Sparton Technology, Inc.
Former Coors Road Plant
Remedial Program

Evaluation of Alternative Systems and Technologies for Aquifer Restoration

S.S. PAPADOPULOS & ASSOCIATES, INC.
Environmental & Water-Resource Consultants

November 25, 2009

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November 25, 2009

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Subject: Sparton Technology, Inc. Former Coors Road Plant Remedial Program
Evaluation of Alternative Systems and Technologies for Aquifer Restoration

Gentlemen:

On behalf of Sparton Technology, Inc. (Sparton), S. S. Papadopulos & Associates, Inc. (SSP&A) is pleased to submit the subject report. The report presents an evaluation of the performance of the existing containment system and of alternative groundwater extraction systems that may be implemented to expedite aquifer restoration. An evaluation of alternative remedial technologies that do not involve groundwater extraction and of their applicability to the Sparton site is also included in the report. Based on these evaluations, it is recommended that the pumping rate of the existing off-site containment well be increased from 225 to 300 gallons per minute to expedite aquifer restoration. The report was prepared by SSP&A; Metric Corporation, Inc. provided assistance in the cost analysis of the existing and of the alternative extraction systems.

I certify under penalty of law that this document and all attachments were prepared under my direction and supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based upon my inquiry of either the person or persons who manage the system and/or the person or persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I further certify, to the best of my knowledge and belief, that this document is consistent with the applicable requirements of the Consent Decree entered among the New Mexico Environment Department, the U.S. Environmental Protection Agency, Sparton Technology, Inc., and others in connection with Civil Action No. CIV 97 0206 LH/JHG, United States District Court for the District of New Mexico. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

If you have any questions concerning the report, please contact me.

Sincerely,

S. S. PAPADOPULOS & ASSOCIATES, INC.

Stavros S. Papadopulos, PhD, PE
Founder & Senior Principal

cc: Secretary, Sparton Technology, Inc., c/o Ms. Susan Widener
Ms. Terri Donahue, Controller, Sparton Technology, Inc.
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Sparton Technology, Inc.
Former Coors Road Plant
Remedial Program

Evaluation of Alternative Systems and Technologies for Aquifer Restoration

Prepared for:

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Prepared by:

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Environmental & Water-Resource Consultants

November 25, 2009

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Executive Summary

Under the terms of Consent Decree entered on March 3, 2000 by the United States Environmental Protection Agency, the State of New Mexico, the County of Bernalillo, the City of Albuquerque, and Sparton Technology, Inc., Sparton is currently operating a containment system to control groundwater that was impacted by past activities at its former Coors Road Plant in Albuquerque, New Mexico. This system includes a source containment well pumping 50 gallons per minute immediately downgradient from the site and a off-site containment well pumping 225 gallons per minute near the leading edge of the off-site contaminant plume.

The goal of the containment system is to restore the impacted aquifer to beneficial use. To evaluate whether this goal can be achieved, Sparton was required to develop and calibrate a model for simulating groundwater flow and contaminant transport under the site and its vicinity, and to use this model for evaluating the performance of the existing and of alternative groundwater extraction systems. Other remedial technologies that do not involve groundwater extraction were also to be included in this performance evaluation.

The required model of the aquifer system was developed in early 2000 and revised and recalibrated several times during the last ten years of the operation of the containment system. In this report, the model was used to evaluate the performance of the existing containment system and of three alternative extraction systems consisting of increasing the pumping rate of the off-site well to 300 or 450 gallons per minute, or of adding a center-of-mass well pumping at 225 gallons per minute. A screening level evaluation of alternative remediation technologies is also included in the report. These evaluations lead to the following conclusions:

- The current sources of contaminants at the Sparton site are at the on-site area and within a low permeability geologic unit that underlies this area;
- The source containment well of the existing system may have to be operated for an indefinite period to contain contaminants that are originating from these sources;
- To restore the aquifer in the off-site area to beneficial use would require the operation of the existing system for a relatively long period of time, possibly as much as 25 years or more;;
- The alternative groundwater extraction systems that were evaluated may reduce the restoration time by 8 to 12 years;
- Only the alternative that considers increasing the pumping rate of the off-site well to 300 gallons per minute is cost-effective for implementation at the site; and
- None of the alternative technologies that were evaluated at a screening level are viable options for expediting aquifer restoration at the Sparton site.
- Based on these conclusions, it is recommended that:

- Data from on-site monitoring wells completed below the low permeability unit and from the source containment well be monitored to assess whether sources within the unit are as large as assumed in the evaluations; and
- The pumping rate of the off-site containment well is increased to 300 gallons per minute, upon approval by the regulatory agencies.

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Section 1
Introduction

Under the terms of Consent Decree[1] entered on March 3, 2000 by the United States Environmental Protection Agency (USEPA), the State of New Mexico, the County of Bernalillo, the City of Albuquerque, and Sparton Technology, Inc. (Sparton), Sparton is currently operating two groundwater extraction systems to contain groundwater that was impacted by past activities at its former Coors Road Plant located at 9621 Coors Boulevard NW, Albuquerque, New Mexico.

The first of these systems, the off-site containment system, was designed to contain impacted groundwater that had migrated several thousand feet (ft) beyond the boundaries of the former plant property and to prevent its further migration. The system, which began operating on December 31, 1998, consists of an off-site extraction well pumping at an average rate of about 225 gallons per minute (gpm), an off-site air stripper for treating the pumped water, and an infiltration gallery in the Arroyo de las Calabacillas for returning the treated water to the aquifer. The second system, the source containment system, was designed to contain and prevent the off-site migration of most of the impacted groundwater emanating from the former plant area. This system, which began operating on January 3, 2002, consists of an extraction well located immediately downgradient from the property and pumping at an average rate of about 50 gpm, an on-site air stripper and four on-site infiltration ponds. Further details on these systems are presented in Section 2.5 of the Annual Reports (S. S. Papadopulos & Associates, Inc. [SSP&A], 2001a; 2001b; and 2002 through 2009) that are submitted each year to USEPA and the New Mexico Environment Department (NMED).

The ultimate goal of these containment systems is to restore the impacted aquifer to beneficial use. To evaluate whether this goal can be achieved, the terms of the Consent Decree, also required Sparton to develop and calibrate a model for simulating groundwater flow and contaminant transport under the site and its vicinity and, when this model is deemed reliable for making future predictions, to use this model to evaluate the performance of the existing and of alternative groundwater extraction systems.[2] Other remedial alternatives that do not involve groundwater extraction but that may be applicable to the site were also to be included in this performance evaluation. Specifically, this evaluation was to include the following:

- Predicted future progress in restoration and projected restoration time with the existing containment systems, and discussion of the feasibility of restoration within a reasonable time period;
- Evaluation of alternate remedial systems involving groundwater extraction (e.g., center of mass extraction), the estimated time in which each alternative remedial system will achieve the restoration goal, and a discussion of its effectiveness, including cost-effectiveness, in accelerating aquifer restoration;

[1] Consent Decree. 2000. City of Albuquerque and the Board of County Commissioners of the County of Bernalillo v. Sparton Technology, Inc. U.S. District Court for the District of New Mexico. CIV 97 0206. March 3.

[2] Work Plan for the Assessment of Aquifer Restoration (SSP&A, 2000), Attachment D to the Consent Decree.

- Evaluation of alternate technologies, other than groundwater extraction, and discussion of their applicability to aquifer restoration at the site;
- Detailed discussion of any alternate remedial system, or technology, proposed for implementation at the site;
- If an alternate system or technology is not proposed for implementation, detailed discussion of the reasons why an alternative system or technology cannot be effectively implemented at the site; and
- Conclusions and recommendations for future actions, including an evaluation of whether attainment of cleanup standards is technically impracticable, as defined in federal regulations or guidance documents, or technically infeasible as defined under state regulations or guidance documents, or the necessity and appropriateness of seeking alternate abatement standards from NMWQCC.

