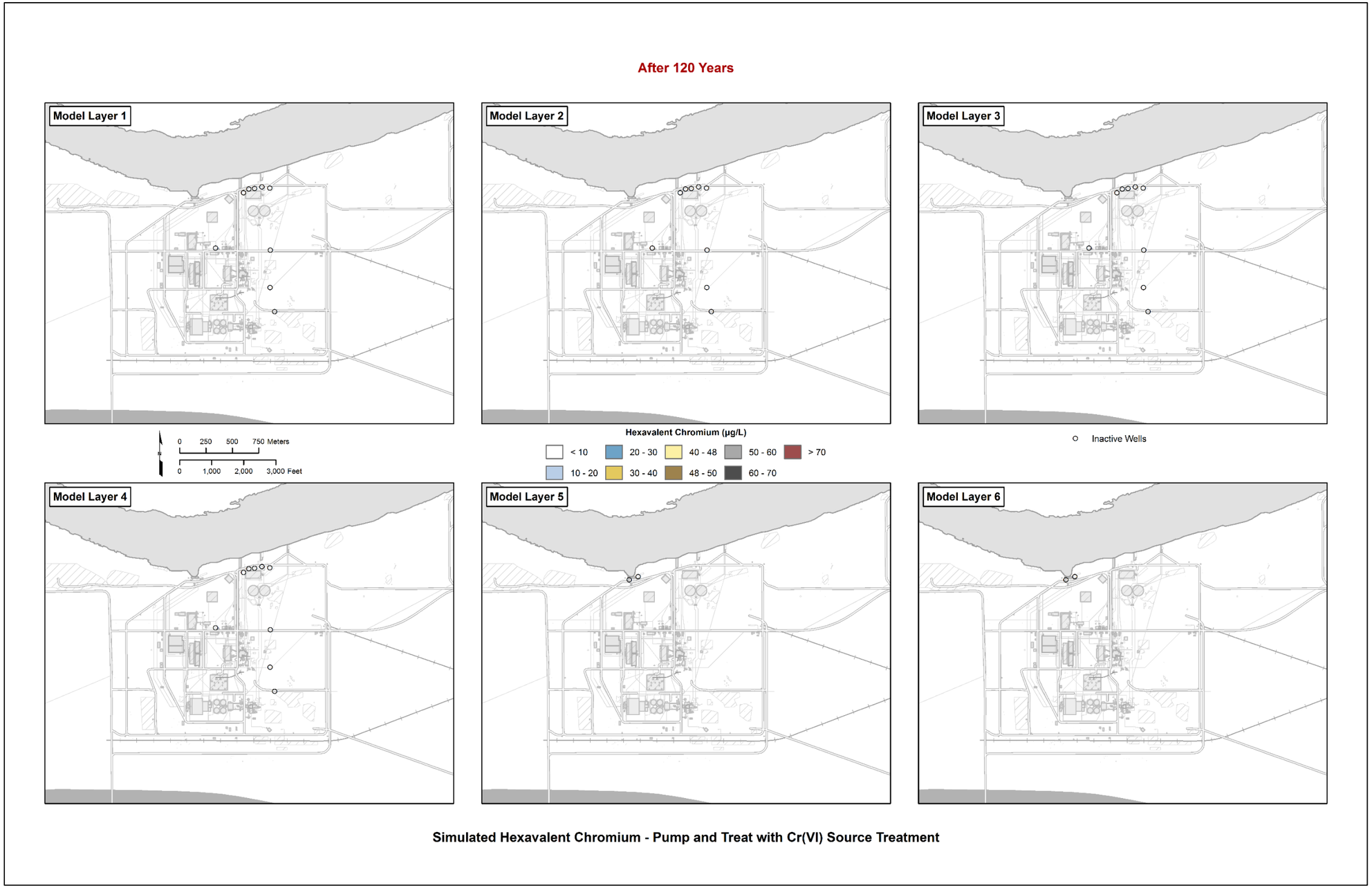
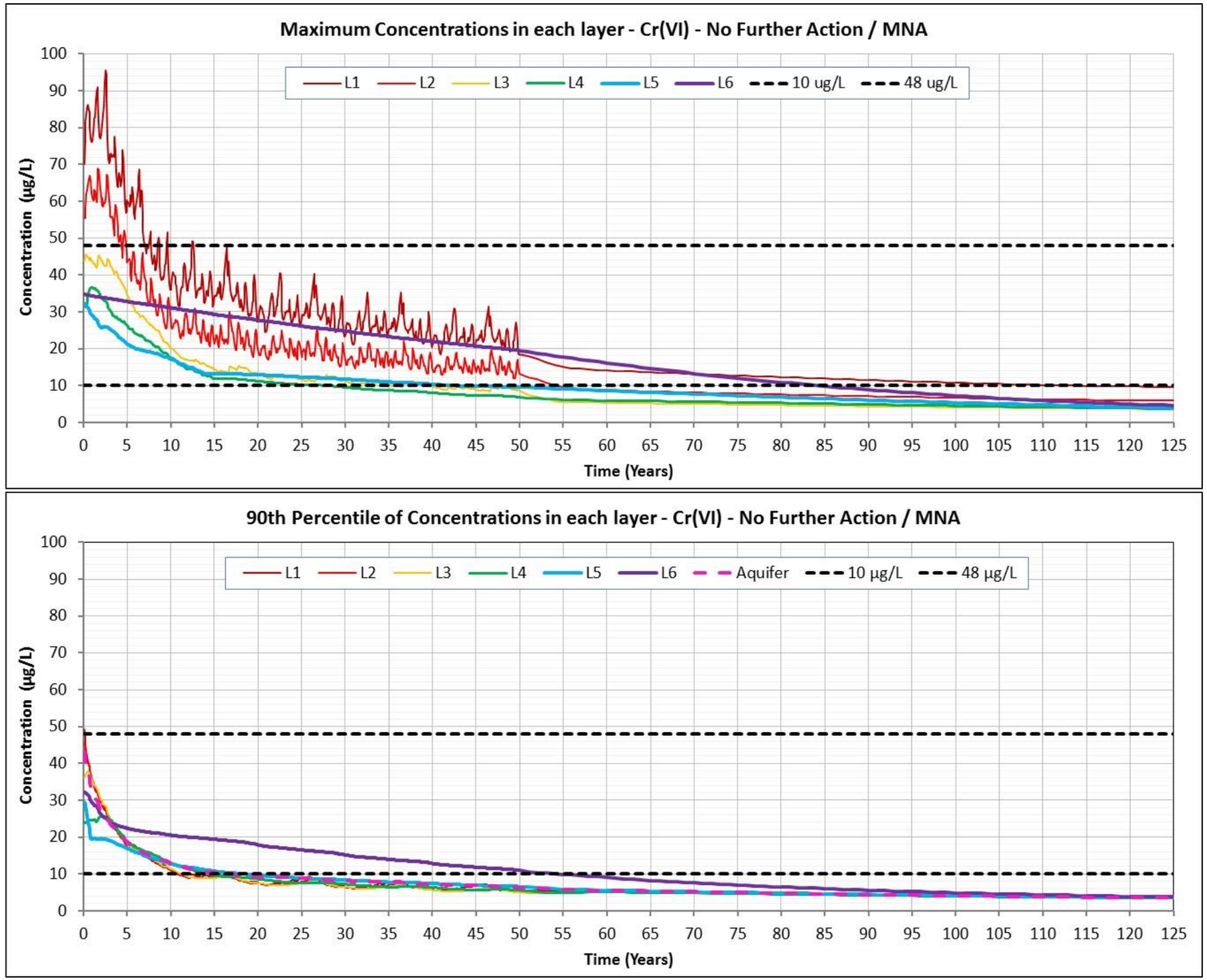


Figure 7-54. Simulated Distribution of Cr(VI) After 120 Years - P&T with Cr(VI) Source Treatment



1 **Figure 7-55. Cr(VI): Concentration Statistics in Each Model Layer – No Further Action or MNA**

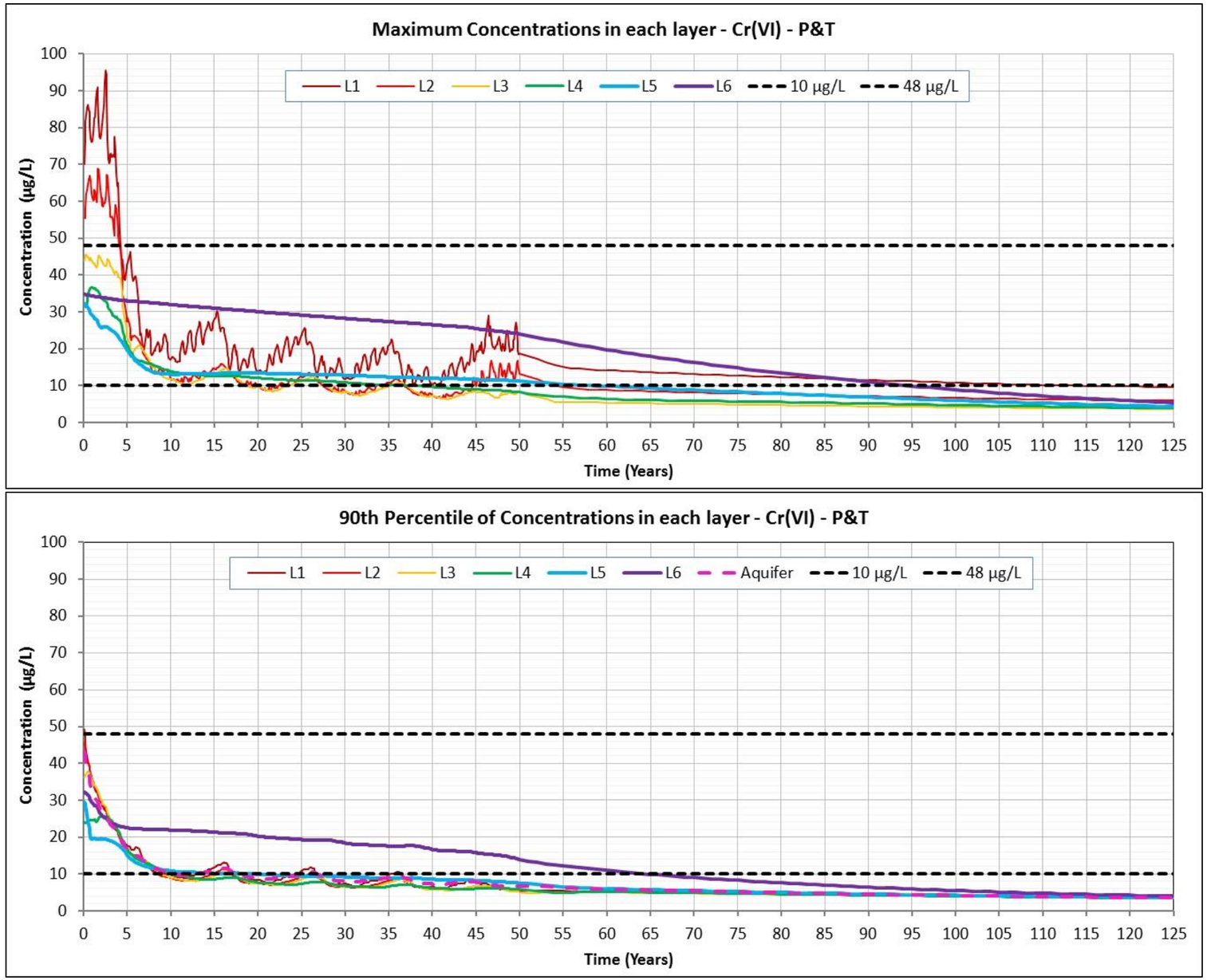


Figure 7-56. Cr(VI): Concentration Statistics in Each Model Layer – P&T

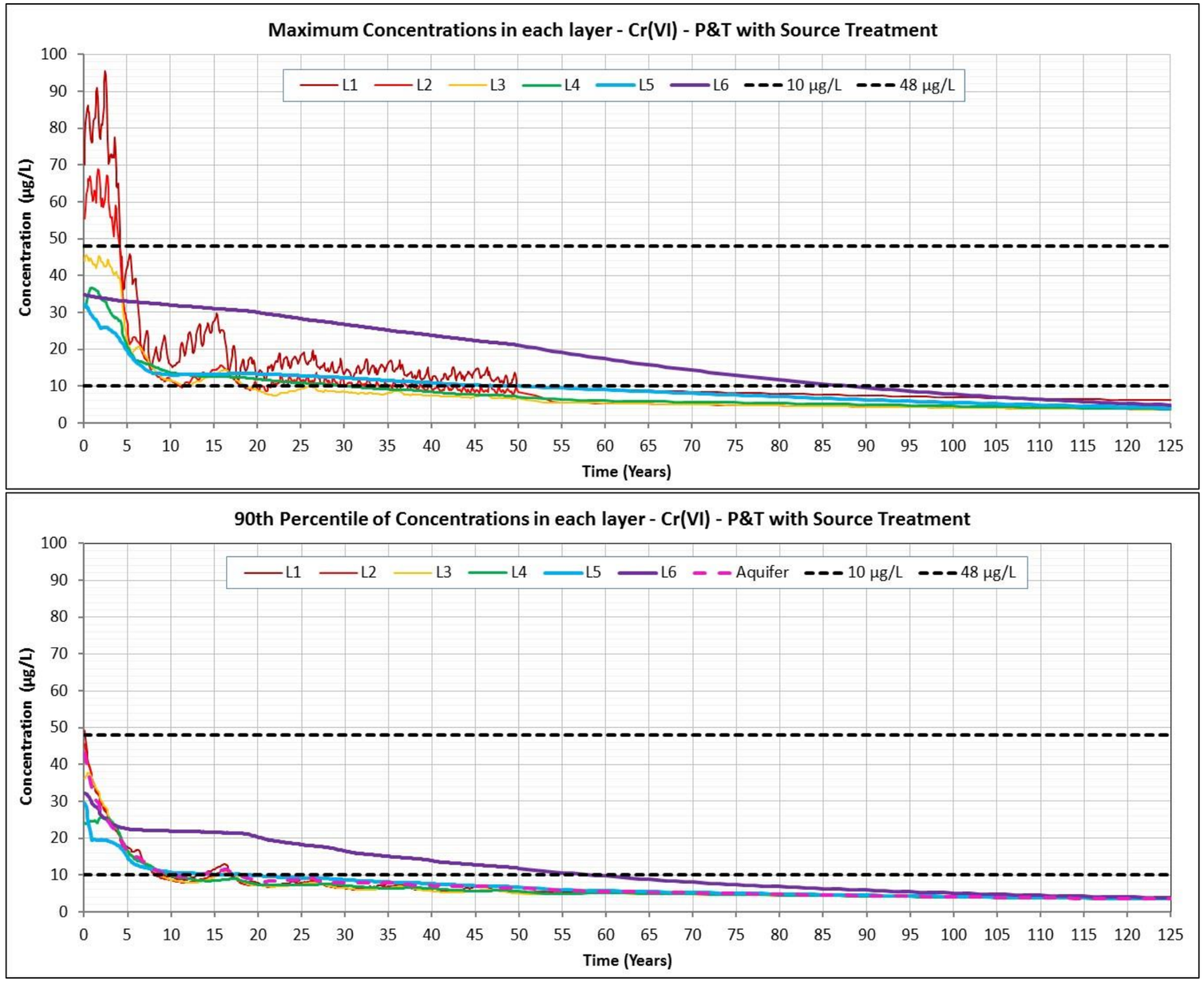


Figure 7-57. Cr(VI): Concentration Statistics in Each Model Layer – P&T with Cr(VI) Source Treatment

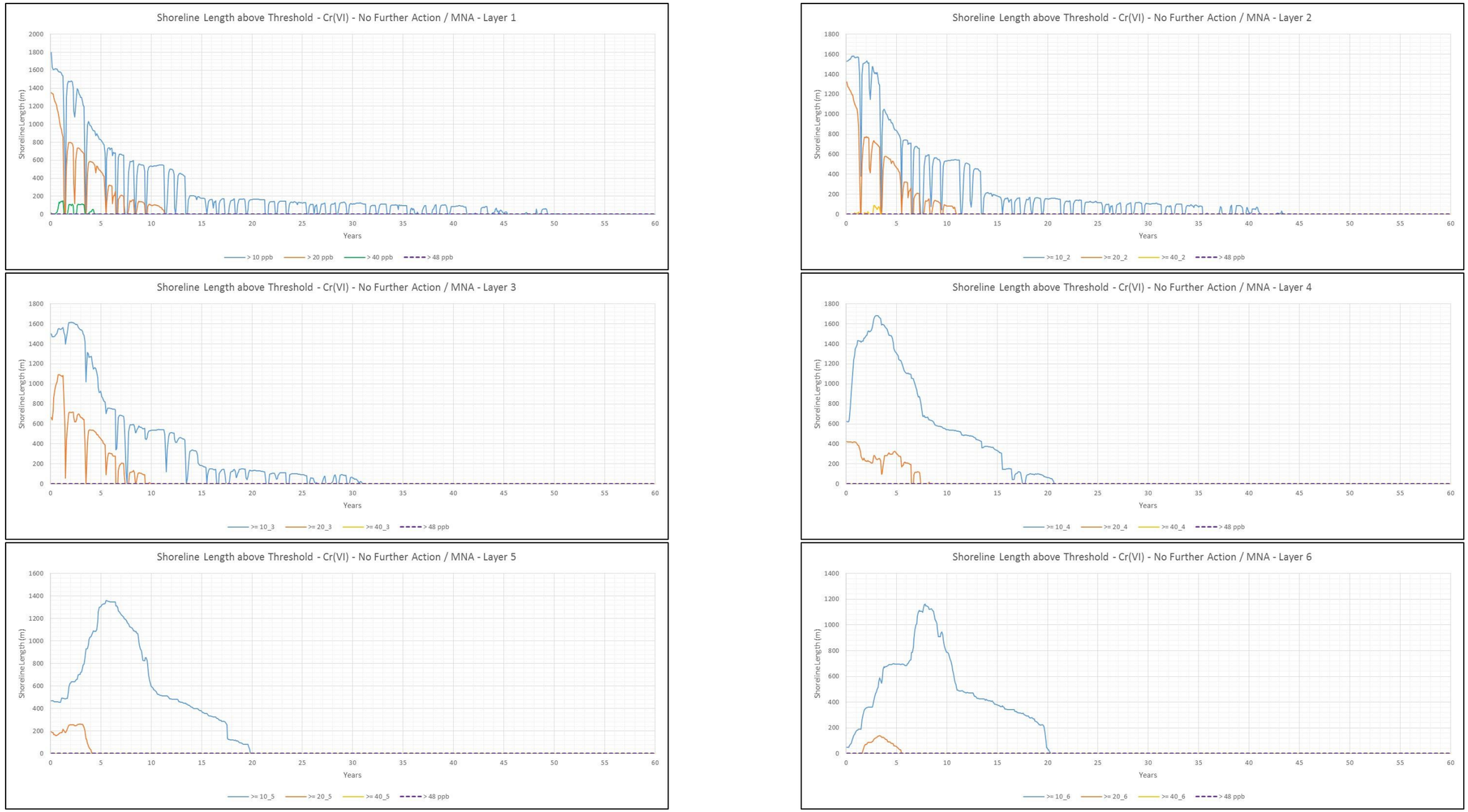


Figure 7-58. Cr(VI): Shoreline Impacted Length in Each Model Layer – No Further Action of MNA

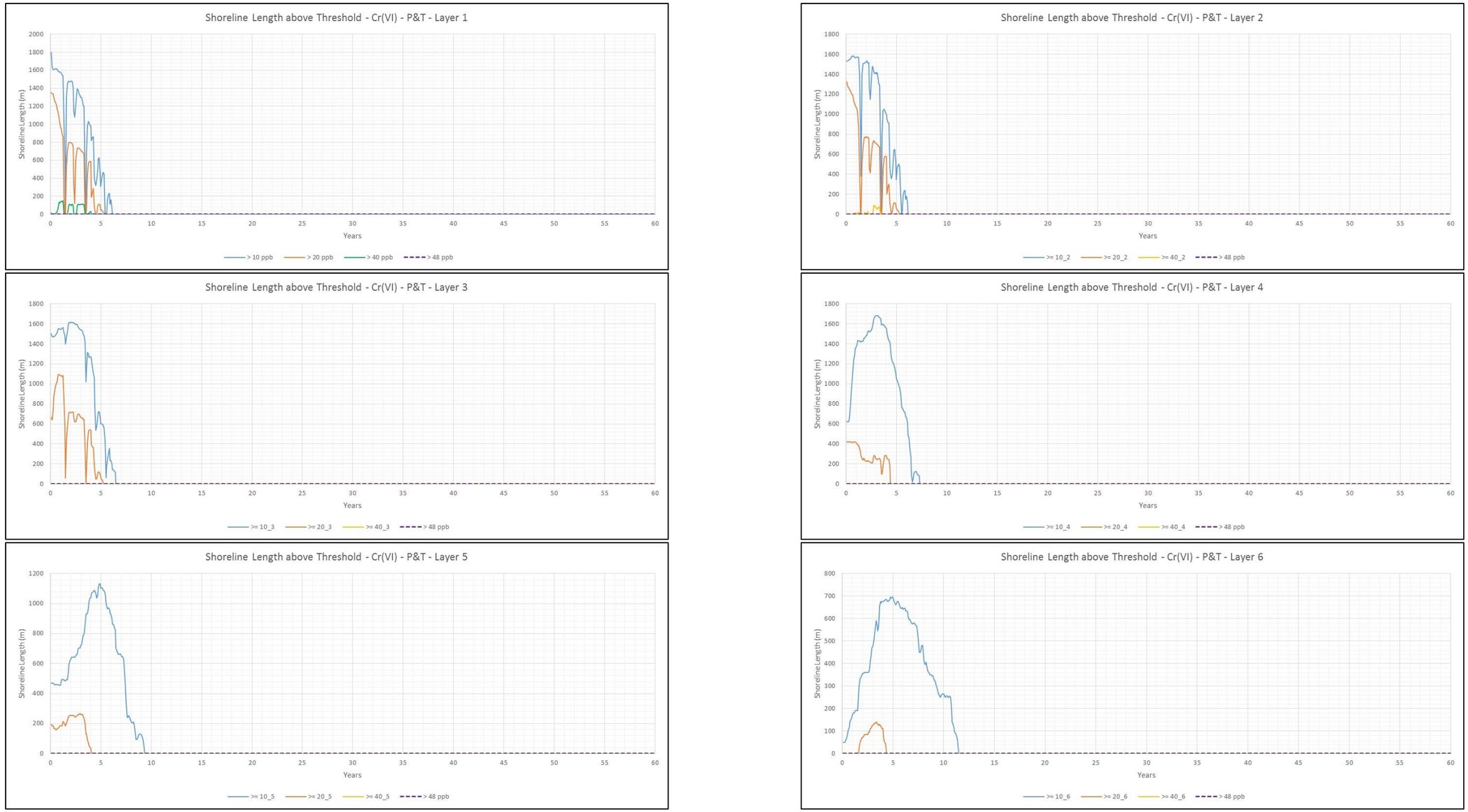


Figure 7-59. Cr(VI): Shoreline Impacted Length in Each Model Layer – P&T

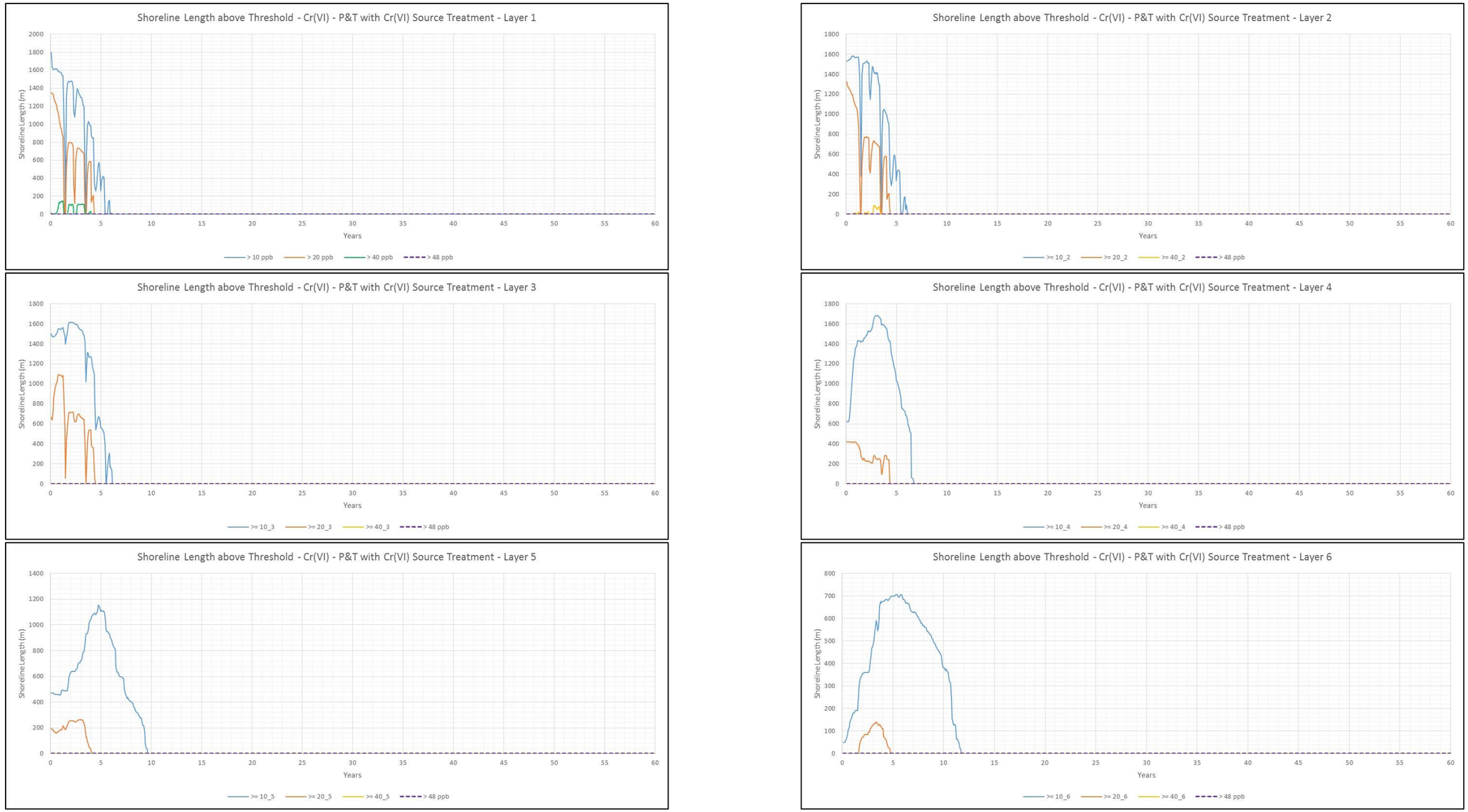


Figure 7-60. Cr(VI): Shoreline Impacted Length in Each Model Layer – P&T with Cr(VI) Source Treatment