The required groundwater flow and contaminant transport model of the aquifer system underlying the site and its vicinity was developed in early 2000 and revised in early 2004, as described in the 1999 and 2003 Annual Reports (SSP&A, 2001; 2004). The model was recalibrated each year against the data set that included new data for the year, and the results were presented in the Annual Report for that year. Major revisions were made to the model in early 2009 to provide a better simulation of regional groundwater flow conditions; these revisions and the results of the recalibration of the revised model were presented in the 2008 Annual Report (SSP&A, 2009). The revised and recalibrated flow and transport model was deemed reliable for evaluating the future performance of the containment systems and of alternative schemes involving groundwater extraction as required by the Consent Decree.

The purpose of this report is to present the results of the evaluations listed above, conclusions based on these evaluations, and recommendations for future actions. The predicted performance of the existing containment system is presented in Section 2. Section 3 describes other groundwater extraction alternatives that were evaluated, and presents the results of their evaluation. Section 4 provides a comparison of the existing containment system to the evaluated alternative extraction systems. Alternative technologies and their applicability, or inapplicability, to the site are discussed in Section 5. Conclusions and recommendations for future action are presented in Section 6, and cited references are listed in Section 7.

Section 2
Performance of the Existing Containment System

The flow and transport model that was developed to simulate groundwater flow and contaminant migration in the aquifer system underlying the site and its vicinity was used to evaluate the future performance of the existing containment system and of the alternative extraction systems that are discussed in Section 3. As discussed in the Section 1, major revisions were made to the model in early 2009 and the model was deemed reliable for making predictions of future conditions under the current or alternate extraction systems [see 2008 Annual Report (SSP&A, 2009)]. However, before using the model to evaluate the performance of the existing and of alternative remedial systems some additional adjustments were made to the initial (November 1998) TCE mass distribution of the model to improve its predictive capability. These adjustments are described in Appendix A.

The performance of the existing containment system was evaluated by running the model to the end of the year 2040. A time step of one year was used in these simulations. Until the end of 2010, the containment wells were operated at the average pumping rates observed during their past operation, 218 gallons per minute (gpm) for the off-site containment well (CW-1) and 48 gpm for the source containment well (CW-2). To facilitate comparison with other extraction alternatives, at the beginning of 2011, the date assumed to be the starting date for other potential alternatives, the pumping rates of the wells were adjusted to their design rates of 225 gpm for CW-1 and 50 gpm for CW-2. The predicted trichloroethene (TCE) concentrations in the water pumped from the source containment well CW-2, the TCE mass removed by the well, and the annual mass-removal rate are shown in Figure 1; the corresponding predictions for the off-site containment well CW-1 are shown in Figure 2.

Note that starting about 2009, the predicted TCE concentration in the water pumped from CW-2 and, therefore, the mass removal rate by the well [Figure 1(a) and (c)] begin to decline at a much slower rate than that observed during the past years of its operation. This behavior is due to the mass of TCE that was introduced into the model during the calibration process in the layer and area representing the portion of the 4,970-foot silt/clay unit that underlies the Sparton site. The soil vapor extraction (SVE) system that was operated at the site, and the infiltration of clean water from the ponds where the water pumped from CW-2 is discharged after treatment have drastically reduced the concentration of contaminants in on-site monitoring wells completed above the 4,970-foot unit. The source containment well, however, continues to produce water with TCE concentrations in the 50-100 µg/L range, and some of the on-site monitoring wells completed below the silt/clay unit (MW-19, MW-42, and MW-72) continue to have TCE concentrations greater than 100 µg/L. This indicates that while the more permeable sands and gravels above the silt/clay unit may now be free of sources of contamination, the silt/clay unit continues to have such sources; downward leakage through the unit and these sources slowly carries contaminants into the underlying aquifer mostly within the capture zone of CW-2. To simulate this process, the initial (November 1998) TCE concentration distribution that was used as the starting point for the model simulations was assumed to have significant concentrations of TCE within the 4,970-foot silt/clay unit, particularly in the vicinity of the former sump area.