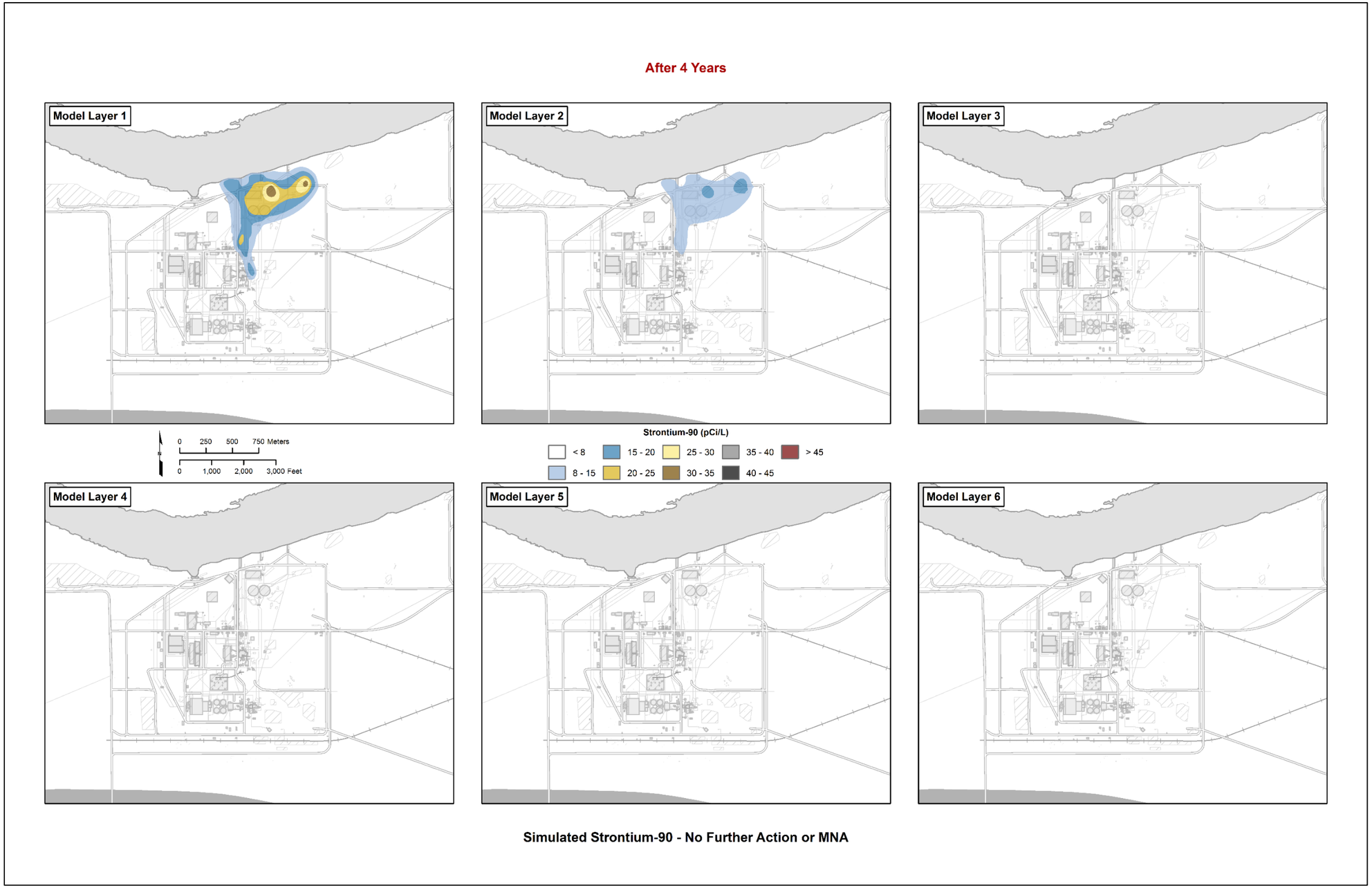


Figure 7-61. Simulated Distribution of Strontium-90 After 4 Years – No Further Action or MNA

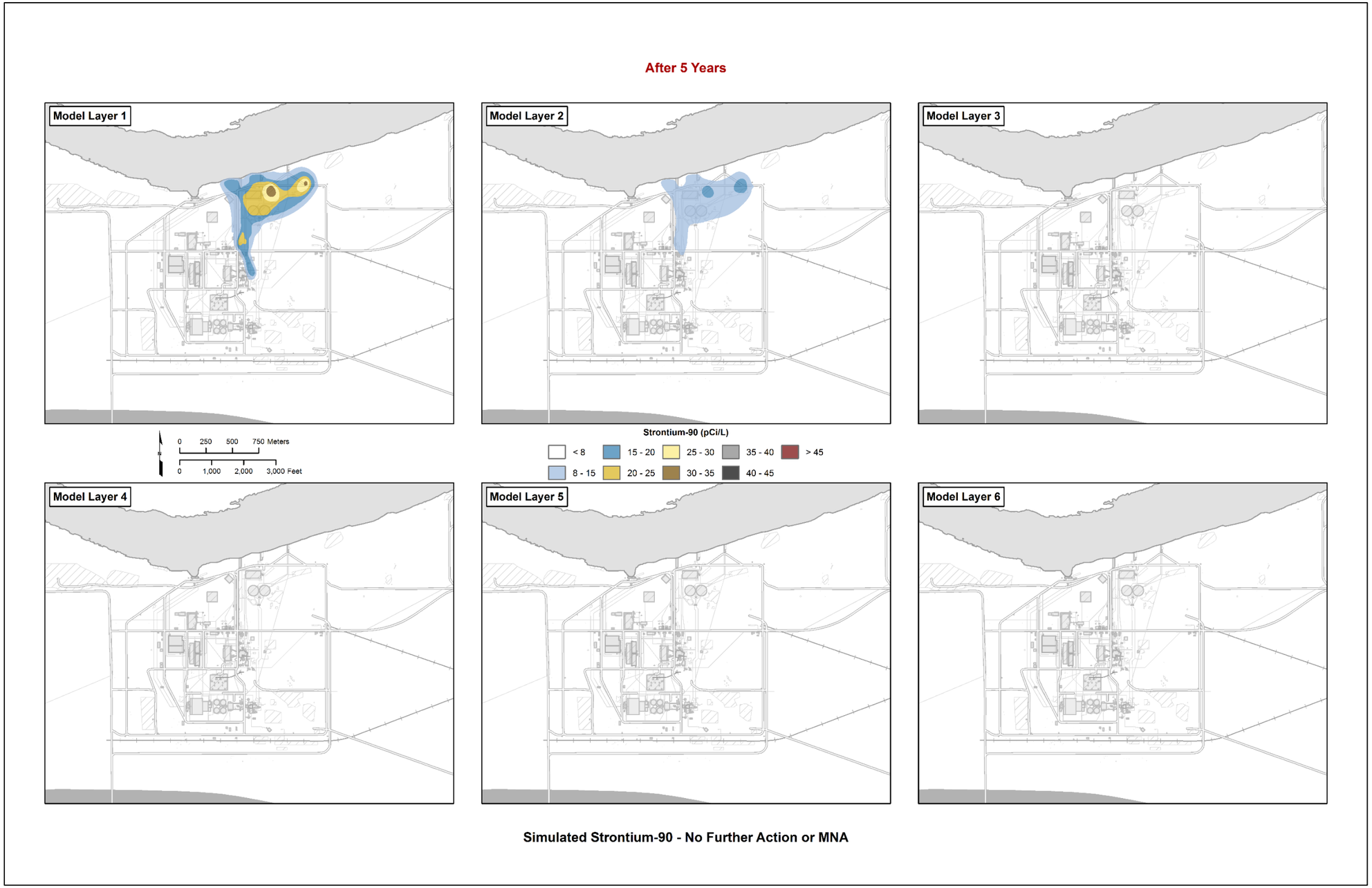


Figure 7-62. Simulated Distribution of Strontium-90 After 5 Years - No Further Action or MNA

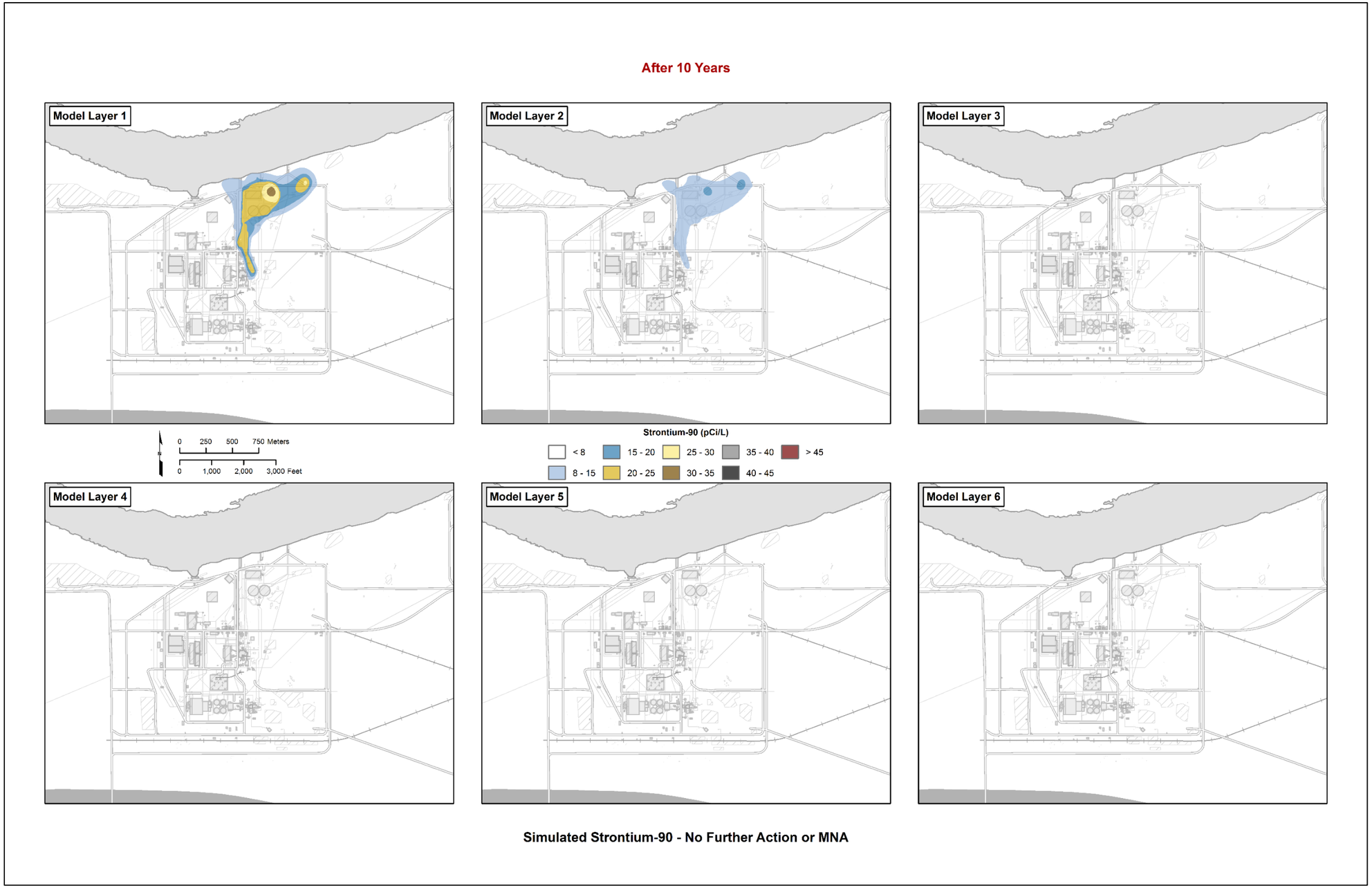


Figure 7-63. Simulated Distribution of Strontium-90 After 10 Years - No Further Action or MNA

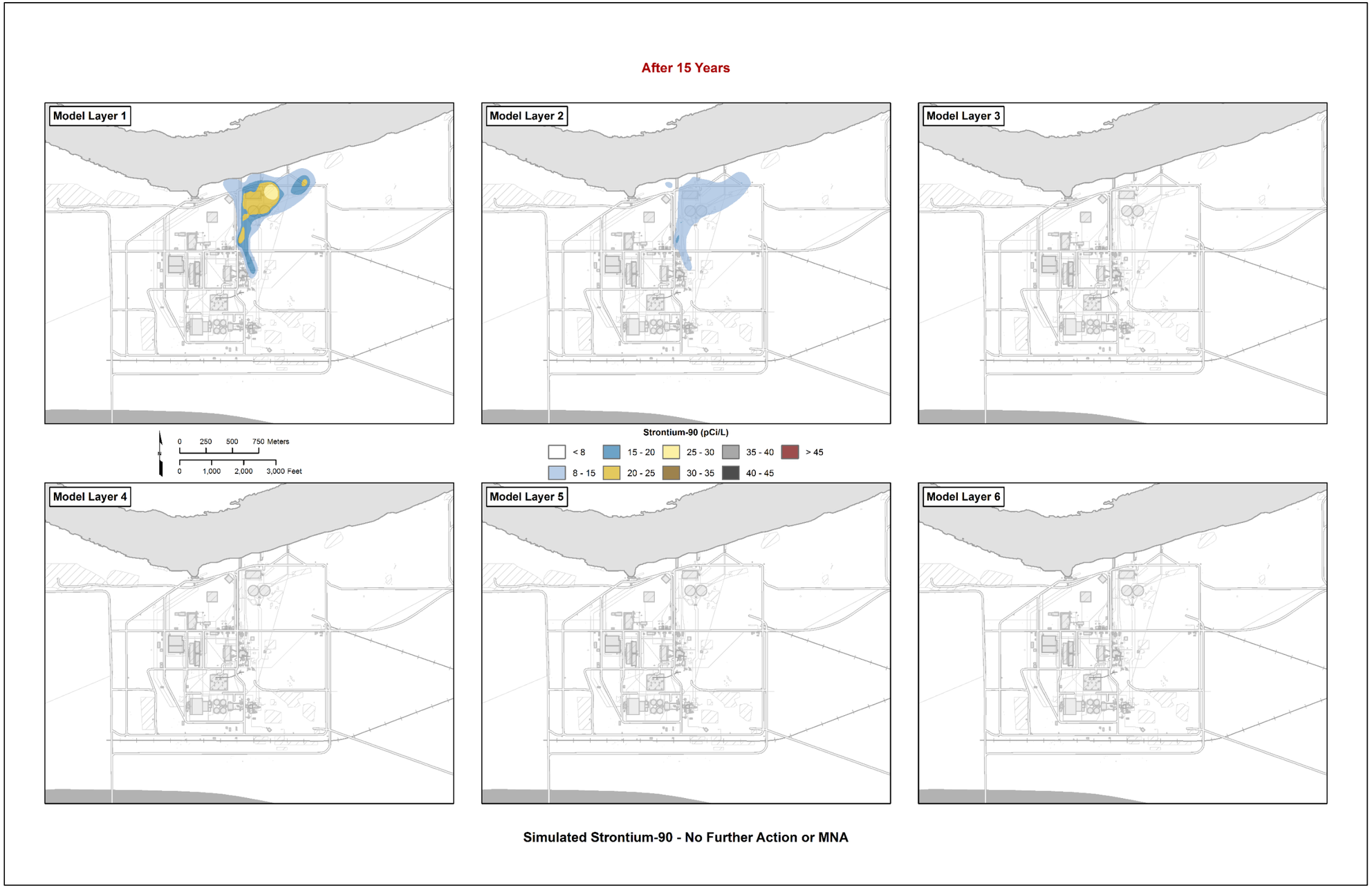


Figure 7-64. Simulated Distribution of Strontium-90 After 15 Years - No Further Action or MNA

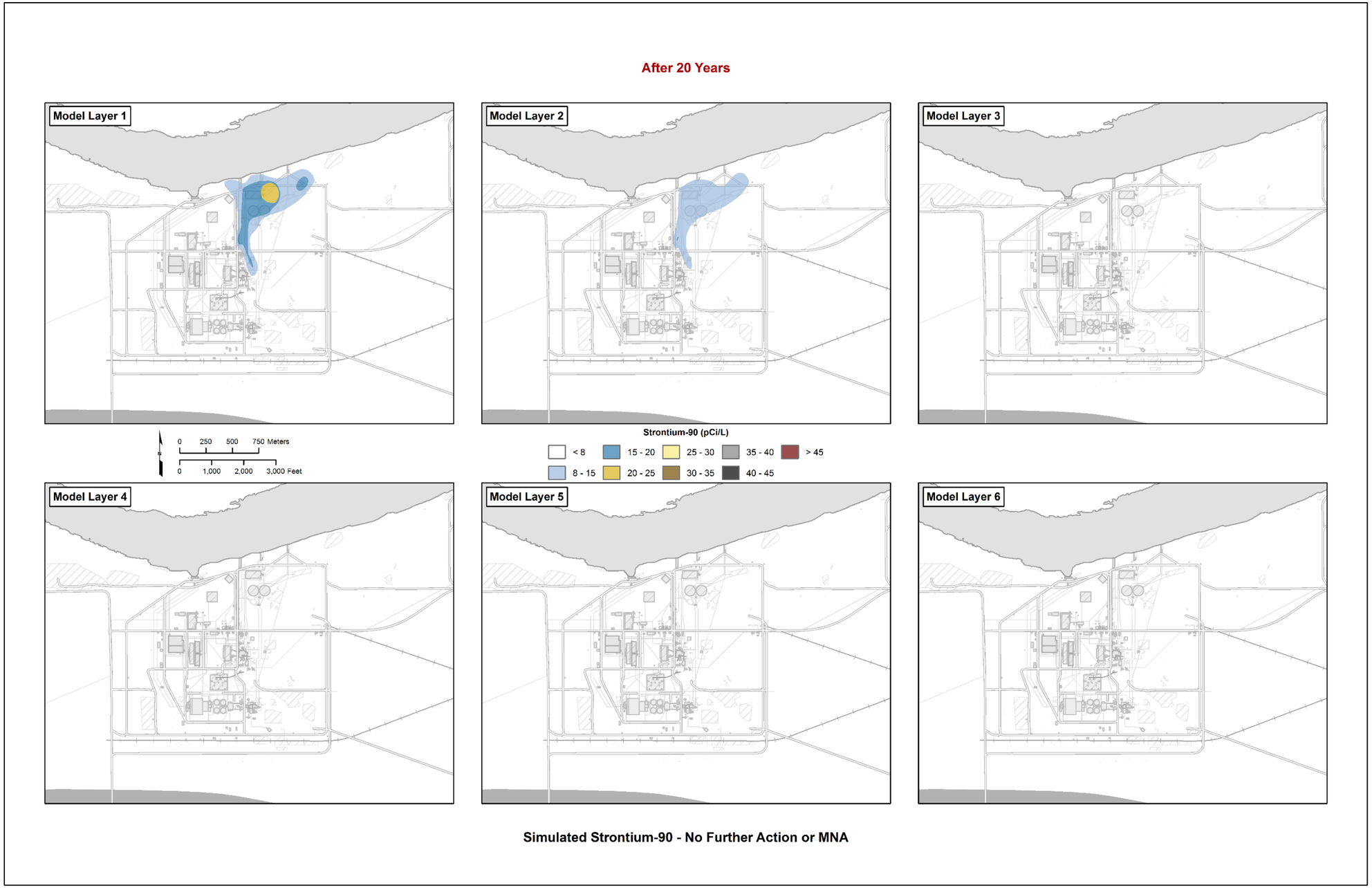


Figure 7-65. Simulated Distribution of Strontium-90 After 20 Years - No Further Action or MNA

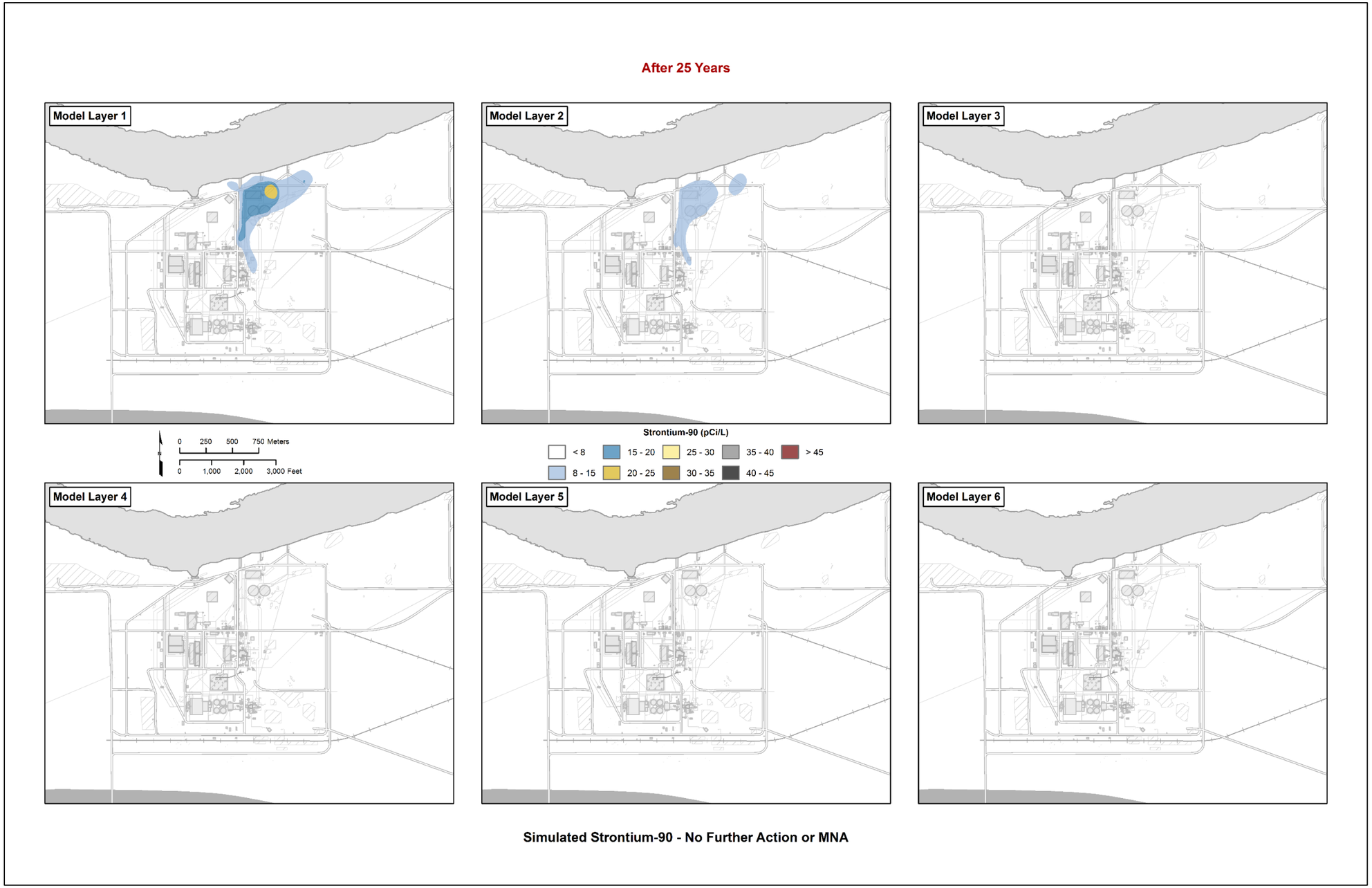


Figure 7-66. Simulated Distribution of Strontium-90 After 25 Years - No Further Action or MNA

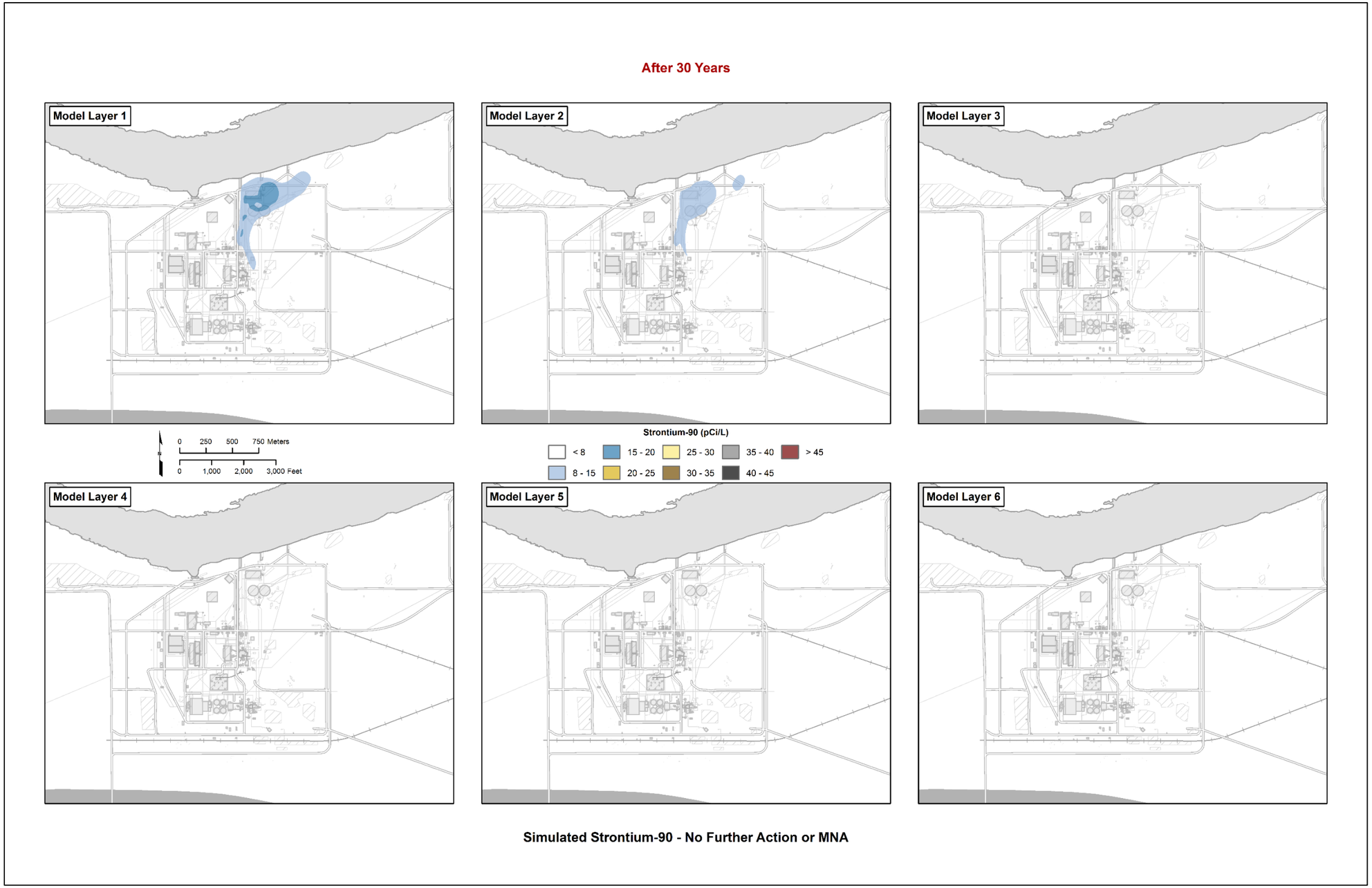


Figure 7-67. Simulated Distribution of Strontium-90 After 30 Years - No Further Action or MNA

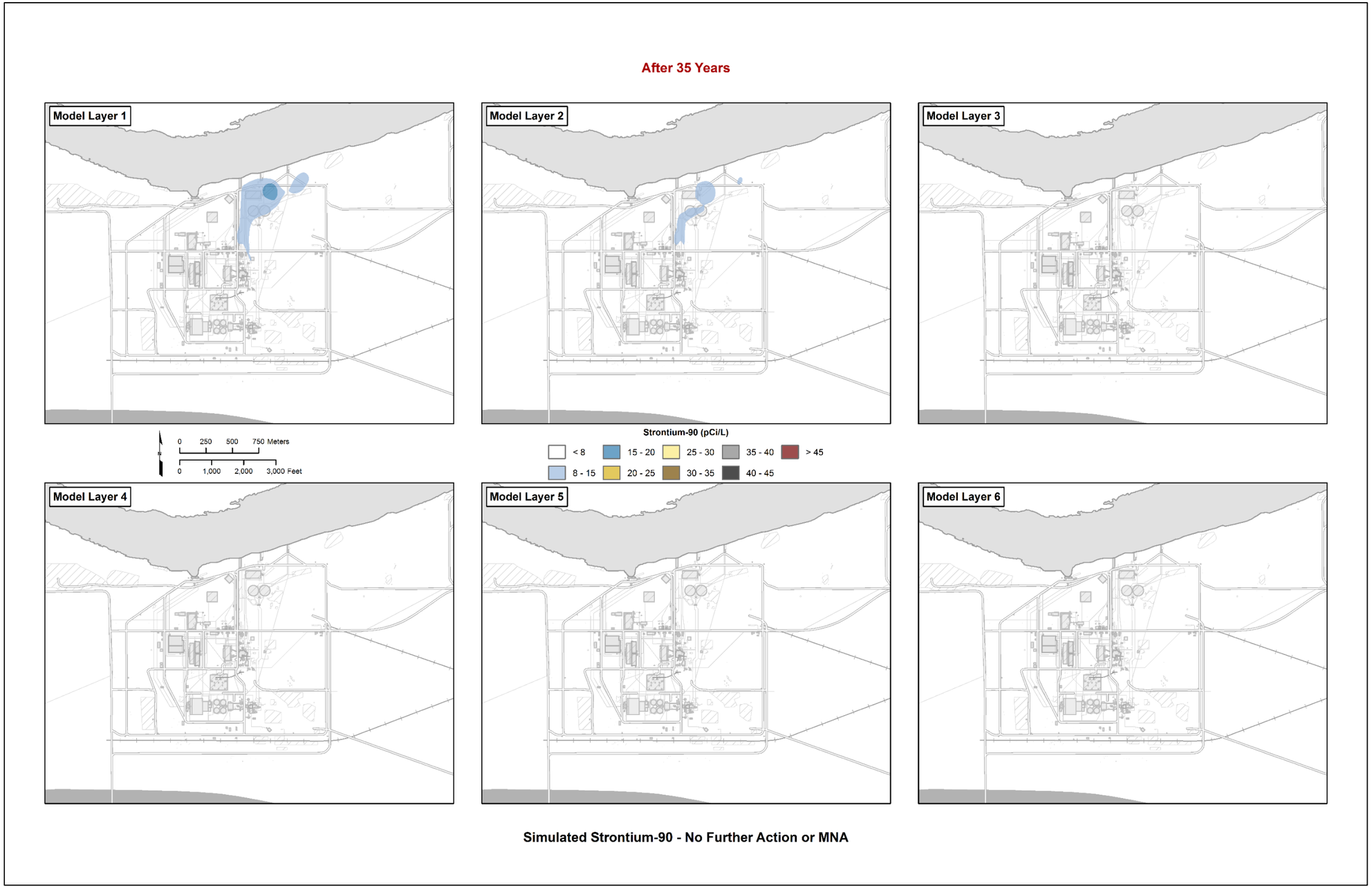


Figure 7-68. Simulated Distribution of Strontium-90 After 35 Years - No Further Action or MNA

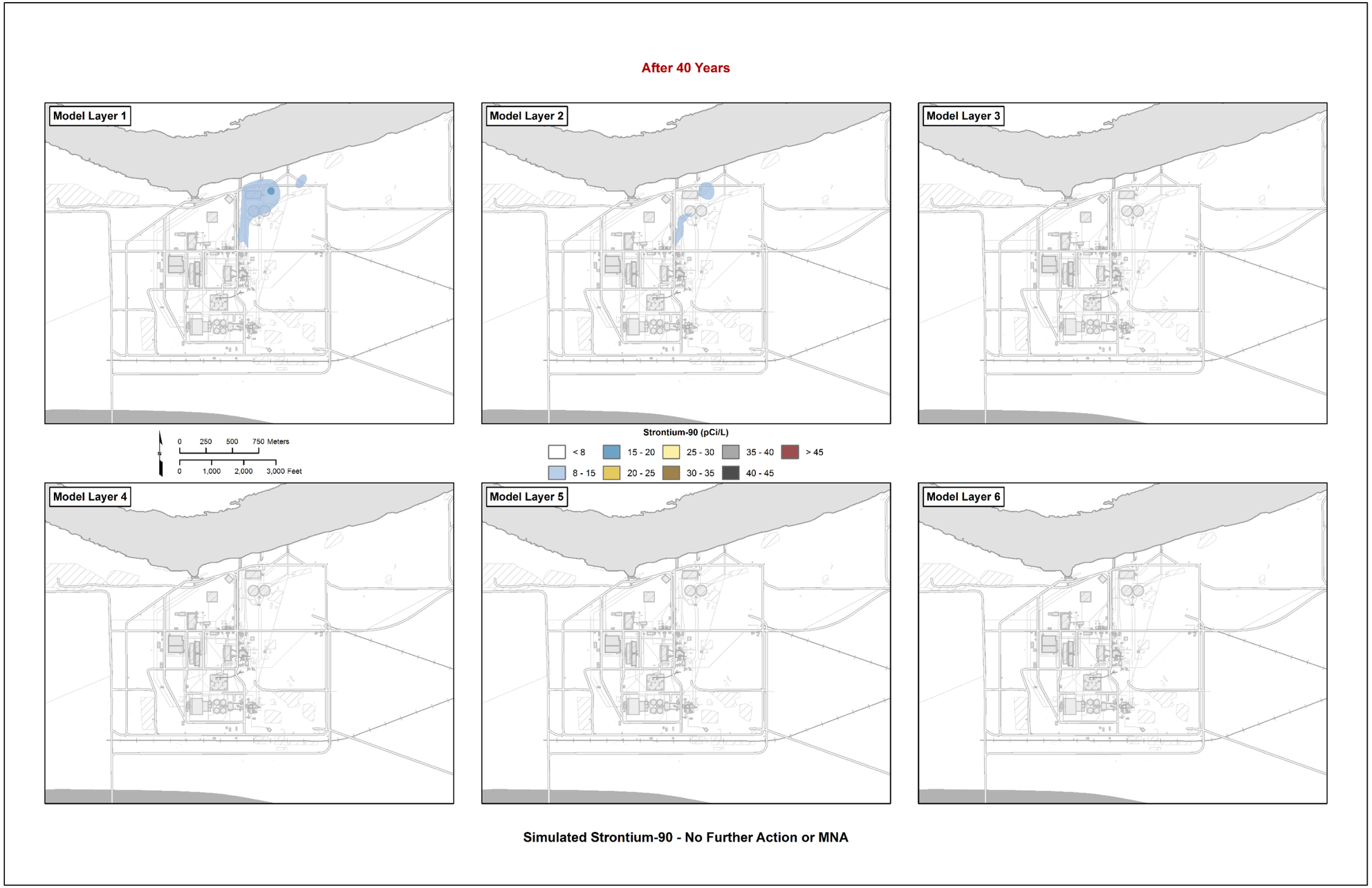


Figure 7-69. Simulated Distribution of Strontium-90 After 40 Years - No Further Action or MNA

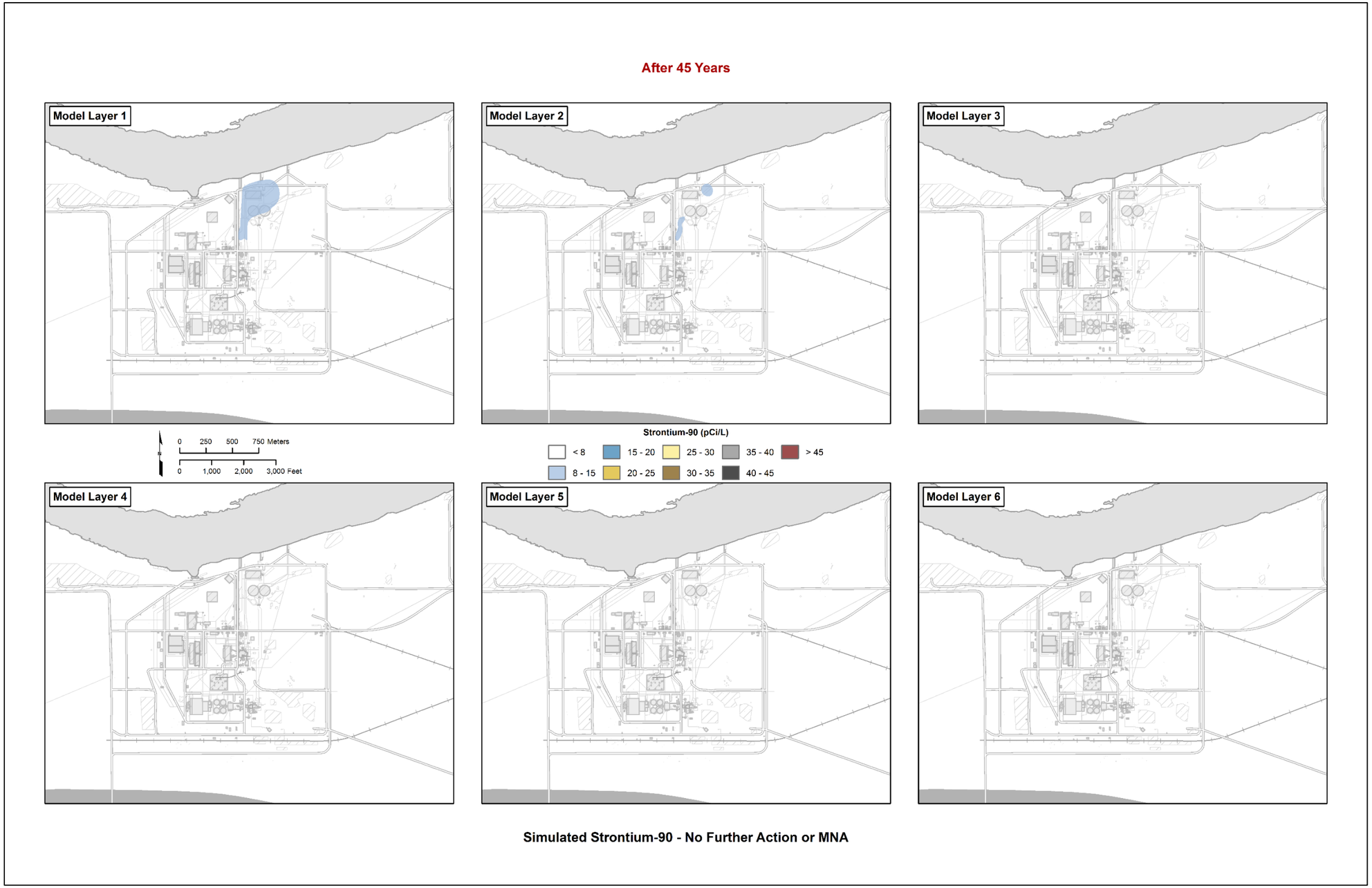


Figure 7-70. Simulated Distribution of Strontium-90 After 45 Years - No Further Action or MNA

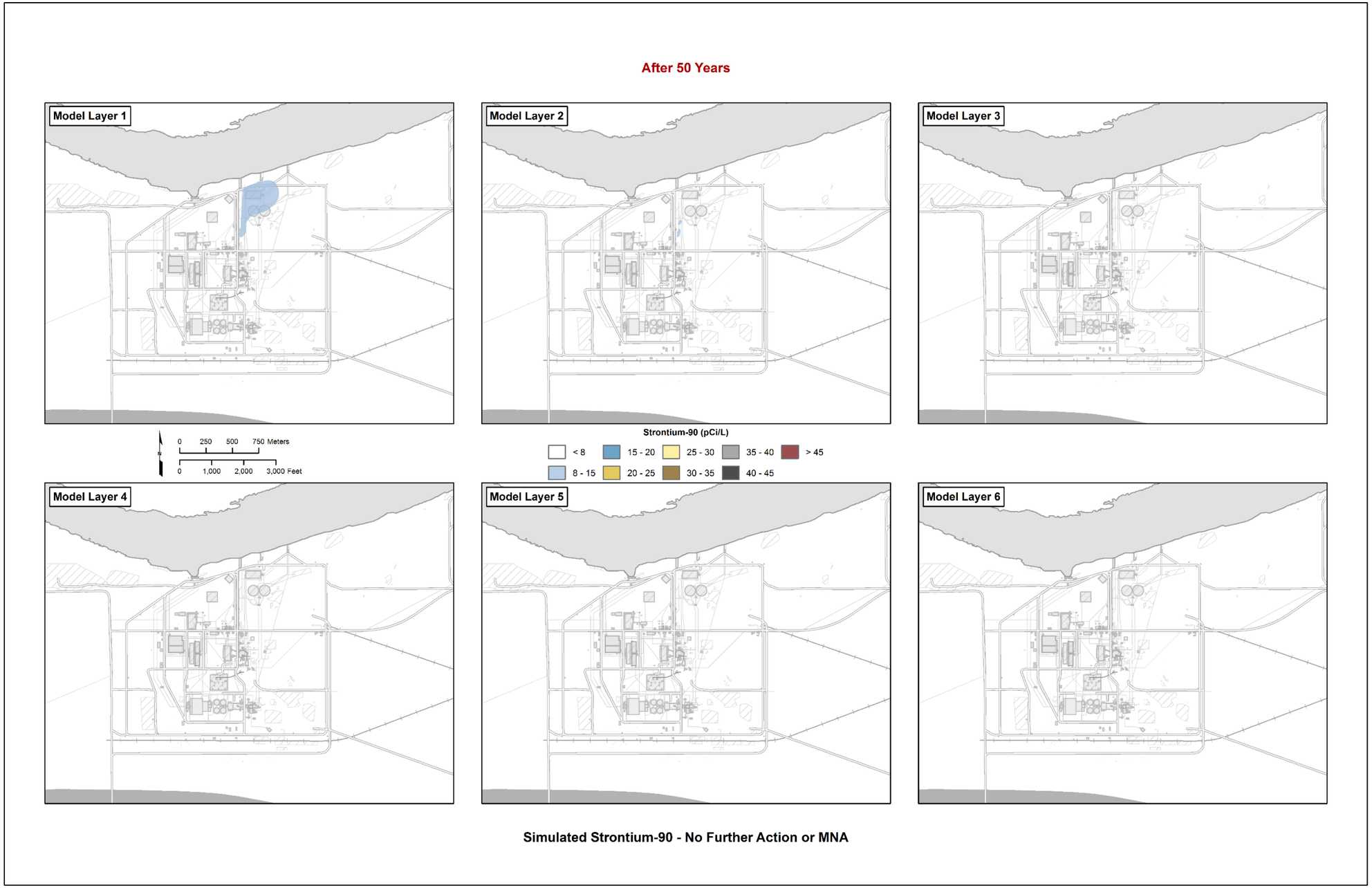


Figure 7-71. Simulated Distribution of Strontium-90 After 50 Years - No Further Action or MNA

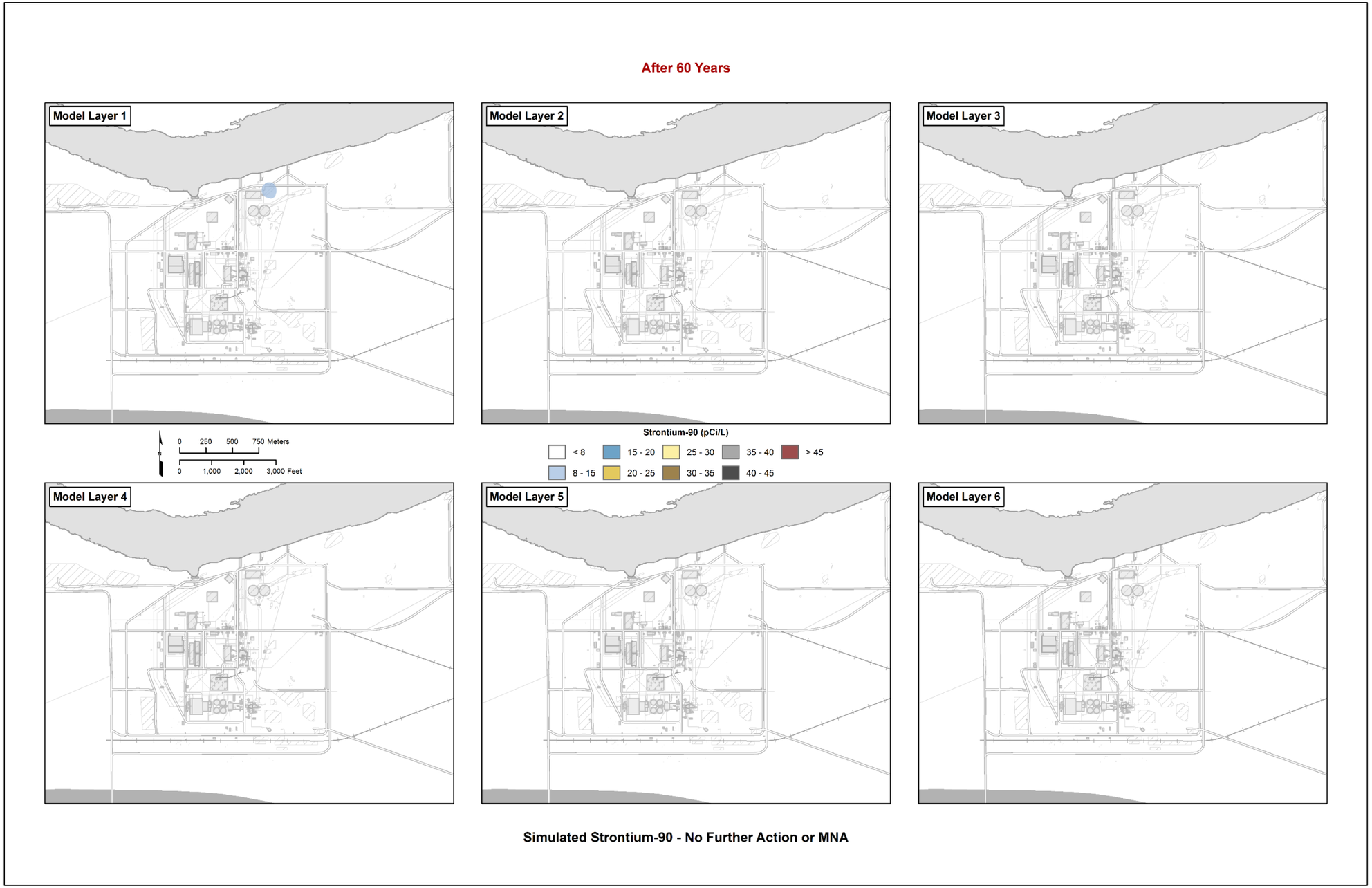


Figure 7-72. Simulated Distribution of Strontium-90 After 60 Years - No Further Action or MNA

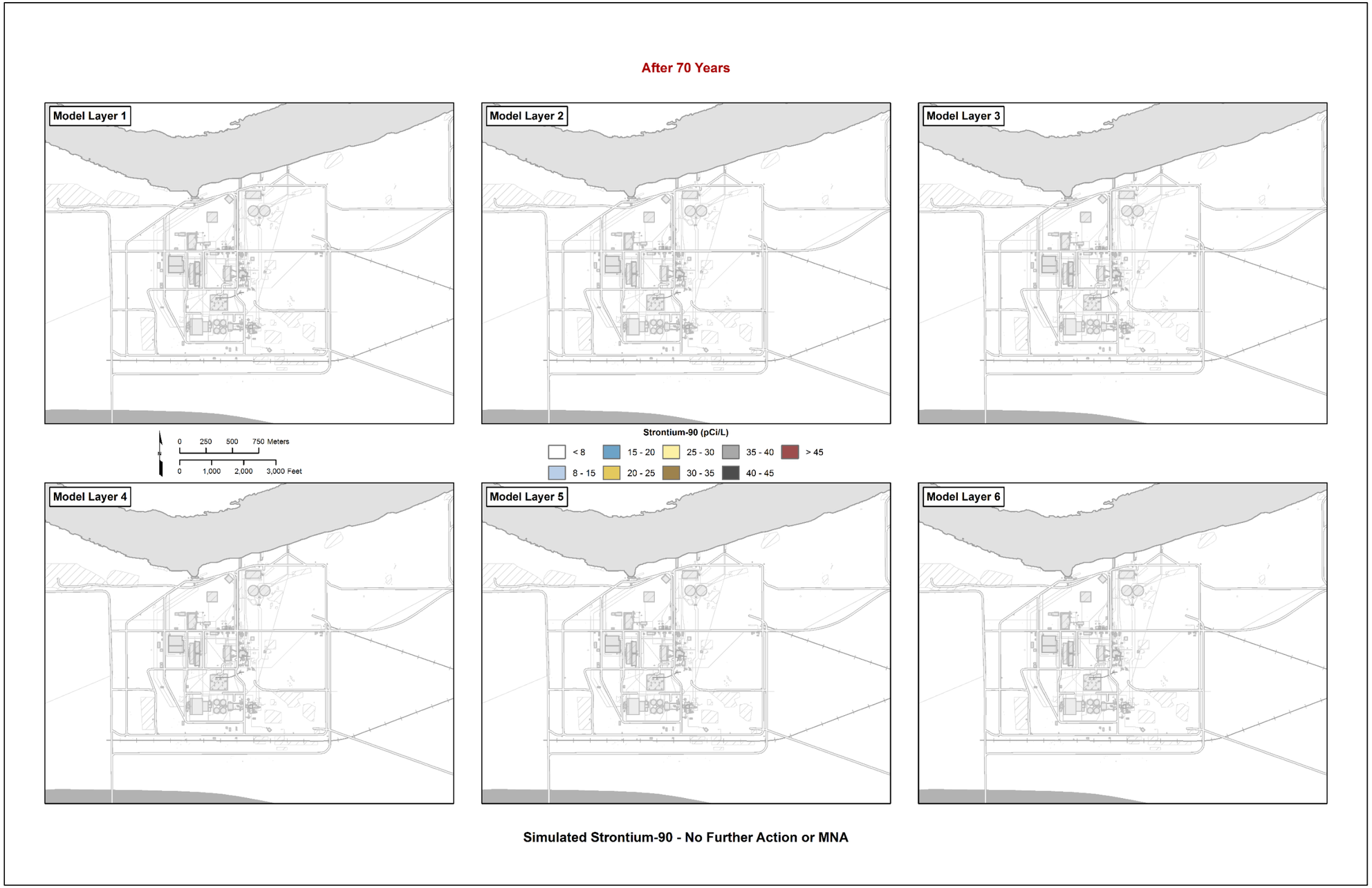


Figure 7-73. Simulated Distribution of Strontium-90 After 70 Years - No Further Action or MNA

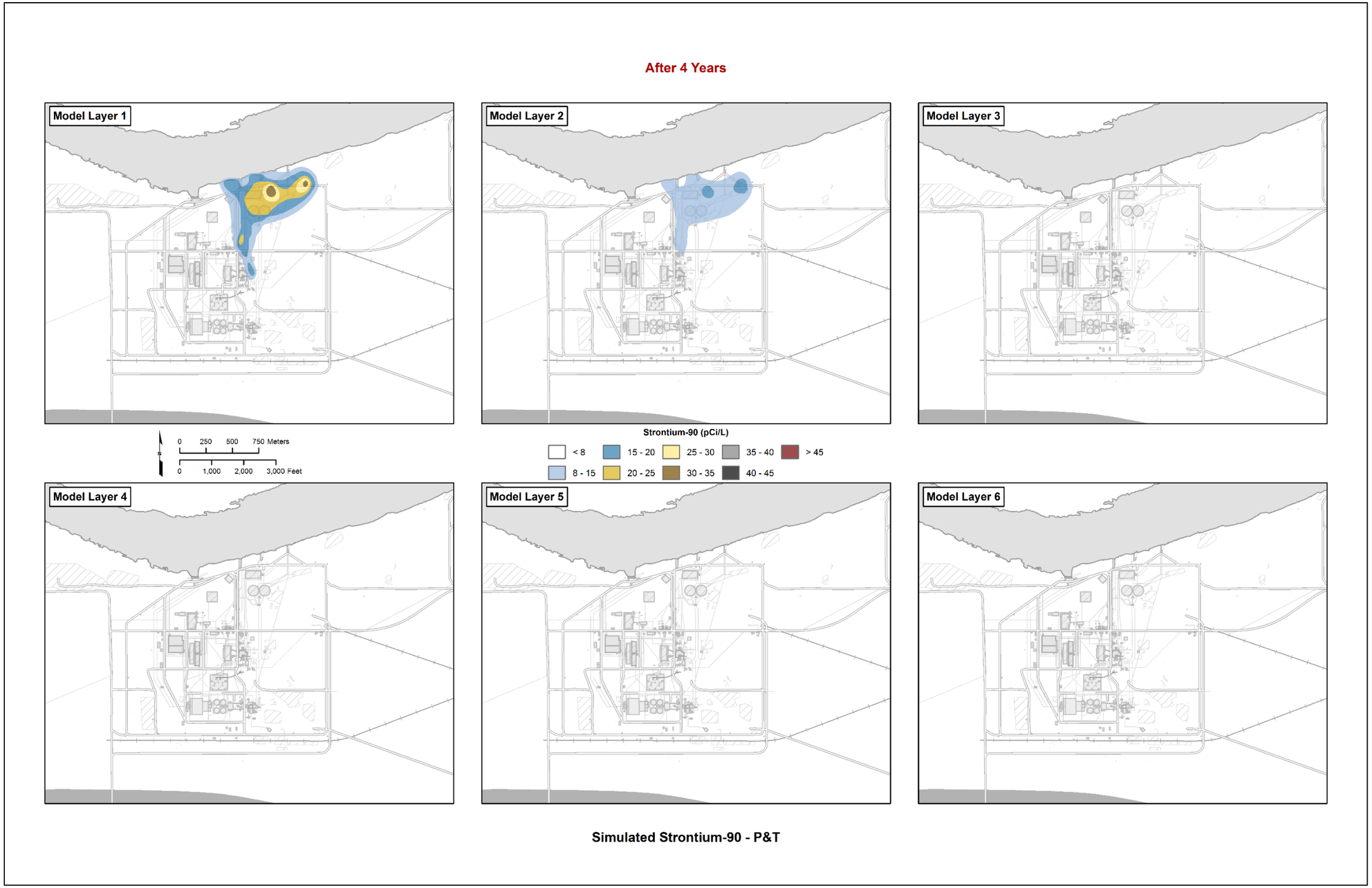


Figure 7-74. Simulated Distribution of Strontium-90 After 4 Years – P&T

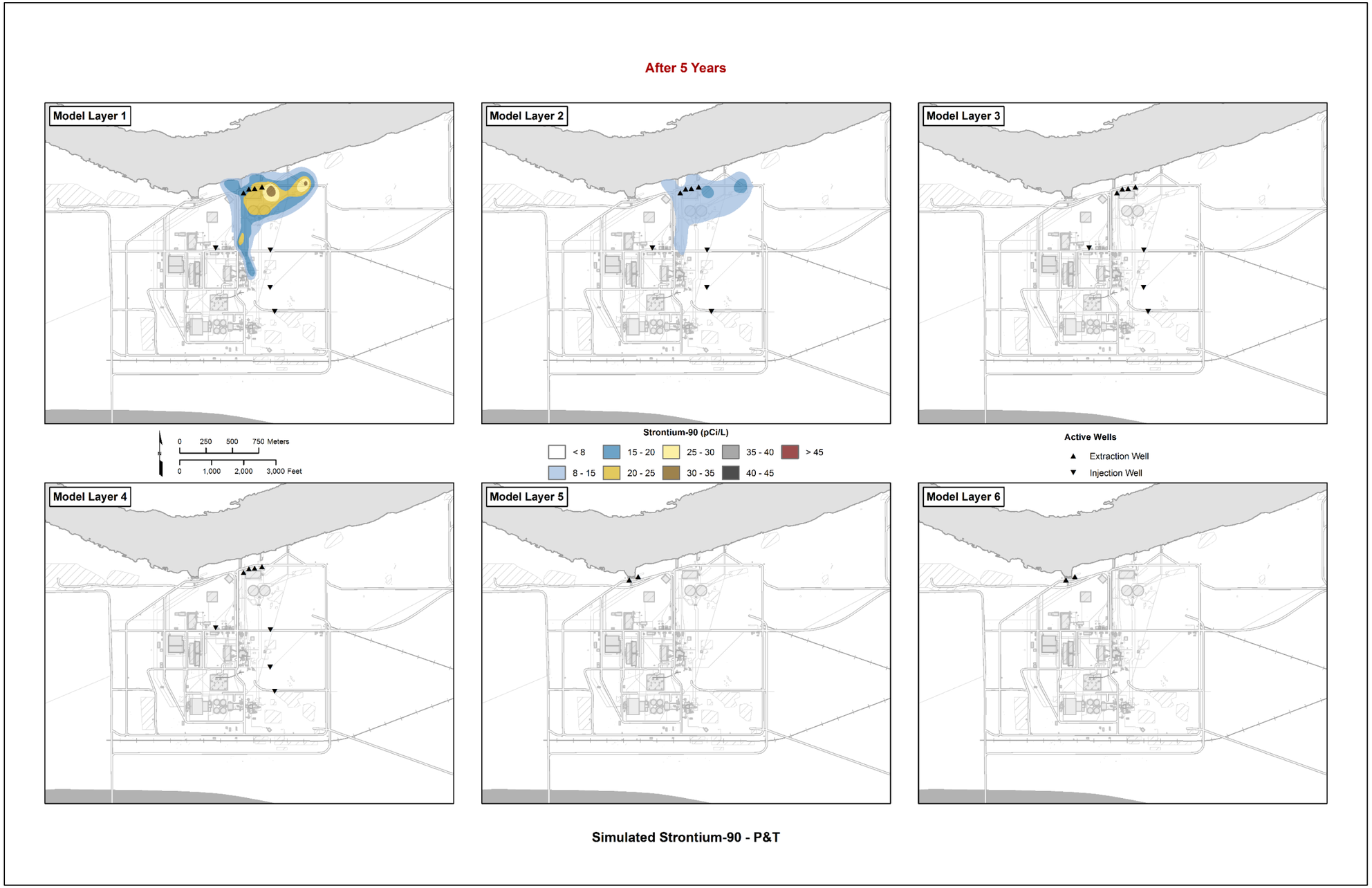


Figure 7-75. Simulated Distribution of Strontium-90 After 5 Years – P&T

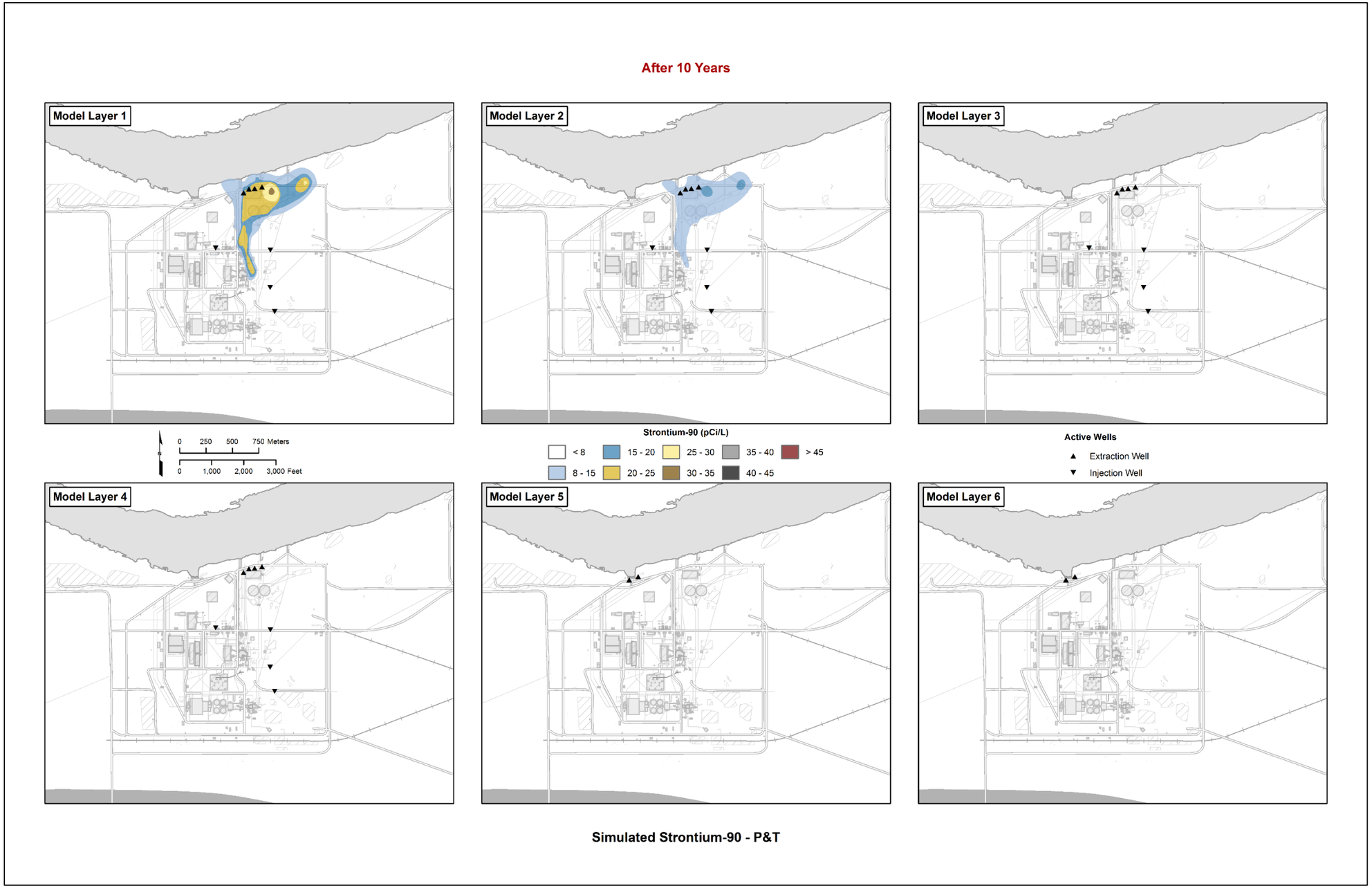


Figure 7-76. Simulated Distribution of Strontium-90 After 10 Years - P&T

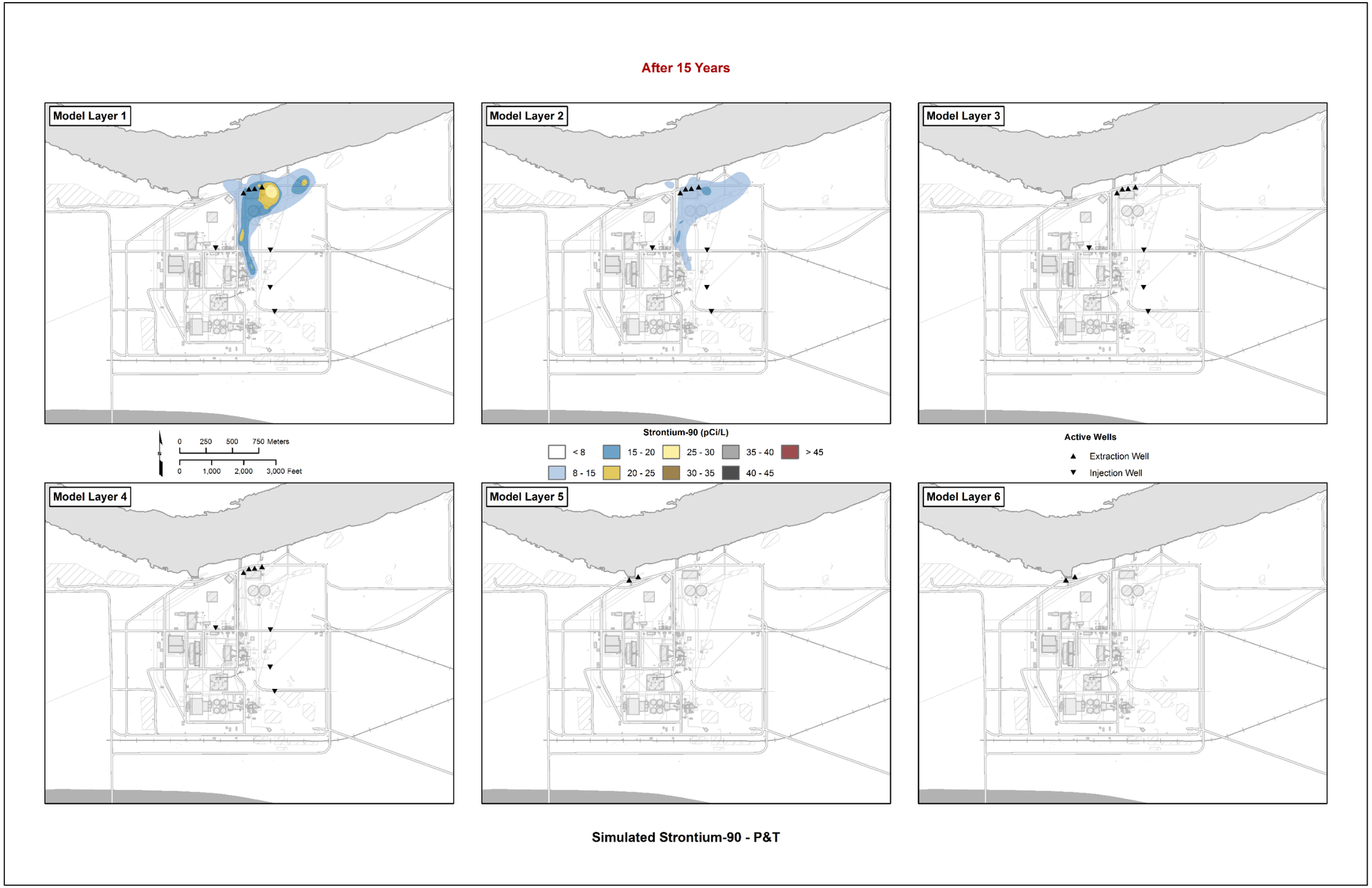


Figure 7-77. Simulated Distribution of Strontium-90 After 15 Years - P&T

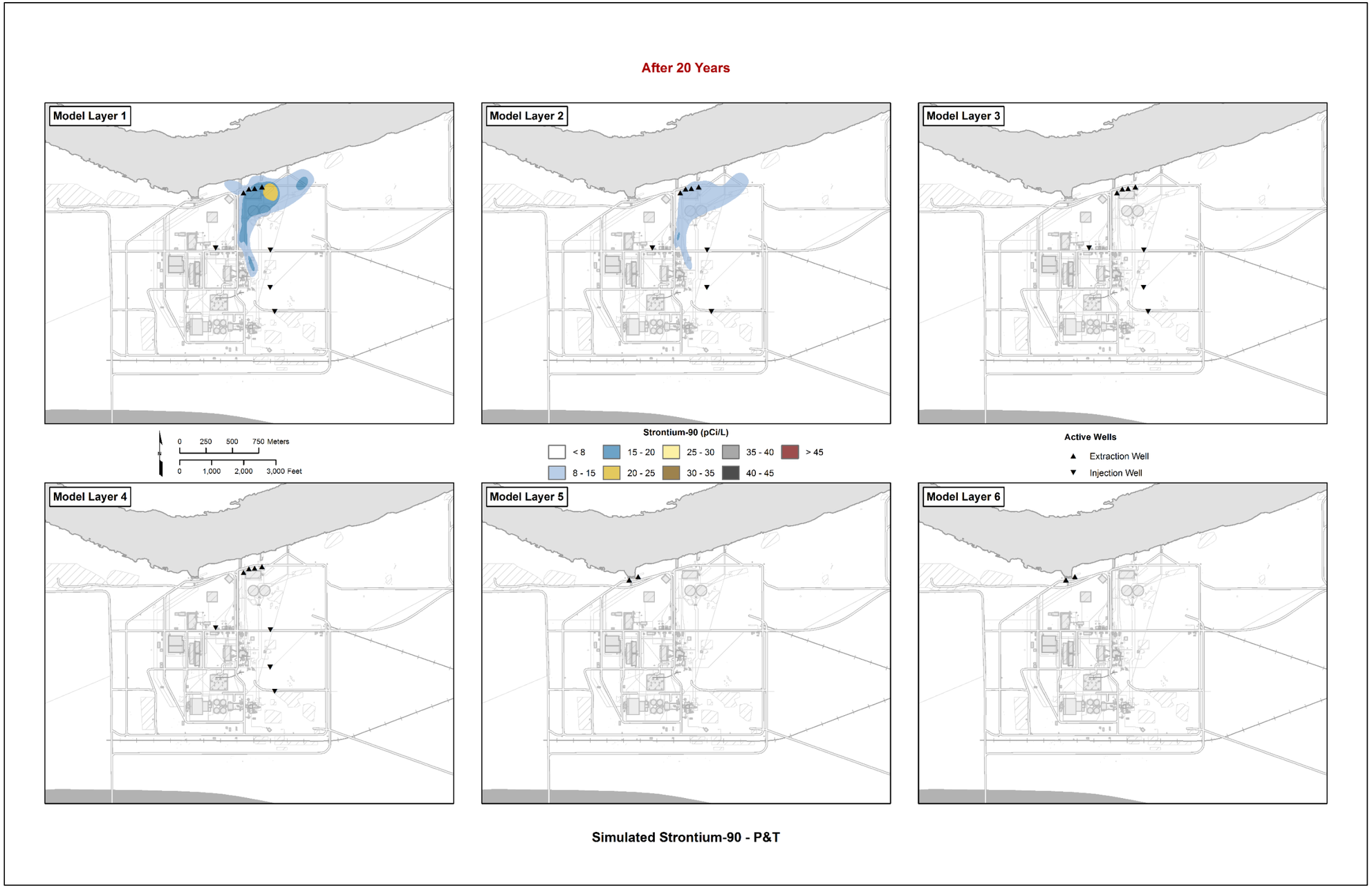


Figure 7-78. Simulated Distribution of Strontium-90 After 20 Years - P&T

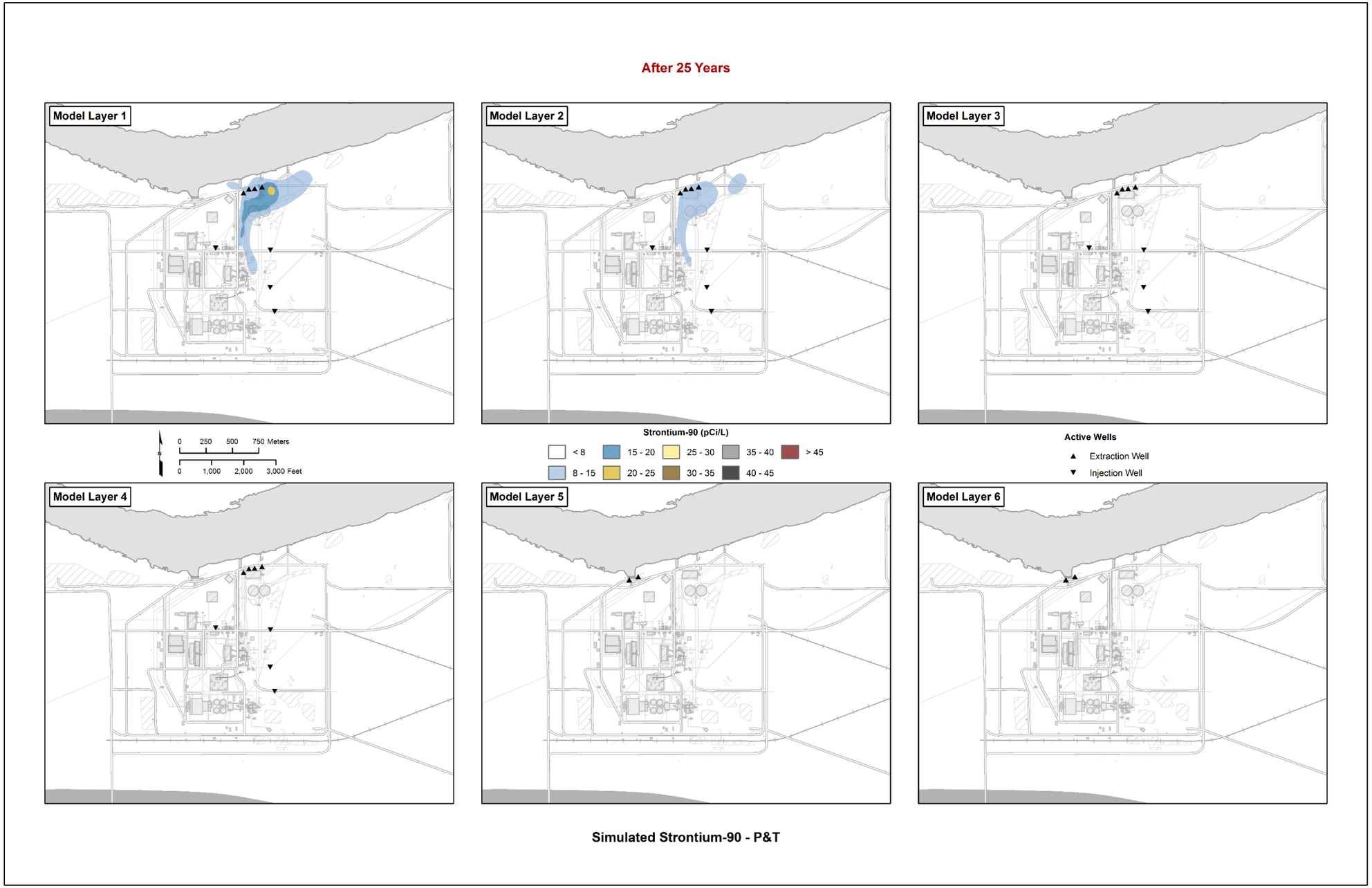


Figure 7-79. Simulated Distribution of Strontium-90 After 25 Years - P&T

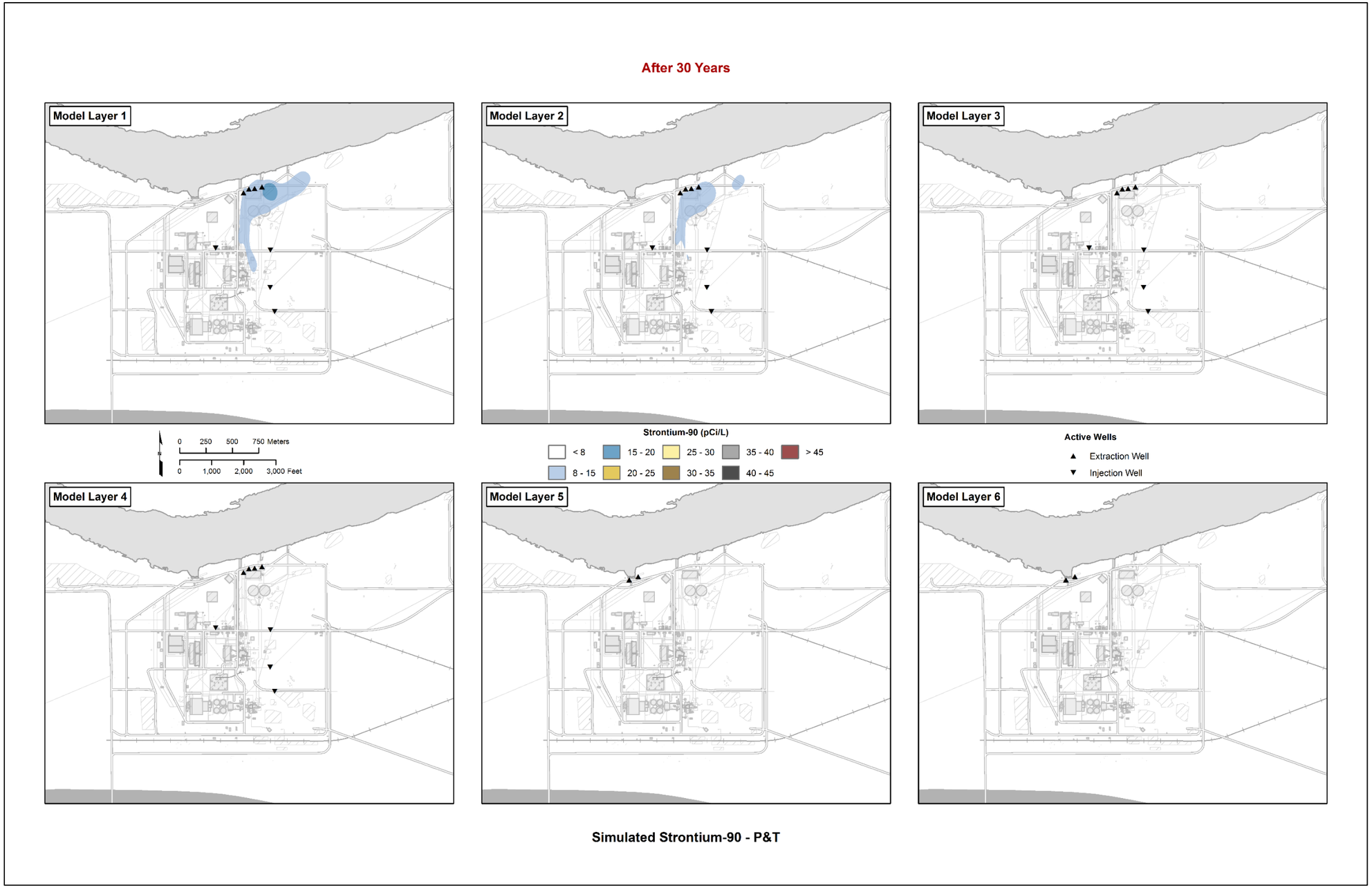


Figure 7-80. Simulated Distribution of Strontium-90 After 30 Years - P&T

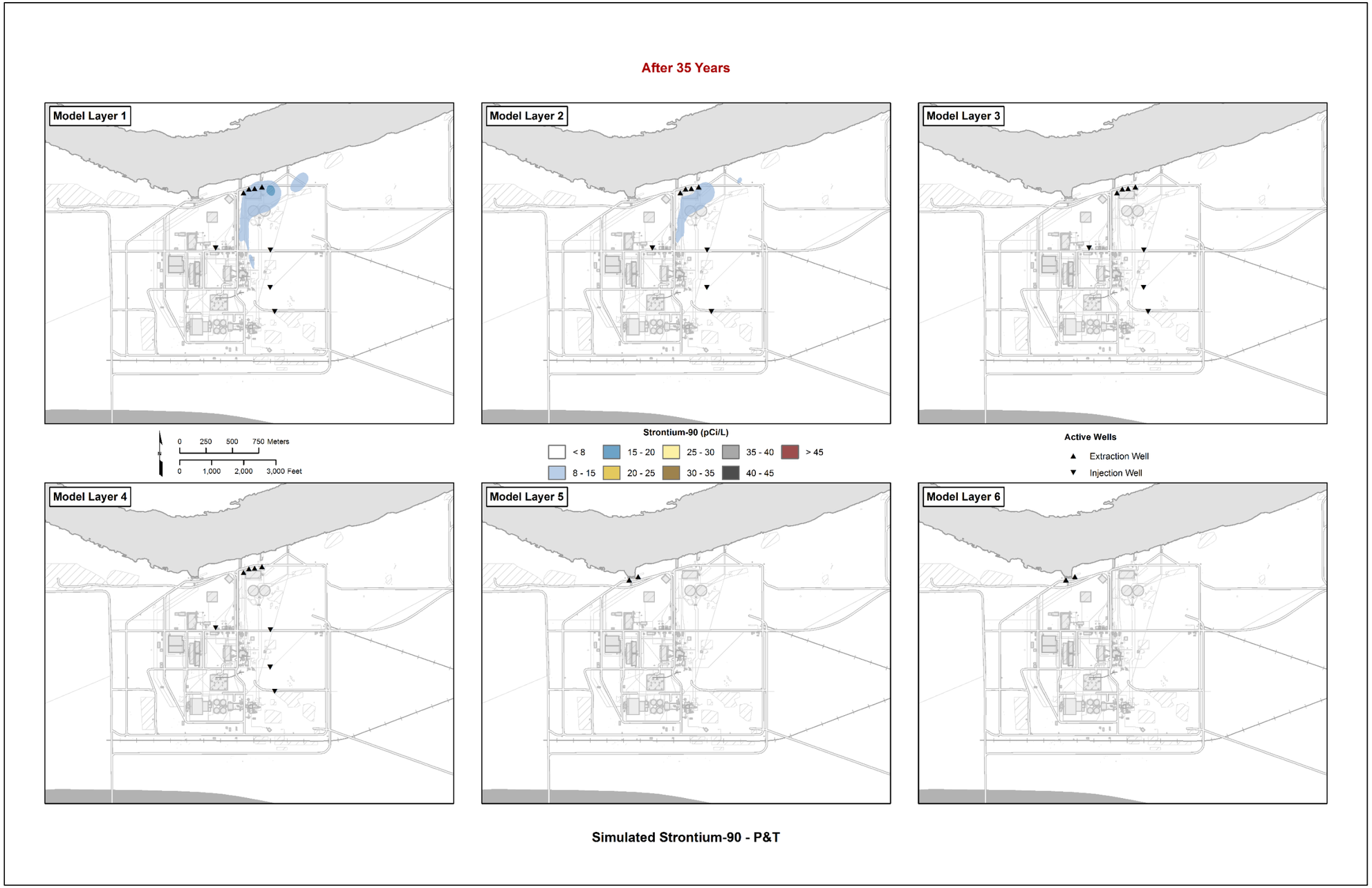


Figure 7-81. Simulated Distribution of Strontium-90 After 35 Years - P&T

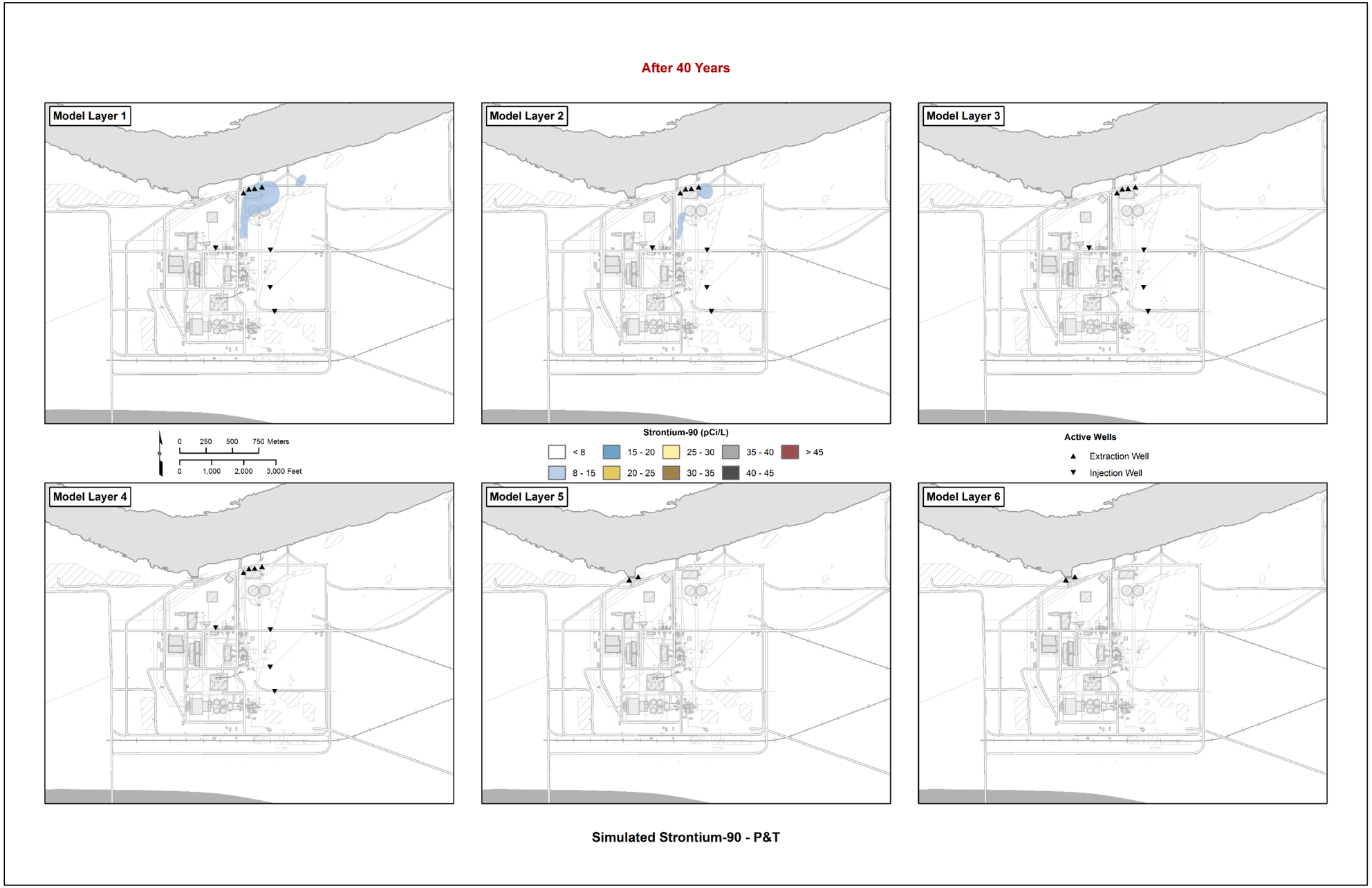


Figure 7-82. Simulated Distribution of Strontium-90 After 40 Years - P&T

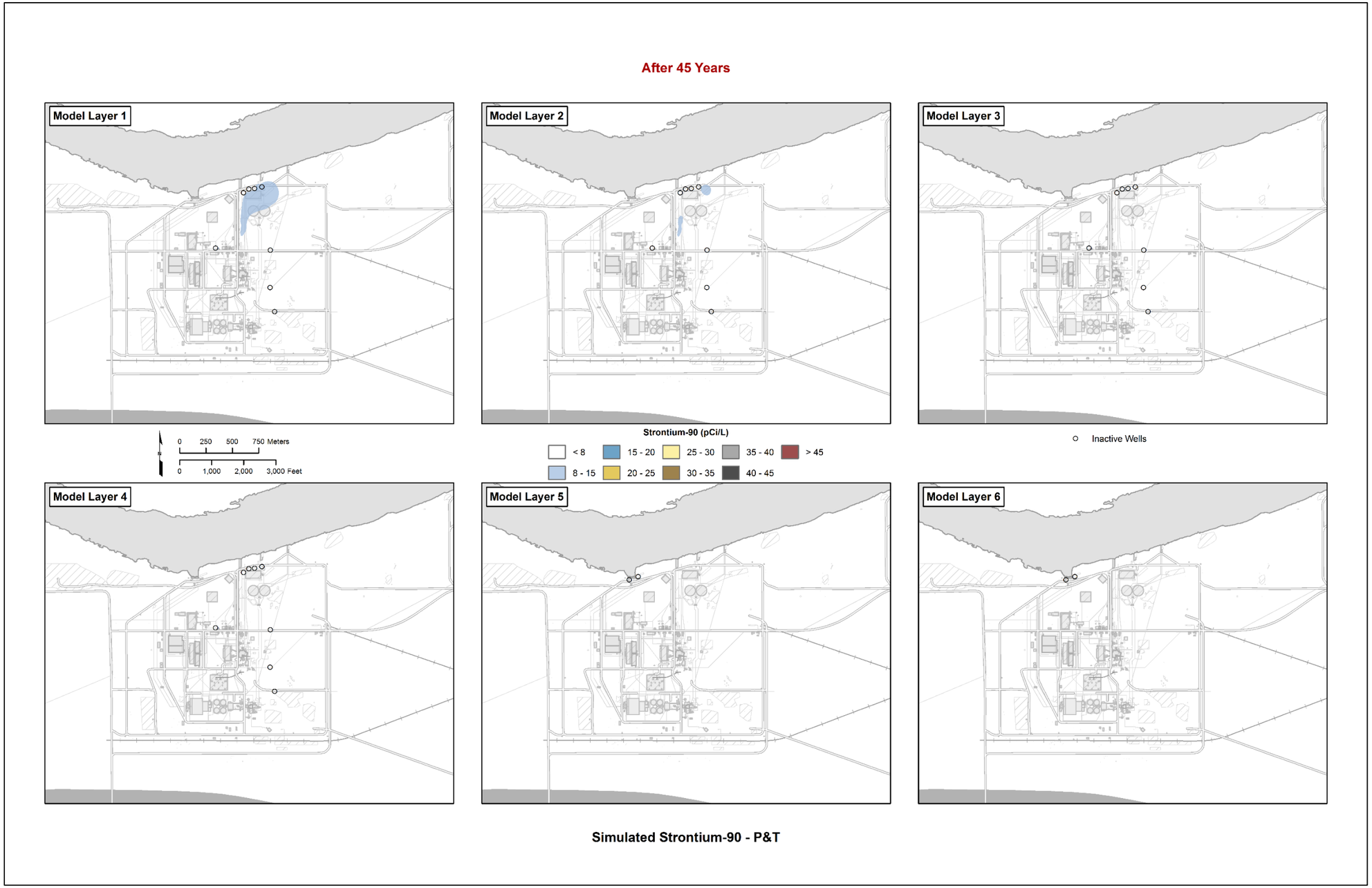


Figure 7-83. Simulated Distribution of Strontium-90 After 45 Years - P&T

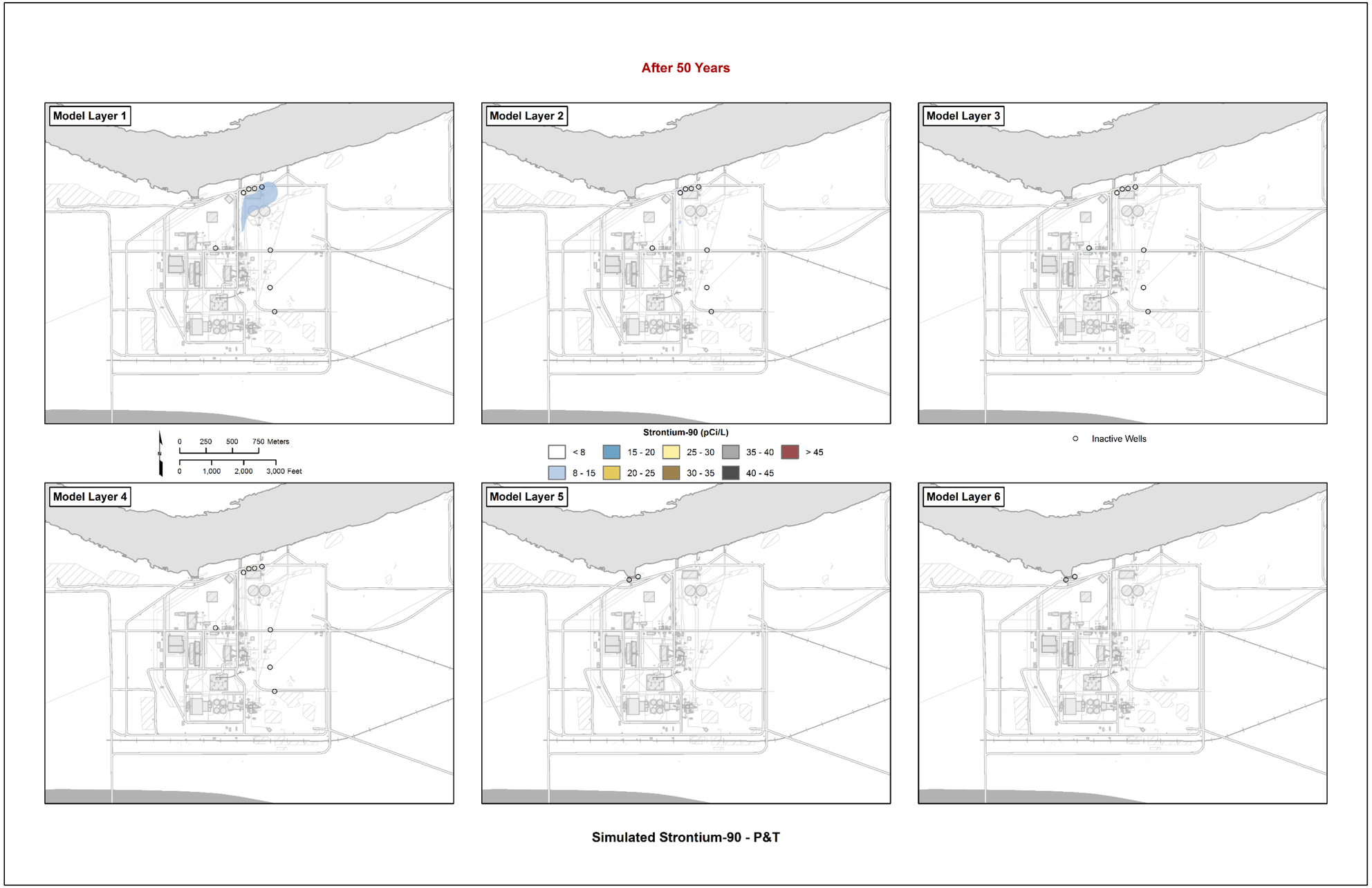


Figure 7-84. Simulated Distribution of Strontium-90 After 50 Years - P&T

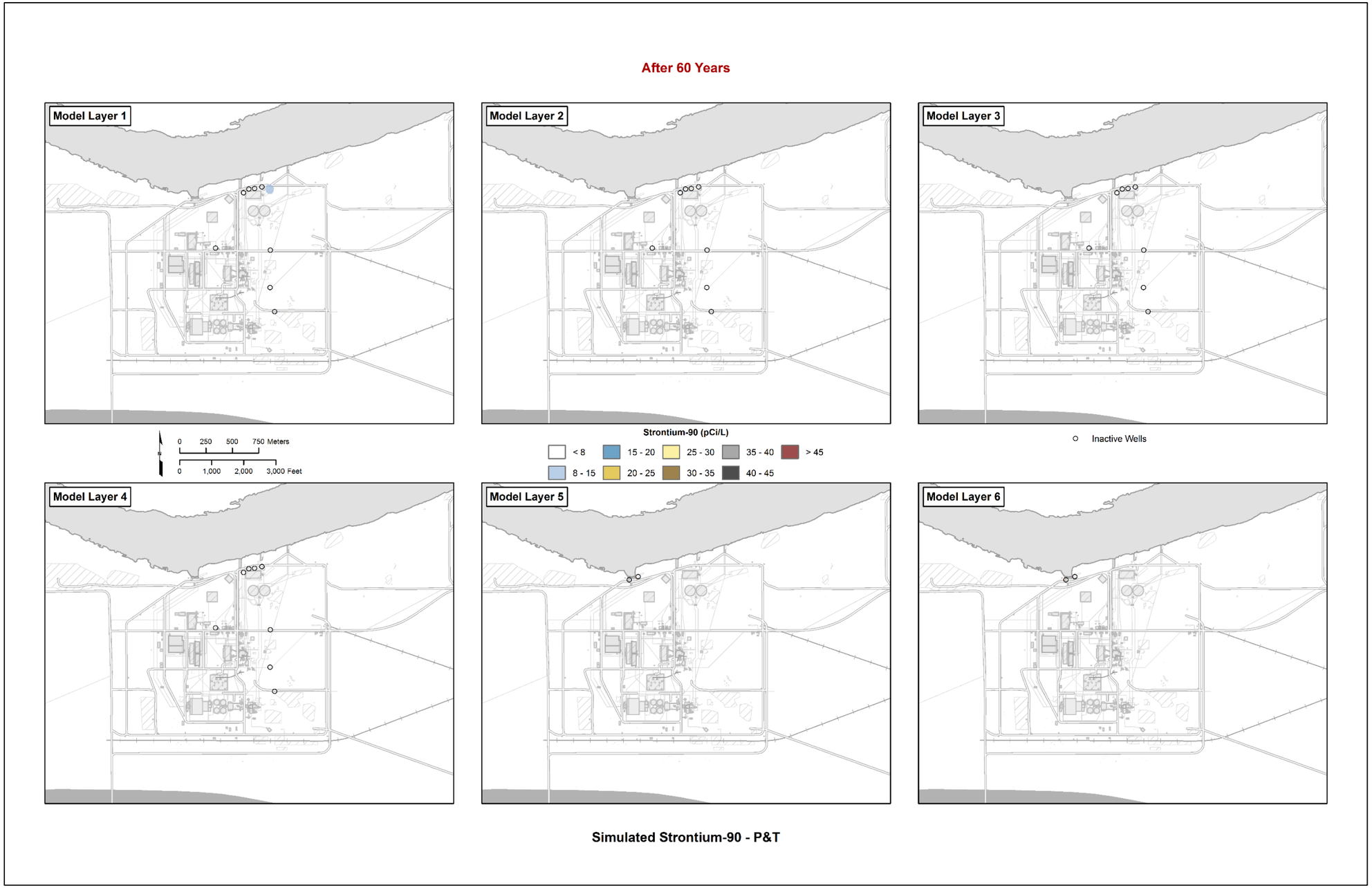


Figure 7-85. Simulated Distribution of Strontium-90 After 60 Years - P&T

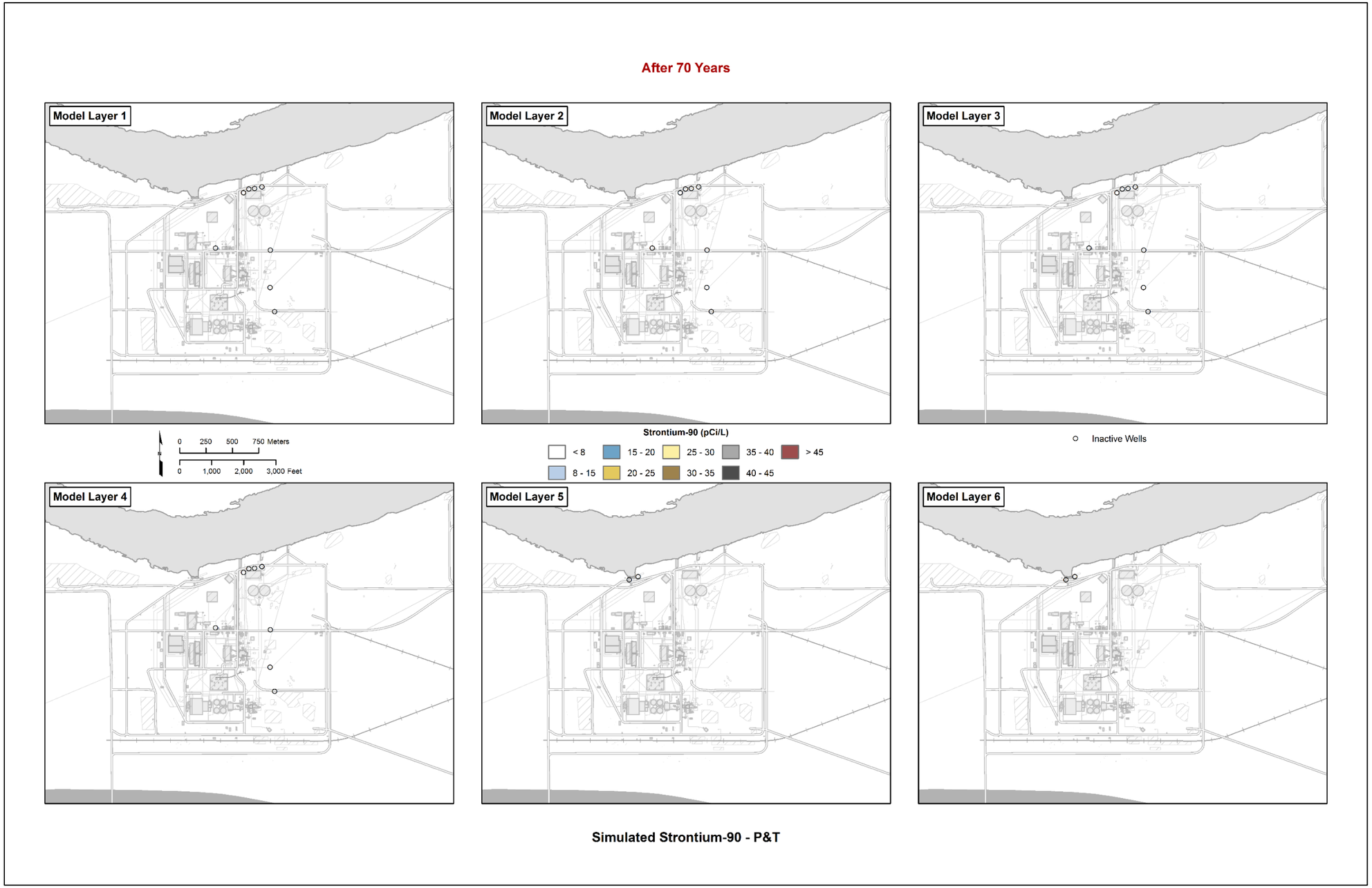


Figure 7-86. Simulated Distribution of Strontium-90 After 70 Years - P&T

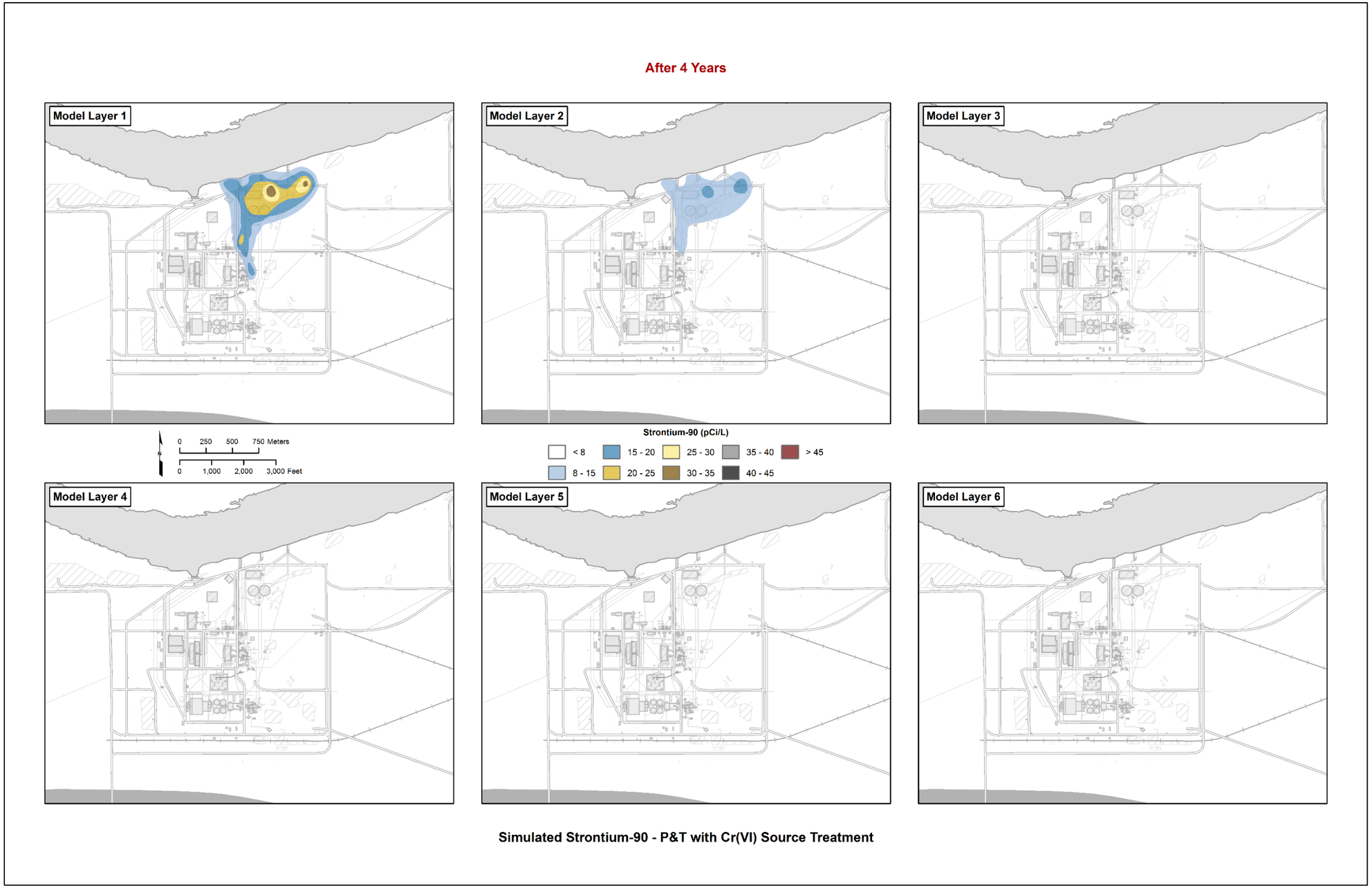


Figure 7-87. Simulated Distribution of Strontium-90 After 4 Years – P&T with Cr(VI) Source Treatment

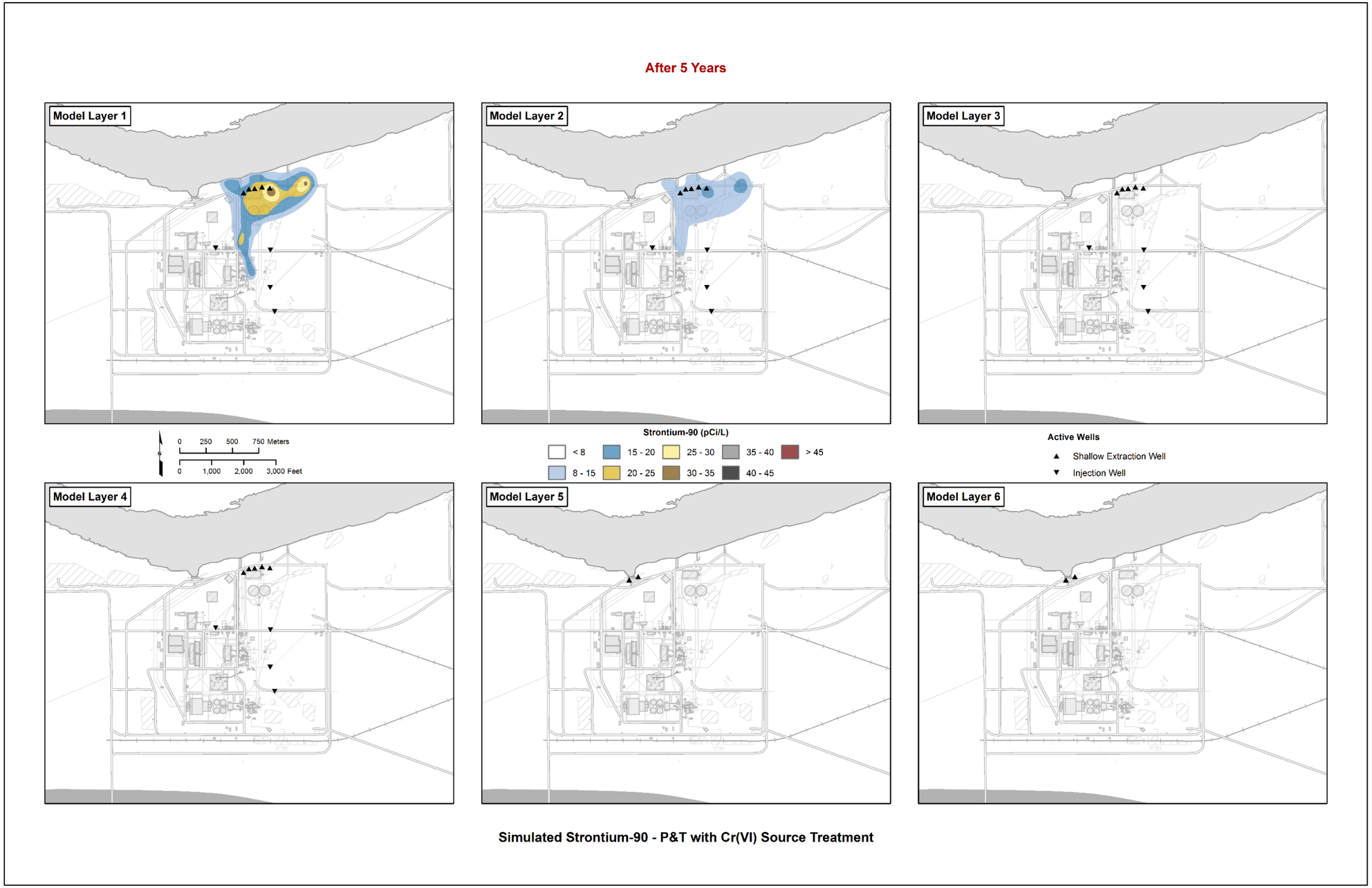


Figure 7-88. Simulated Distribution of Strontium-90 After 5 Years – P&T with Cr(VI) Source Treatment

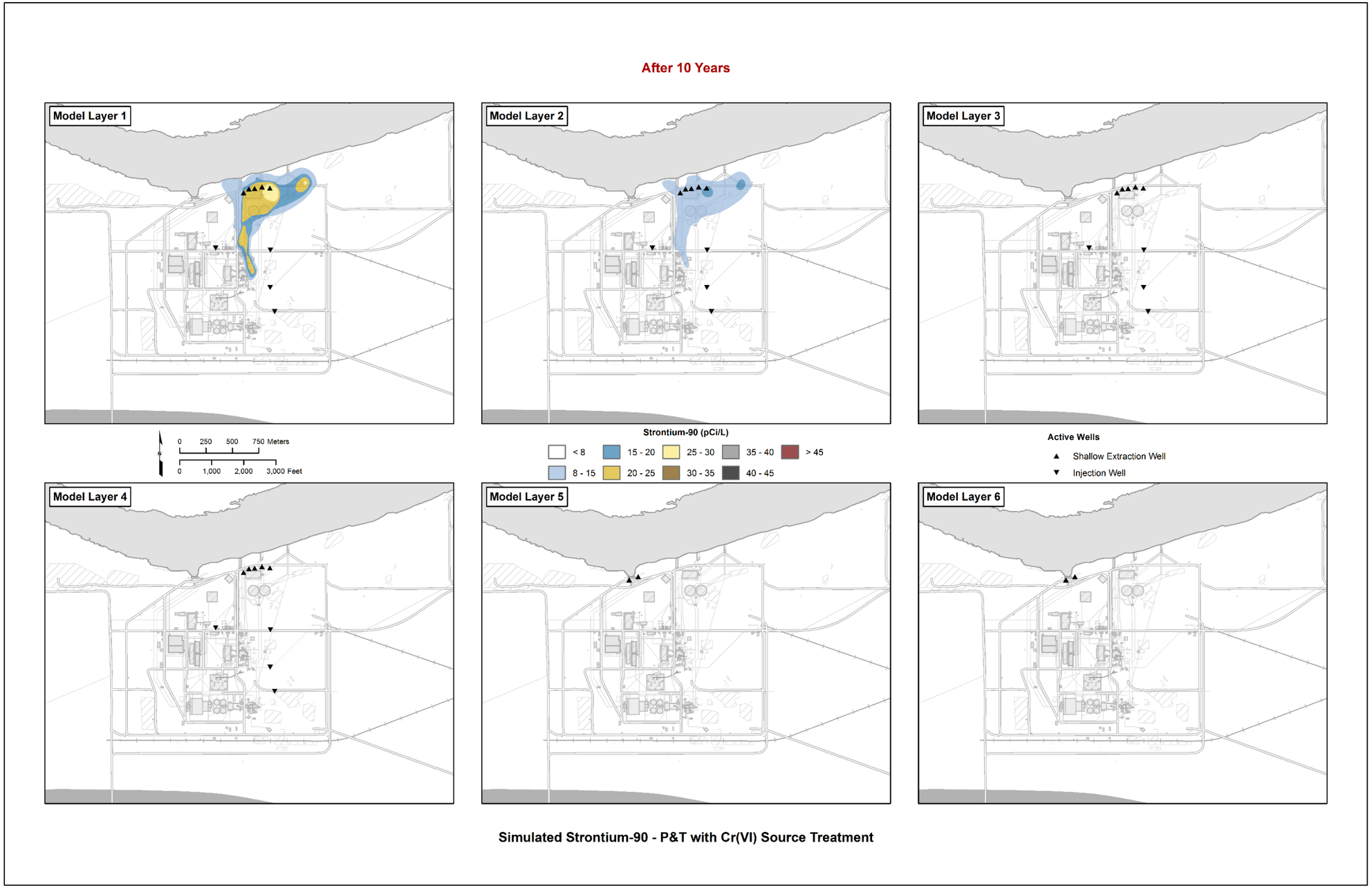


Figure 7-89. Simulated Distribution of Strontium-90 After 10 Years - P&T with Cr(VI) Source Treatment

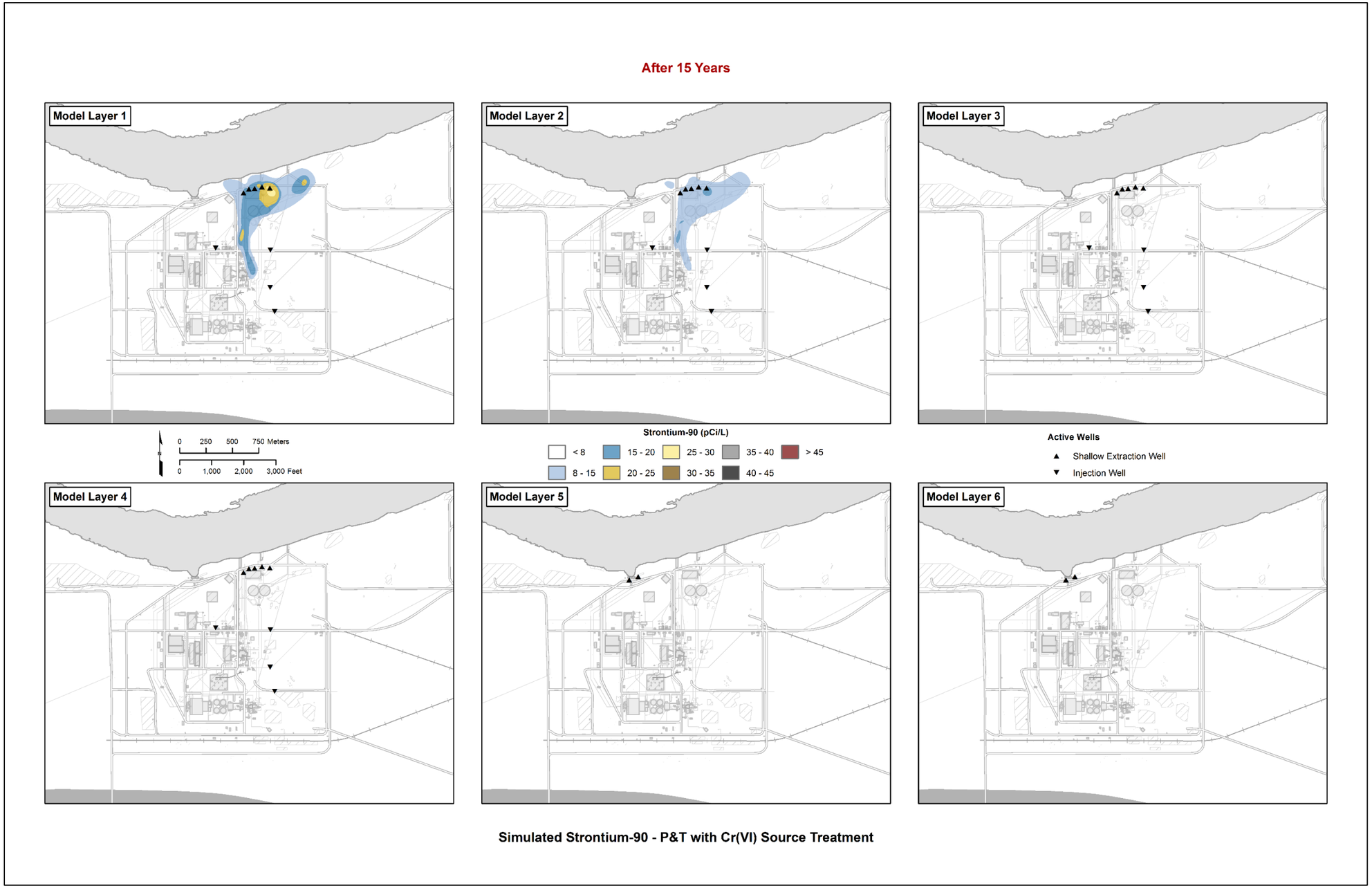


Figure 7-90. Simulated Distribution of Strontium-90 After 15 Years - P&T with Cr(VI) Source Treatment

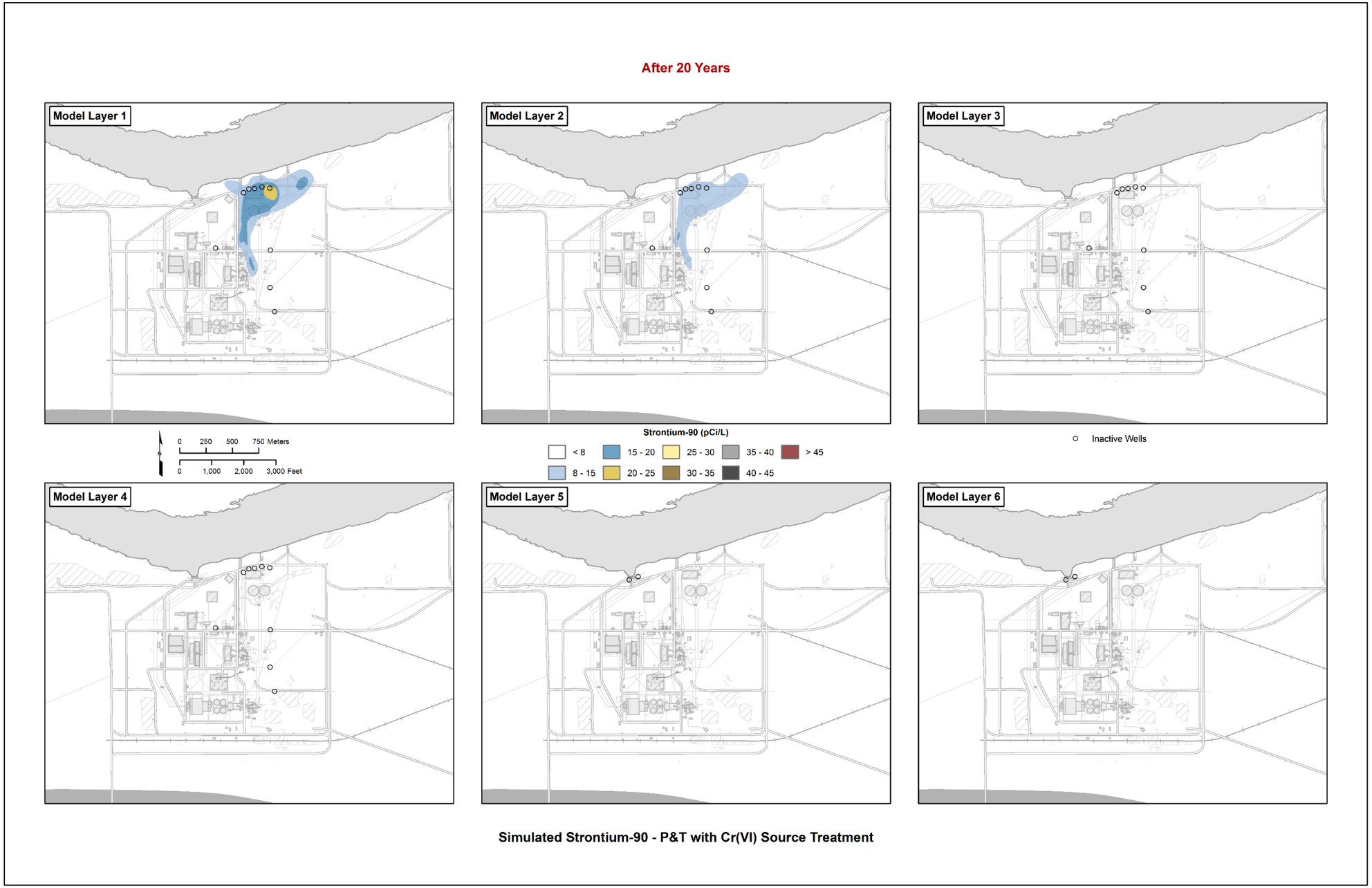


Figure 7-91. Simulated Distribution of Strontium-90 After 20 Years - P&T with Cr(VI) Source Treatment

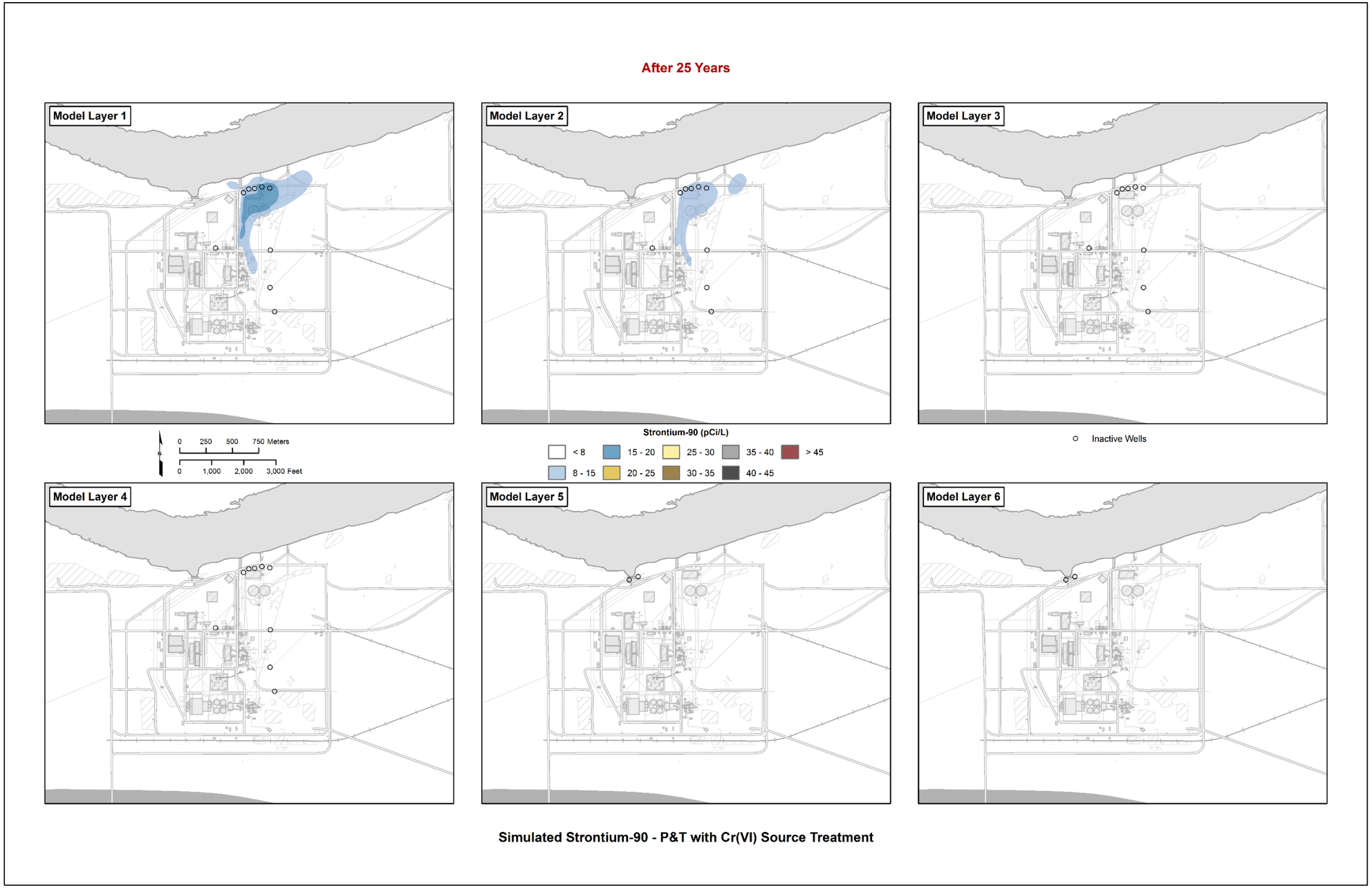


Figure 7-92. Simulated Distribution of Strontium-90 After 25 Years - P&T with Cr(VI) Source Treatment

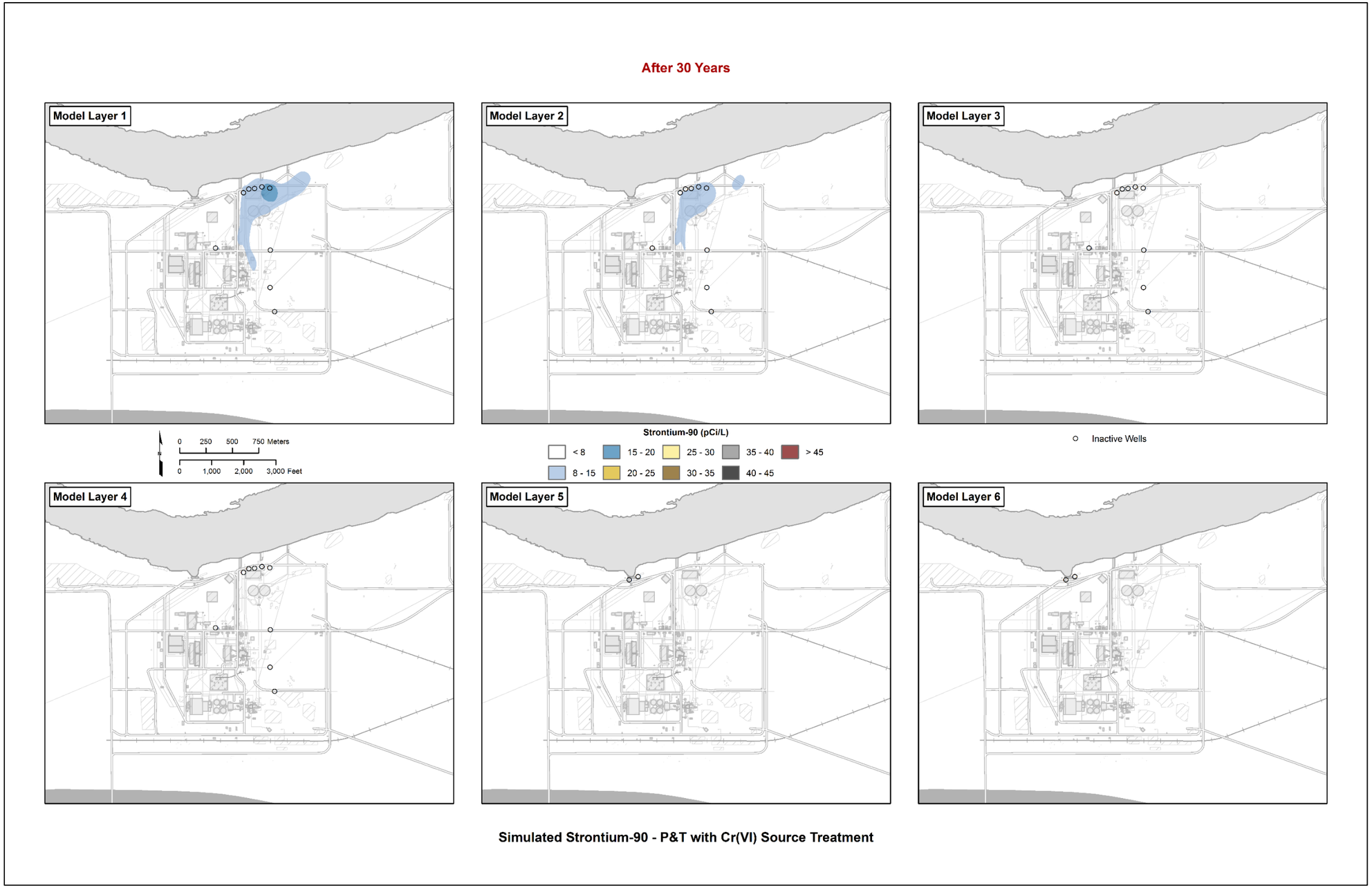


Figure 7-93. Simulated Distribution of Strontium-90 After 30 Years - P&T with Cr(VI) Source Treatment

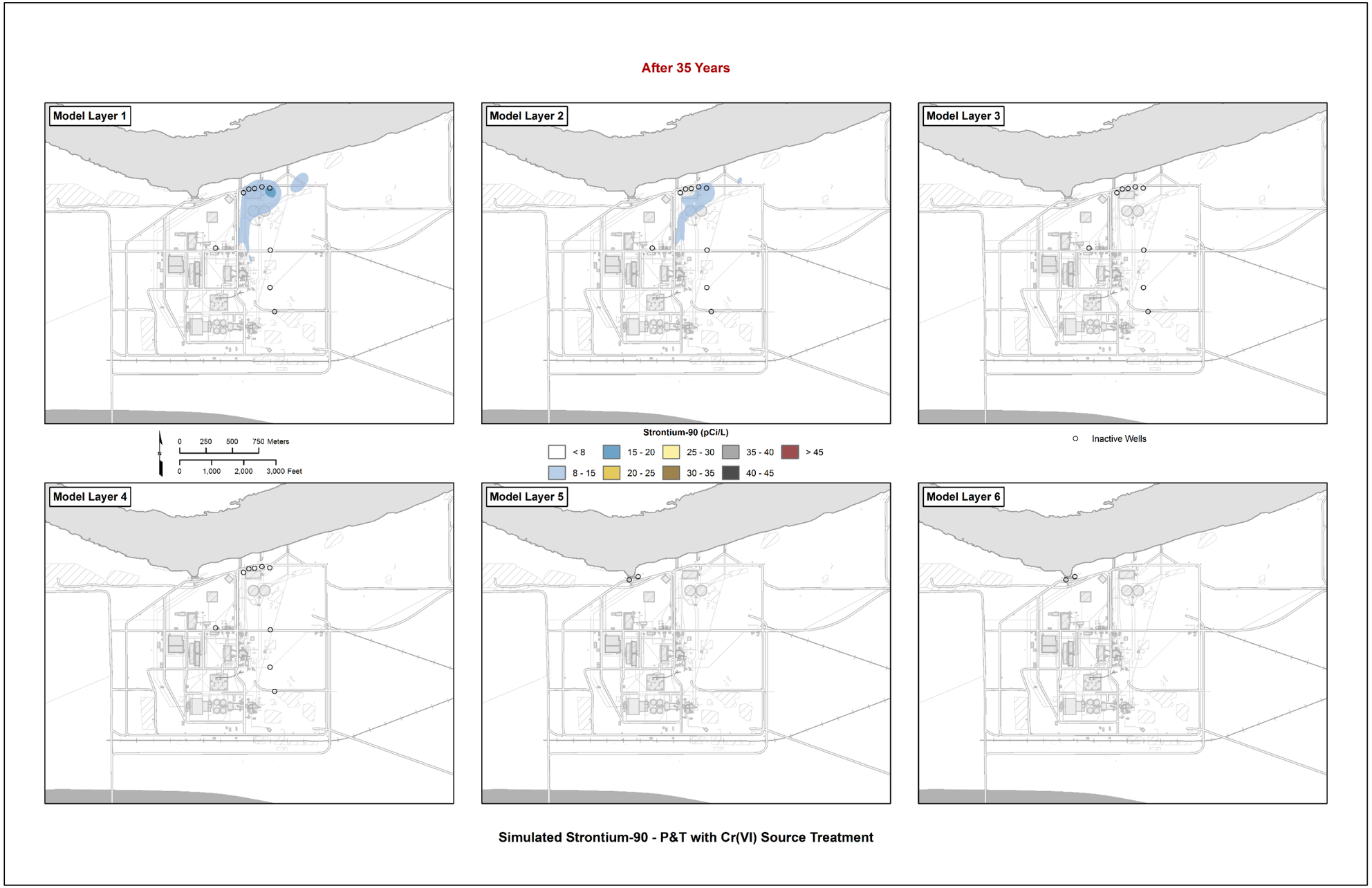


Figure 7-94. Simulated Distribution of Strontium-90 After 35 Years - P&T with Cr(VI) Source Treatment

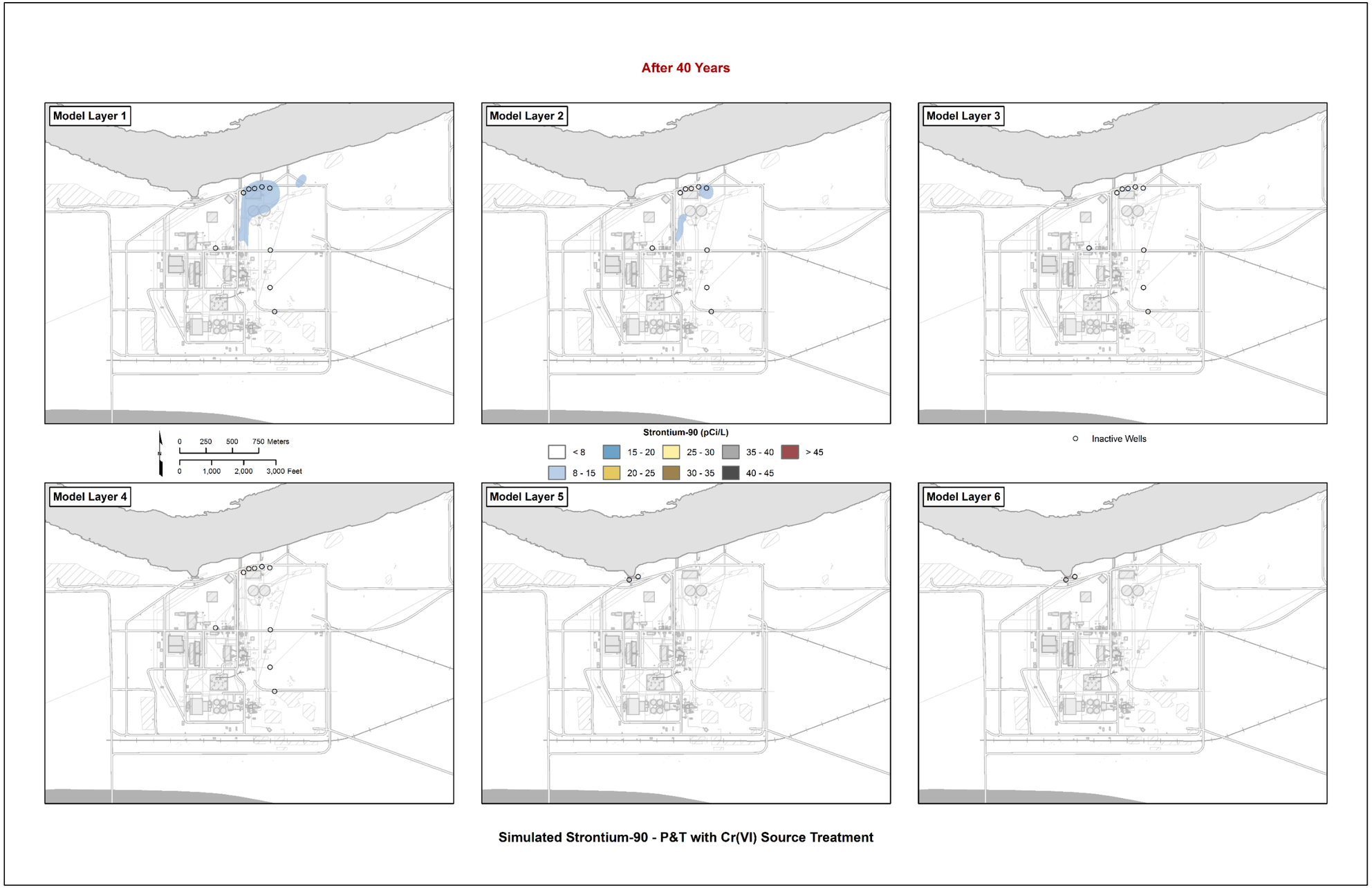


Figure 7-95. Simulated Distribution of Strontium-90 After 40 Years - P&T with Cr(VI) Source Treatment

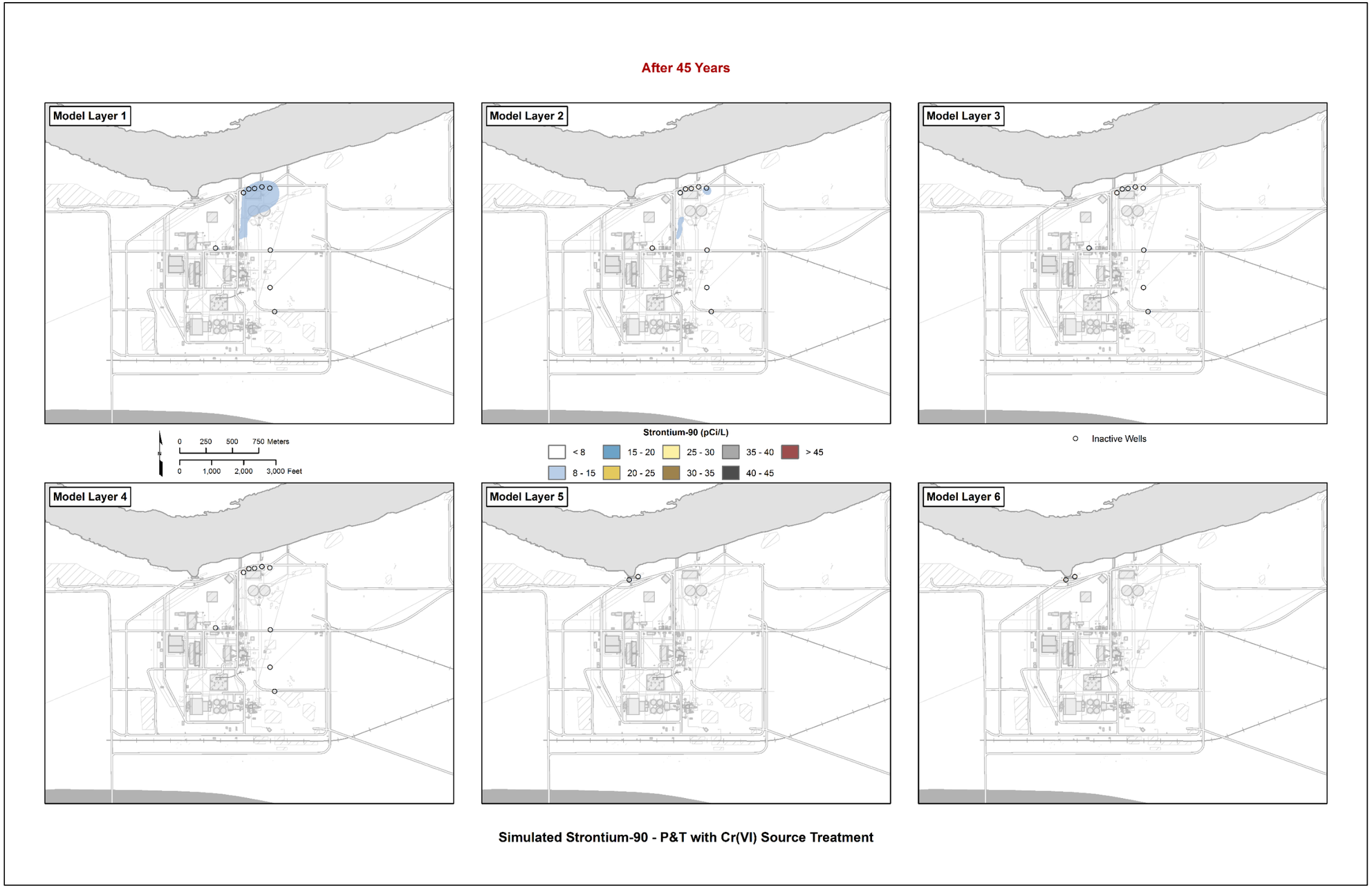


Figure 7-96. Simulated Distribution of Strontium-90 After 45 Years - P&T with Cr(VI) Source Treatment

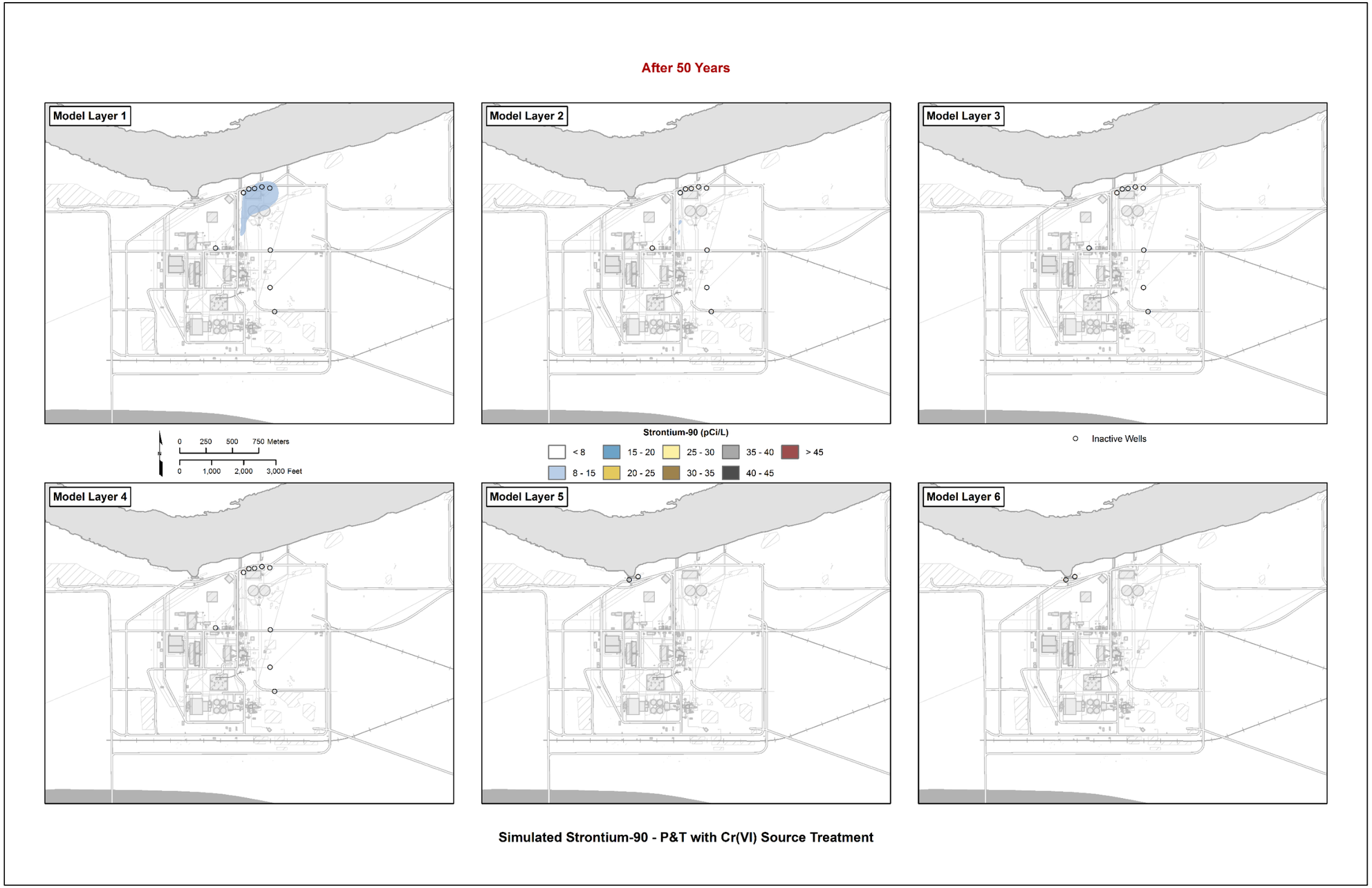


Figure 7-97. Simulated Distribution of Strontium-90 After 50 Years - P&T with Cr(VI) Source Treatment

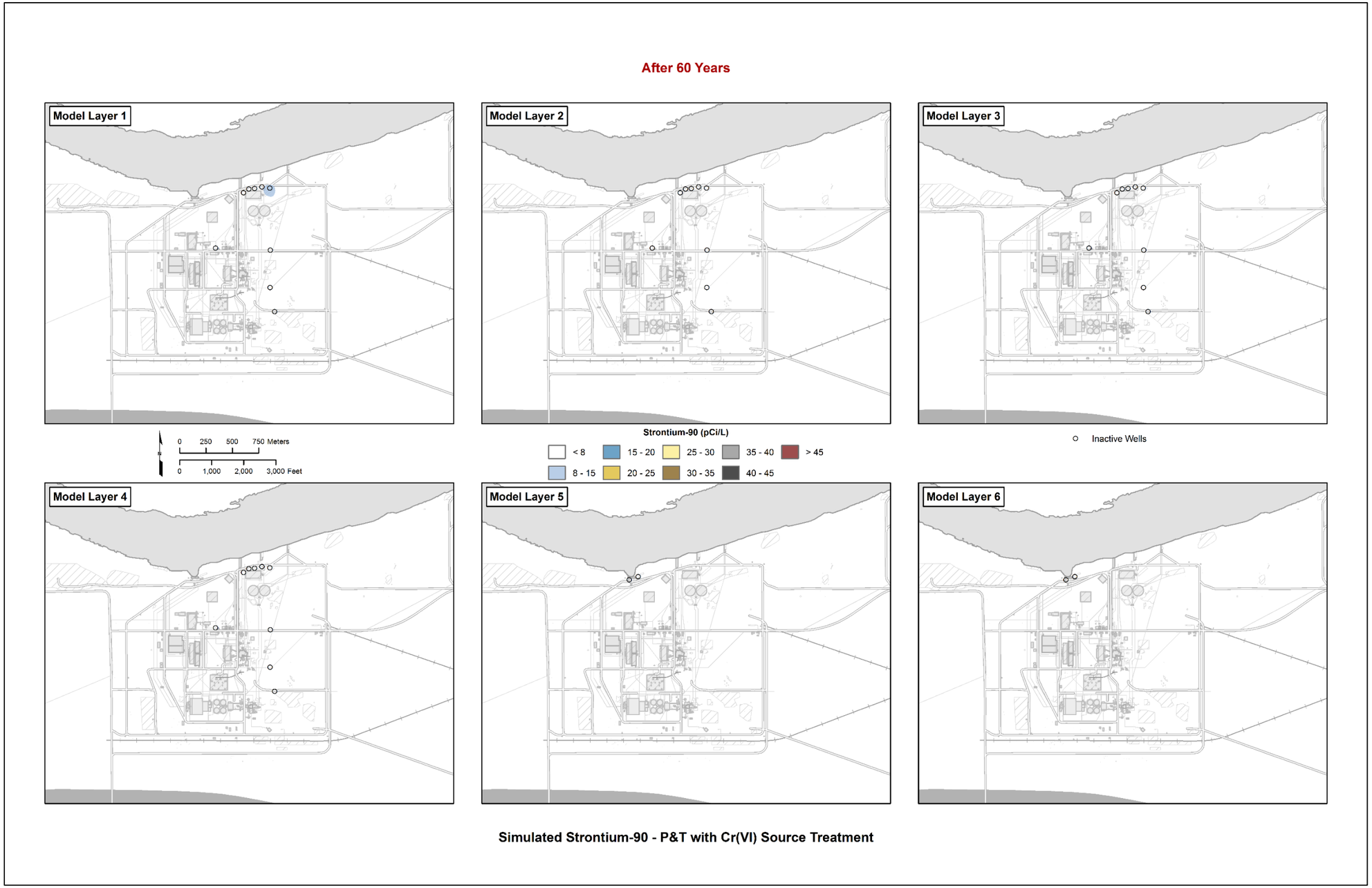


Figure 7-98. Simulated Distribution of Strontium-90 After 60 Years - P&T with Cr(VI) Source Treatment

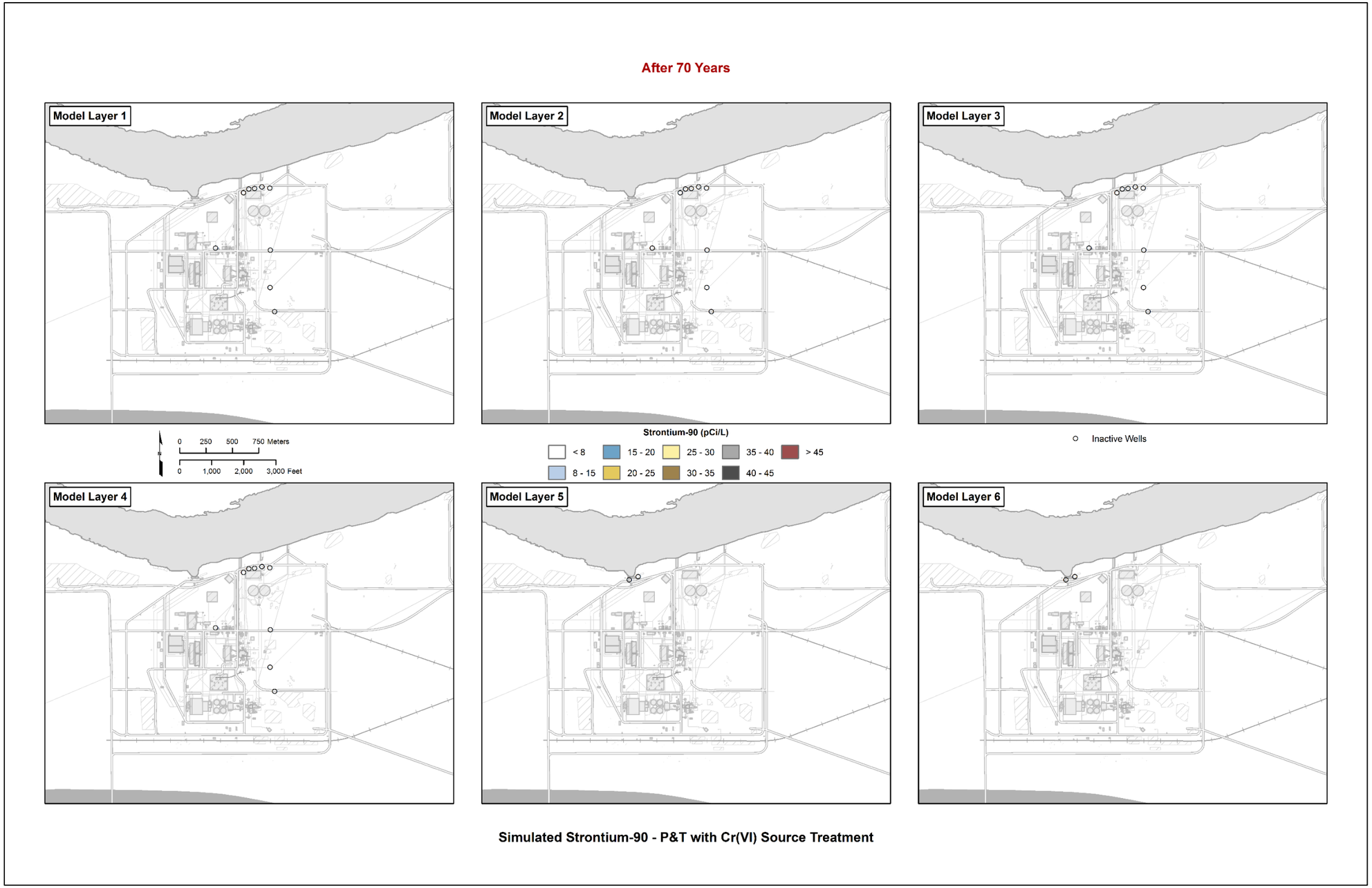
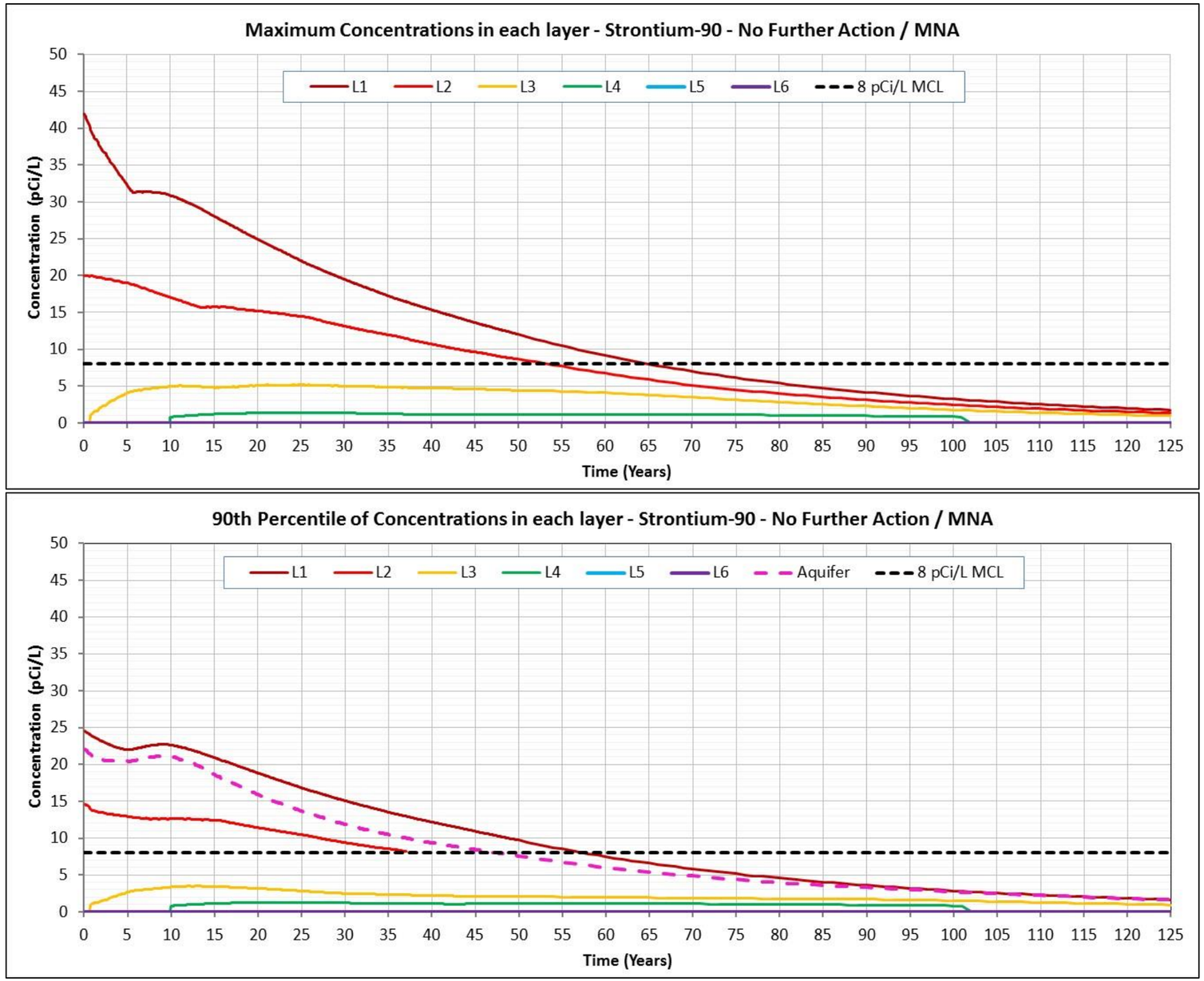
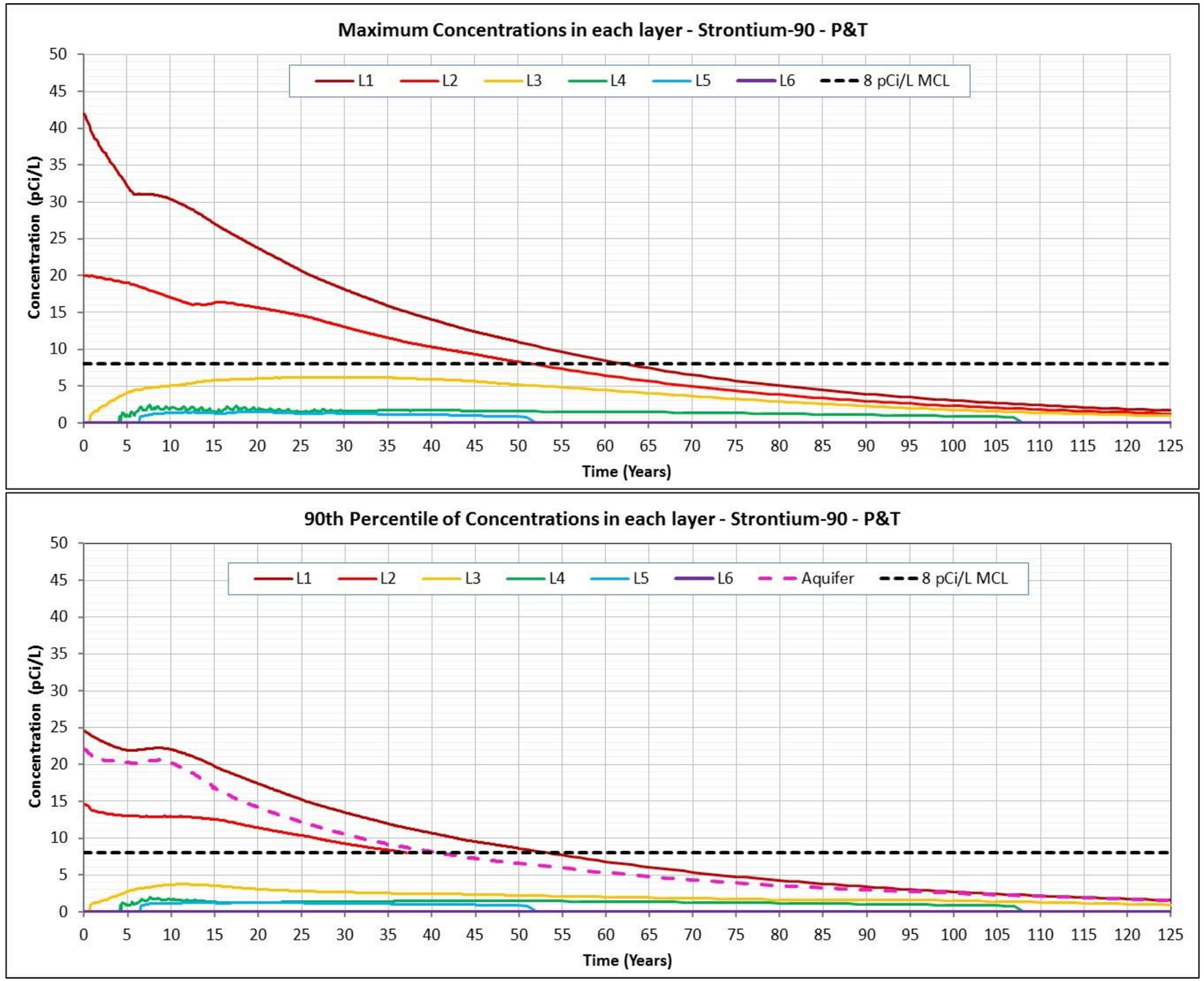


Figure 7-99. Simulated Distribution of Strontium-90 After 70 Years - P&T with Cr(VI) Source Treatment



1 **Figure 7-100. Strontium-90: Concentration Statistics in Each Model Layer – No Further Action or MNA**



1 **Figure 7-101. Strontium-90: Concentration Statistics in Each Model Layer – P&T**

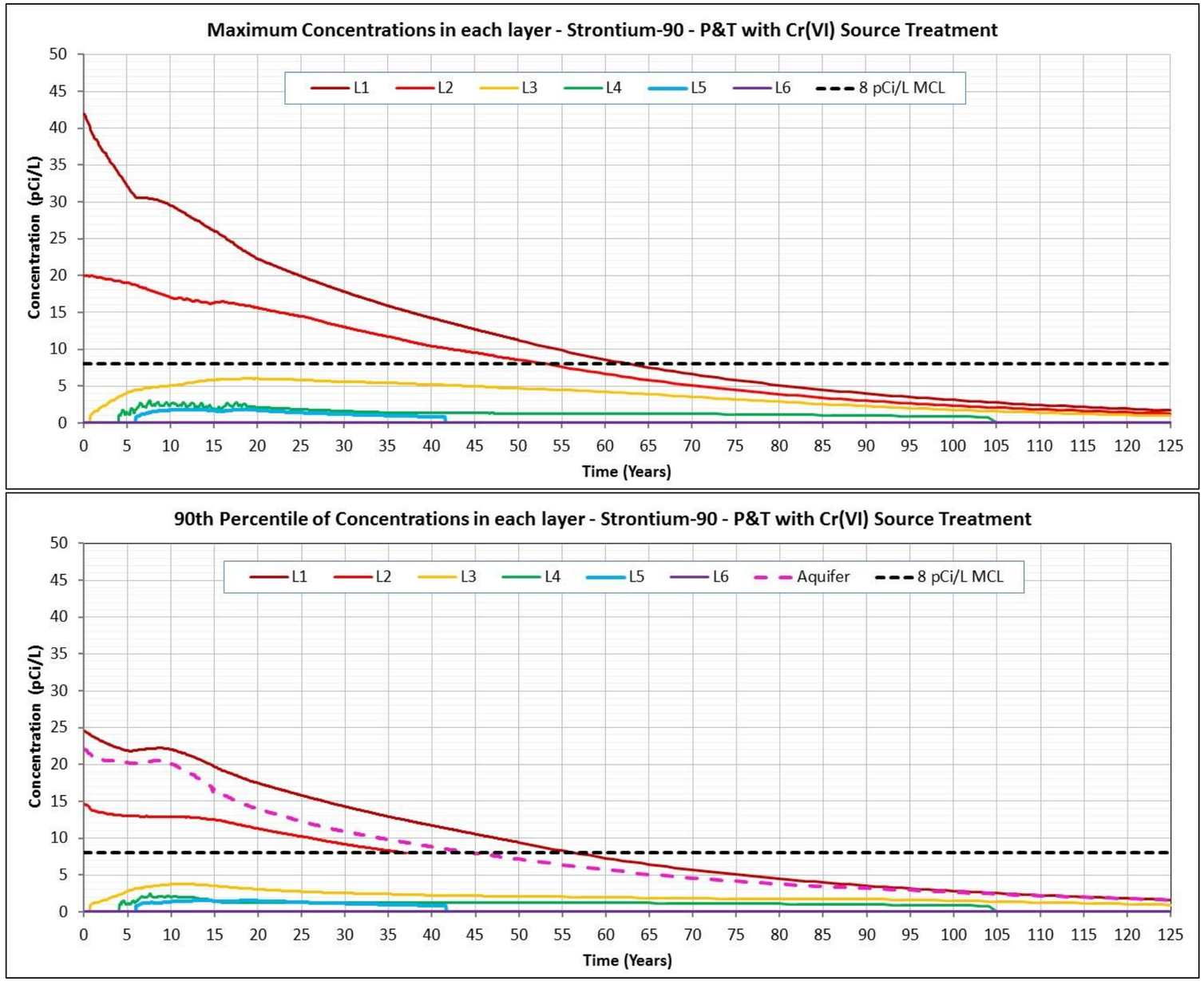


Figure 7-102. Strontium-90: Concentration Statistics in Each Model Layer – P&T with Cr(VI) Source Treatment

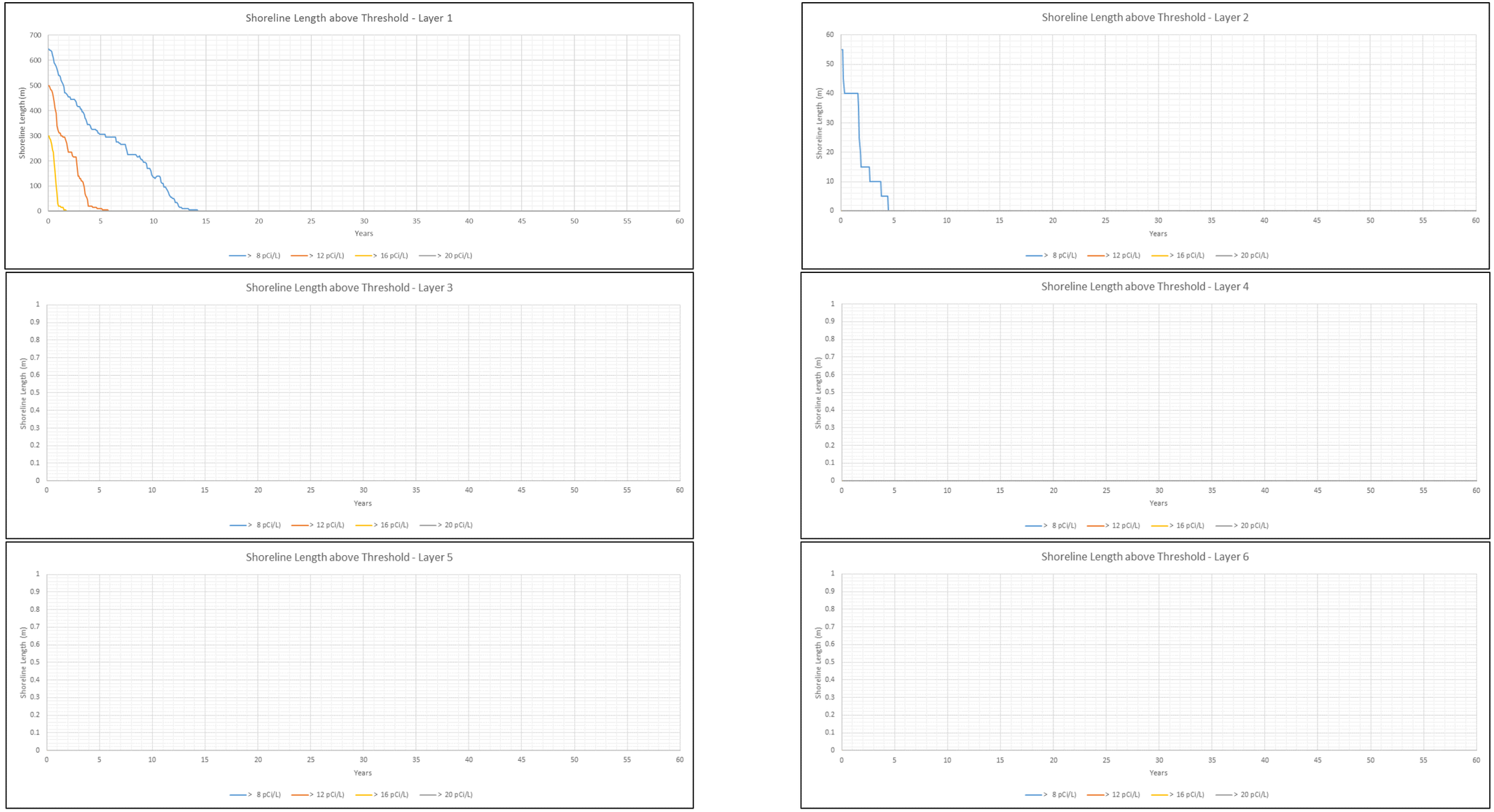


Figure 7-103. Strontium-90: Shoreline Impacted Length in Each Model Layer – No Further Action or MNA

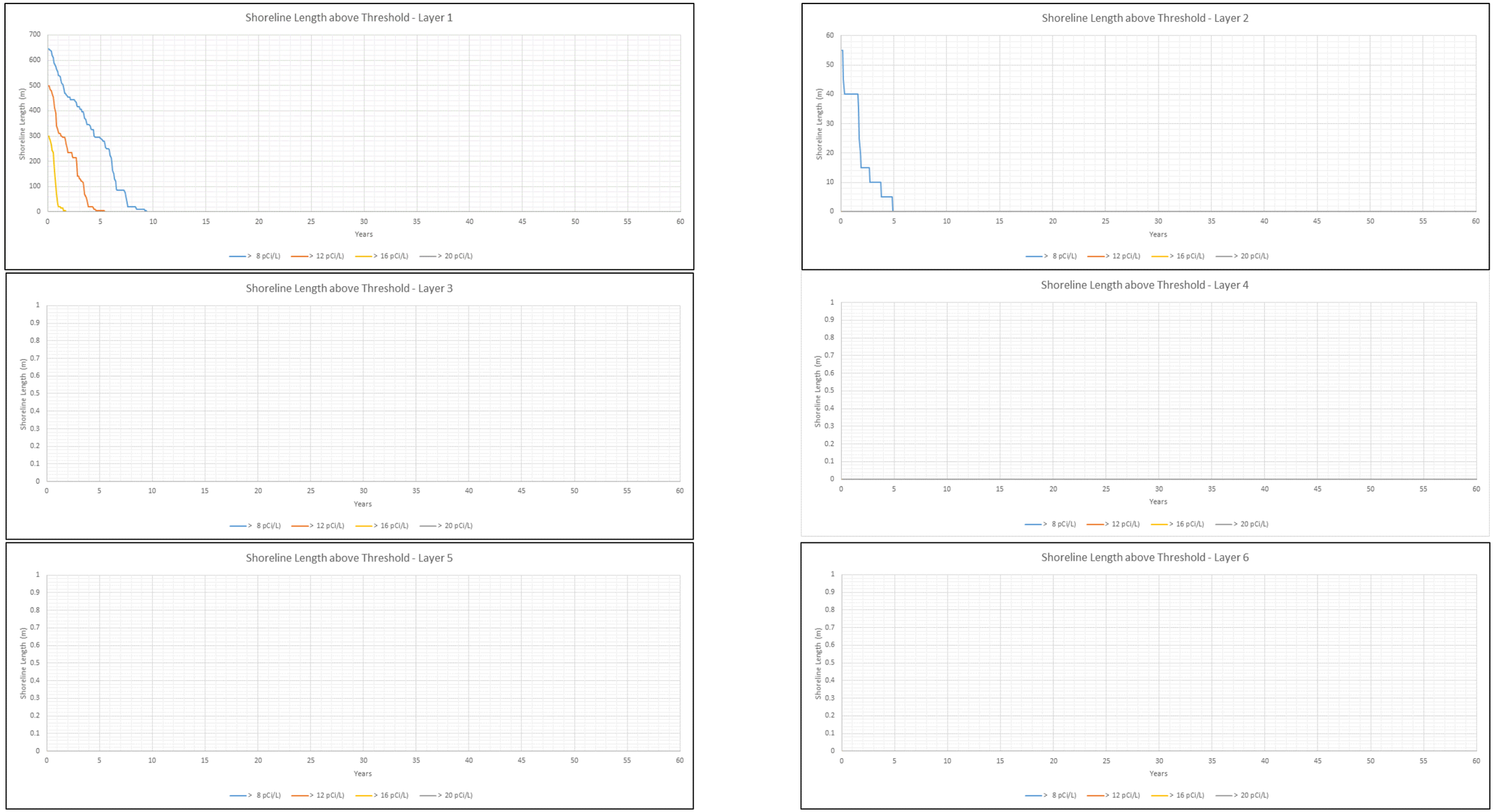


Figure 7-104. Strontium-90: Shoreline Impacted Length in Each Model Layer – P&T

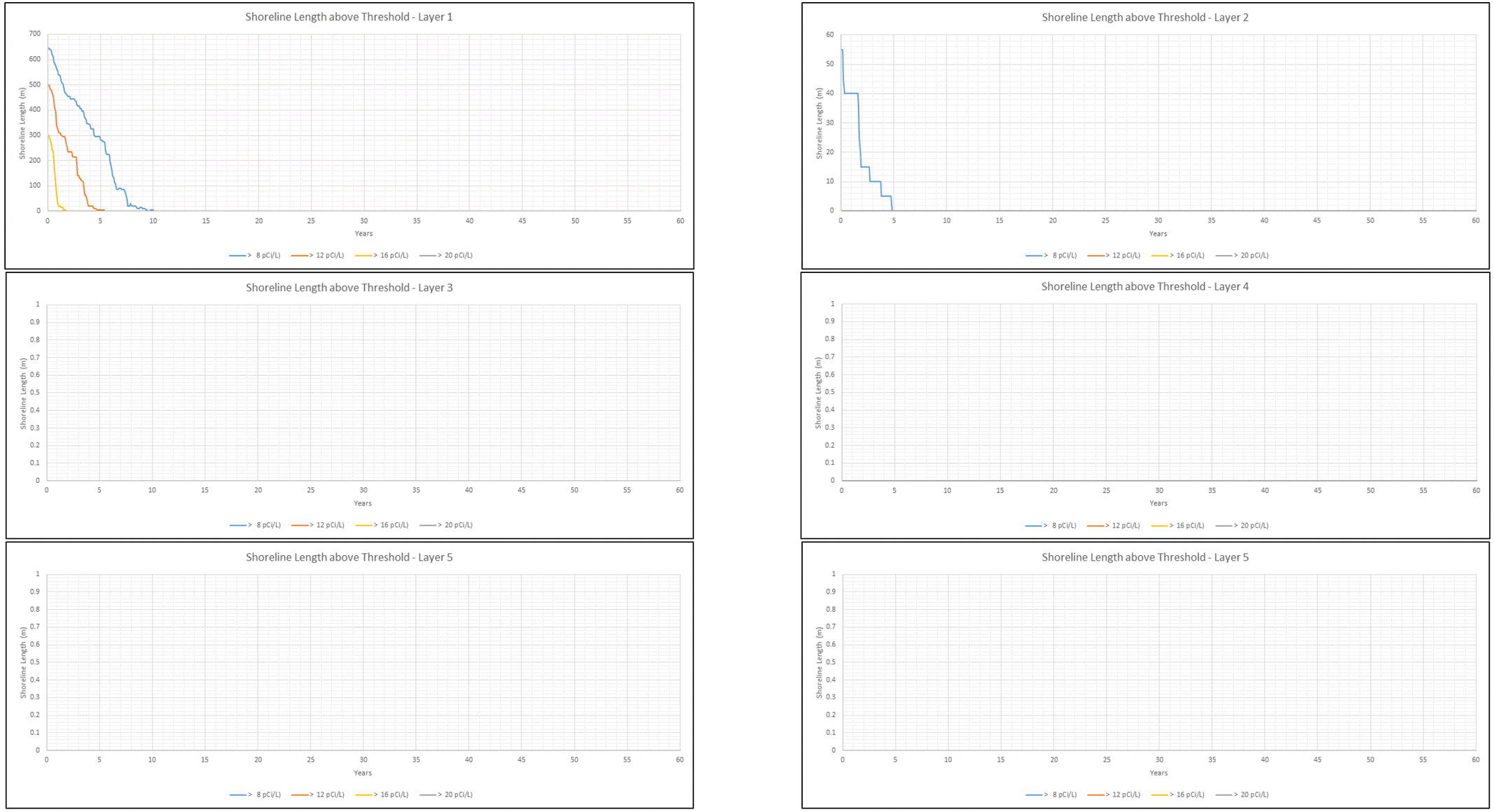


Figure 7-105. Strontium-90: Shoreline Impacted Length in Each Model Layer – P&T with Cr(VI) Source Treatment

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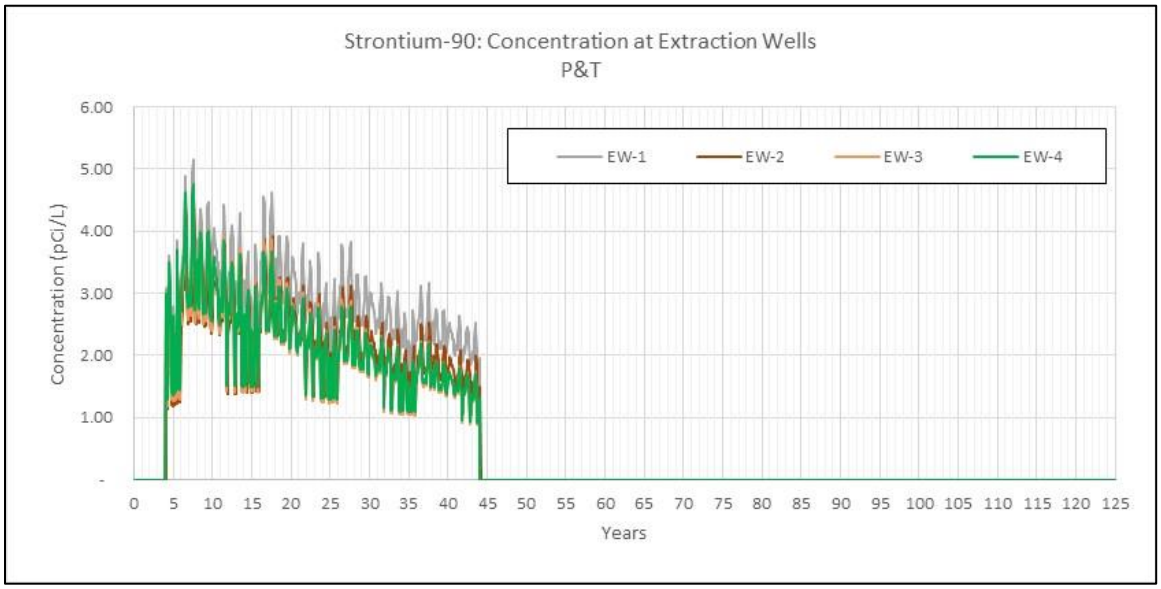

Figure 7-106. Strontium-90 Concentration at Extraction Wells – Alternative 3: P&T

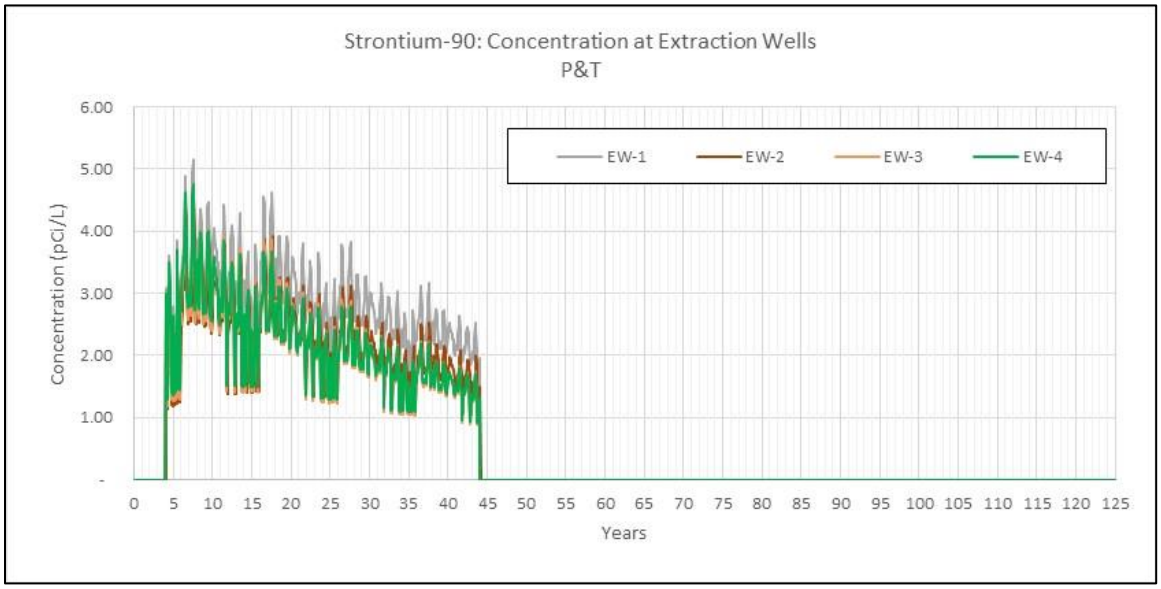

Figure 7-107. Strontium-90 Concentration at Extraction Wells – Alternative 4: P&T with Cr(VI) Source Treatment

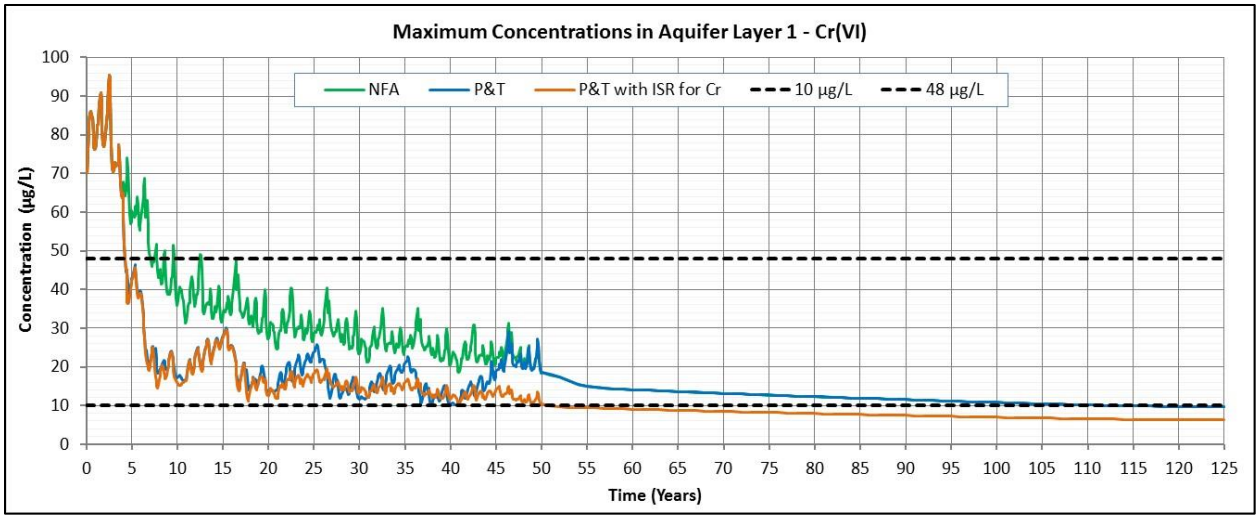

Figure 7-108. Comparison of Maximum Cr(VI) Concentration in Layer 1 for each Alternative

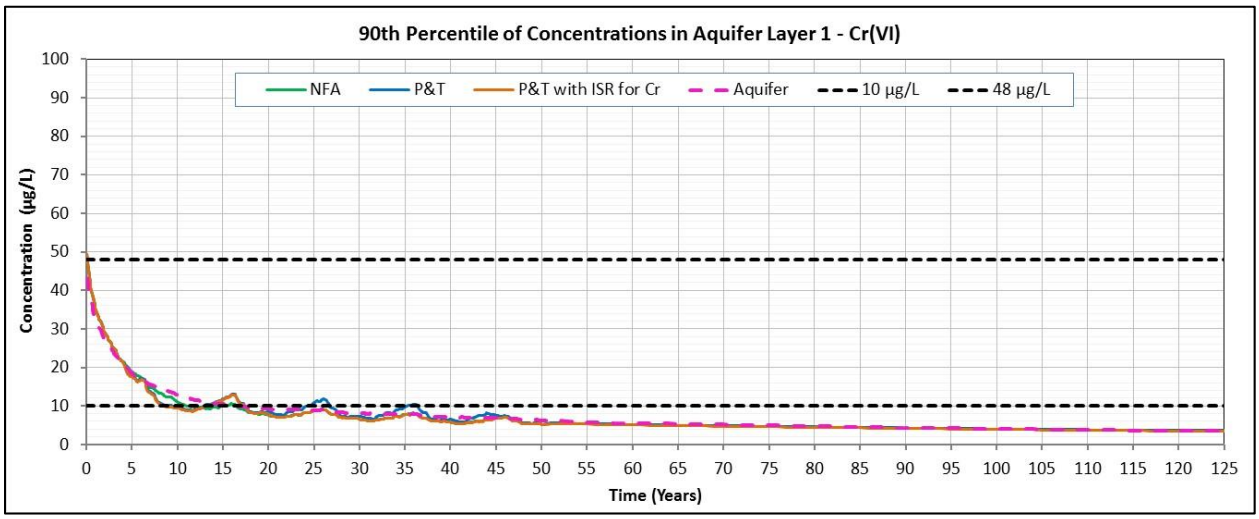

Figure 7-109. Comparison of 90th Percentile of Cr(VI) Concentration in Layer 1 for each Alternative

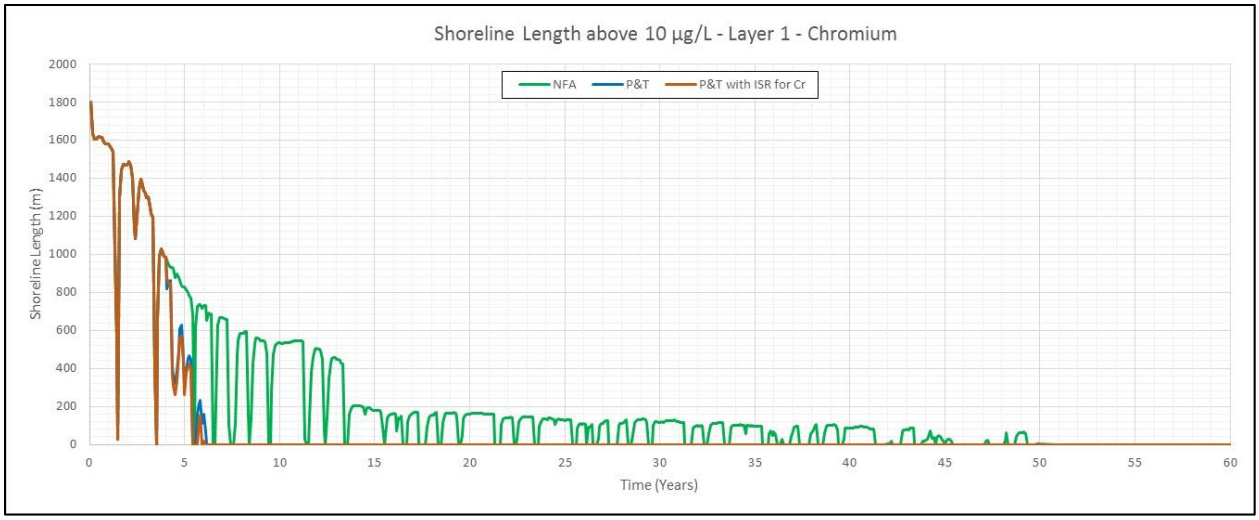

Figure 7-110. Comparison of Cr(VI) Shoreline Impacted Length in Layer 1 for each Alternative

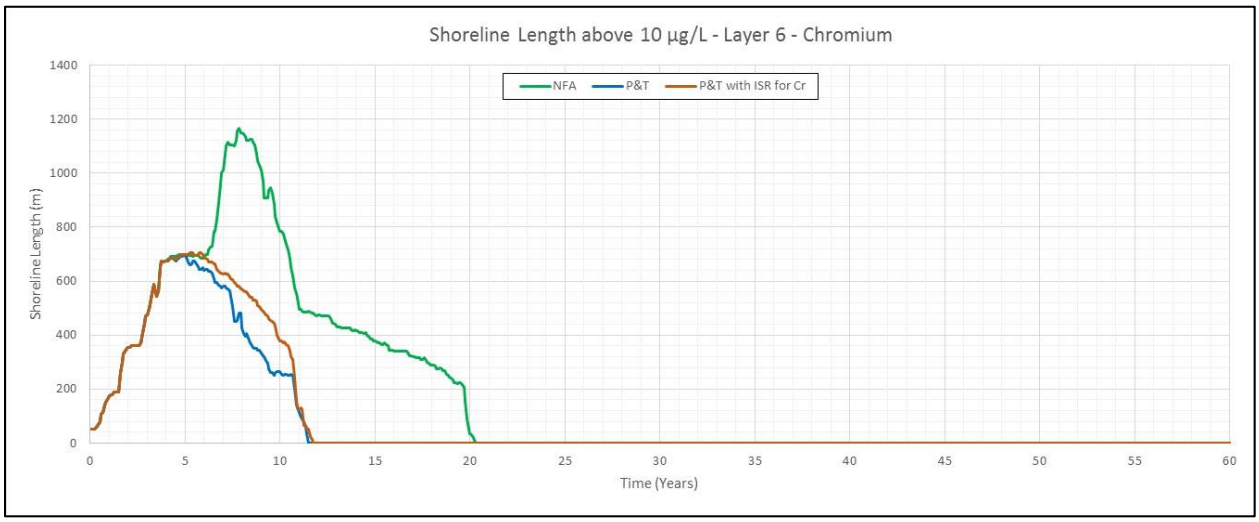

Figure 7-111. Comparison of Cr(VI) Shoreline Impacted Length in Layer 6 for each Alternative

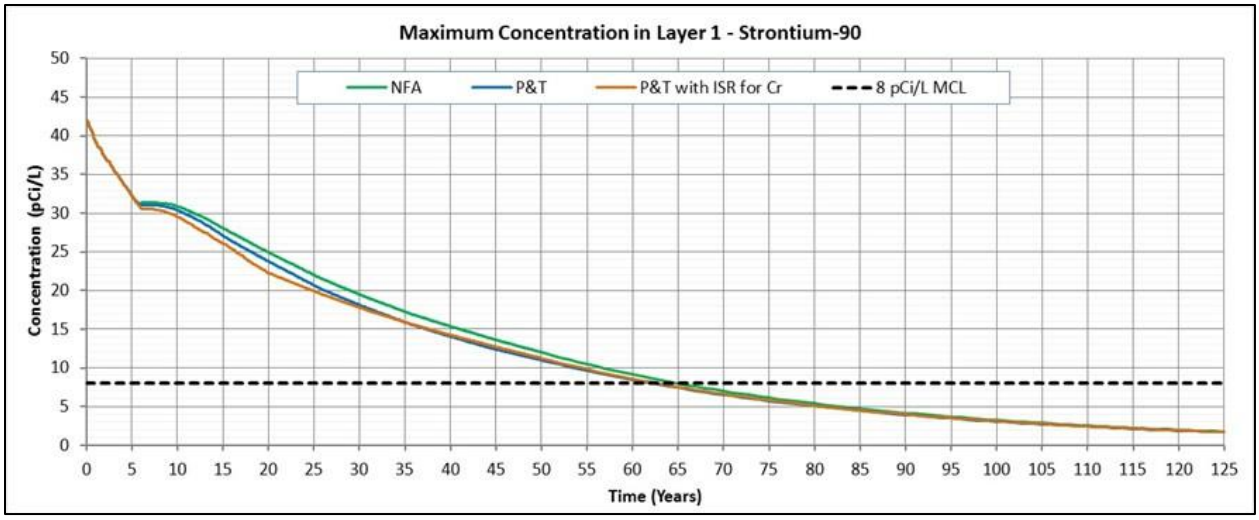

Figure 7-112. Comparison of Maximum Strontium-90 Concentration in Layer 1 for each Alternative

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Appendix A

SICO Forms

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CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM

Software Owner Instructions:
Complete Fields 1-13, then run test cases in Field 14. Compare test case results listed in Field 15 to corresponding Test Report outputs. If results are the same, sign and date Field 19. If not, resolve differences and repeat above steps.

Software Subject Matter Expert Instructions:
Assign test personnel. Approve the installation of the code by signing and dating Field 21, then maintain form as part of the software support documentation.

GENERAL INFORMATION:

1. Software Name: MODFLOW and Related Codes Software Version No.: Bld 8

EXECUTABLE INFORMATION:

2. Executable Name (include path):

Following executable files in directory: _____

MD5 Signature (unique ID)	Executable File Name	
919F74196F5FB5BF0364FC373011B507	mf2k-chprc08dpl.exe	MODFLOW-2000 double precision
EAF037703ADD2C62CDD9CBC47468D2F6	mf2k-chprc08spl.exe	MODFLOW-2000 single precision
4E7F29DD5496D2CBA7144ADACB13DAAD	mf2k-mst-chprc08dpv.exe	MODFLOW-2000-MST single prec
CEB80288C616E0552E4CE5A2D4719387	mf2k-mst-chprc08spv.exe	MODFLOW-2000-MST double prec
ECA9828530B68D2D7C34078C019D5D0C	mt3d-chprc08dpl.exe	MT3DMS double precision
0920CC235862665D94D0A3FC80F682DD	mt3d-chprc08spl.exe	MT3DMS single precision
5C61432D2C898E83DDFE242C52A755AB	mt3d-mst-chprc08dpv.exe	MT3DMS-MST double precision
68F89DAF2E6913D257BDE53CBD34FBA0	mt3d-mst-chprc08spv.exe	MT3DMS-MST single precision

3. Executable Size (bytes): MD5 signatures listed above uniquely identify executable files

COMPILATION INFORMATION:

4. Hardware System (i.e., property number or ID):

Vendor Provided (SSP&A)

5. Operating System (include version number):

Vendor Provided (SSP&A)

INSTALLATION AND CHECKOUT INFORMATION:

6. Hardware System (i.e., property number or ID):

7. Operating System (include version number):

8. Open Problem Report? ◉ No ○ Yes PR/CR No.

TEST CASE INFORMATION:

9. Directory/Path:

[ ]\test-windows

10. Procedure(s):

CHPRC-00259 Rev 3, MODFLOW and Related Codes Software Test Plan

11. Libraries:

N/A (static linking)

12. Input Files:

MF-ITC-1 and MT-ITC-1 inputs

13. Output Files:

MF-ITC-1 and MT-ITC-1 outputs

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CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM (continued)

1. Software Name: MODFLOW and Related Codes Software Version No.: Bld 8

14. Test Cases:

MF-ITC-1 (both standard and MST versions of MODFLOW)- run for single & double precision
MT-ITC-1 - run for single and double precision

15. Test Case Results:

```
MODFLOW, MODFLOW-MST, and MT3DMS-MST Installation Testing Log
Eight instances of /FC: no differences encountered/ in log below indicates
that all installation tests were successful.
Alex_Z
Wed 05/04/2016
03:33 PM

---------- TESTRESULTS.LOG

---------- TESTRESULTS.LOG

---------- TESTRESULTS.LOG

---------- TESTRESULTS.LOG

---------- TESTRESULTS.LOG

---------- TESTRESULTS.LOG

---------- TESTRESULTS.LOG

---------- TESTRESULTS.LOG
```

16. Test Performed By:

17. Test Results: (•) Satisfactory, Accepted for Use ( ) Unsatisfactory

18. Disposition (include HISI update):

Prepared By:

19.	WE Nichols	
Software Owner (Signature)	Print	Date

20. Test Personnel:

Spiliotopoulos	Alex Spiliotopoulos	2/15/2016
Sign	Print	Date
Sign	Print	Date
Sign	Print	Date

Approved By:

21.	N/R (CHPRC-00258 Rev 3)	
Software SME (Signature)	Print	Date

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