The slow rate of release of the contaminants from this low-permeability unit into the capture zone of CW-2 causes the predicted concentrations and mass-removal rates for this well to decline at a much slower rate than in the past.

The actual mass of contaminants in the 4,970-foot silt/clay unit may be less than that assumed in the model. Note, for example, that TCE concentrations observed in CW-2 during 2008 and 2009 are lower than predicted by the model [Figure 1 (a)]. The fact remains, however, that there are contaminant sources within the silt/clay unit, and that the presence of these sources may require the source containment well CW-2 to be operated for a very long time, even after the off-site plume has been restored. Data from this well and from on-site monitoring wells completed below the silt/clay unit will continue to be evaluated to determine whether further adjustments are necessary to the mass of TCE that has been assumed to be present in the silt/clay unit. However, for the purposes of this report, well CW-2 is assumed to continue pumping for an indefinite period under the existing system and under the other groundwater extraction alternatives that were evaluated.

The TCE concentrations in the water pumped from the off-site containment well CW-1 [Figure 2 (a)] are predicted to reach the maximum contaminant level (MCL) of 5 μg/L for TCE in drinking water in the year 2023, and the current detection limit (DL) of 1 μg/L for this compound near the end of 2026. Any water pumped by the well after 2023 would not need to be treated as it would meet the water-quality requirements of the discharge permit for the infiltration gallery.

To compare the performance of the existing system with that of the alternatives discussed in the next section, a common criterion is needed for terminating the operation of off-site systems. For this purpose, and solely for this purpose, a plume area of less than an acre was selected as a convenient termination criterion. That is, it was assumed that the off-site well, or off-site wells, could be shut down at the end of the year during which the areal extent of the TCE plume[3] becomes less than one acre. The areal extent of the plume at the end of each annual time step of the simulation was calculated until it was less than one acre. A plot of the results of these calculations is shown in Figure 3. As shown in this figure, the existing system will meet the one-acre plume criterion during 2035; therefore, the off-site well is assumed to be shutdown at the end of that year. The areal extent of the plume at the time of the shutdown is shown in Figure 4. Note that the only remaining plume areas at that time are those associated with the leakage from the edge of the 4970-foot silt/clay unit. The mass of TCE present in these plume areas is about 0.02 kg and, even if these plumes are not artifacts of the modeling process, they would not impact downgradient users of groundwater, the closest of which is about 2 miles away (see Appendix D of the 2008 Annual Report, SSP&A, 2009).

[3] As also discussed in the Annual Reports for the Sparton site, the areal extent of the TCE plume is defined by the 5 μg/L contour generated by kriging the horizontal projection of the maximum concentrations present at any depth within the aquifer.

Section 3
Other Groundwater Extraction Alternatives

The groundwater flow and transport model was also used to evaluate three other groundwater extraction alternatives. In the first alternative the pumping rate of CW-1 is increased to 300 gpm, the design capacity of the off-site treatment system. In the other two alternatives extraction from the off-site area is doubled to 450 gpm either by increasing the pumping rate of CW-1 to 450 gpm, or by adding a new "center-of-mass" extraction well, CW-3, to the off-site extraction system and pumping this well at 225 gpm. The proposed location for this new well is shown in Figure 5. To summarize, the three alternatives that were evaluated are:

- Alternative 1 - Increase the pumping rate of CW-1 to 300 gpm;
- Alternative 2 - Increase the pumping rate of CW-1 to 450 gpm; and
- Alternative 3 - Add a center-of-mass well pumping at a rate of 225 gpm.

Under all three of these alternatives, source containment well CW-2 is assumed to continue to pump at 50 gpm; the concentration in and mass removal by the well remains the same as that shown in Figure 1. The implementation date for any of these three alternatives is assumed to be the beginning of 2011, and the performance of the alternatives is simulated until they meet the termination criterion of "a plume of less than one acre" for shutdown.

3.1 Alternative 1 - Well CW-1 Pumping at 300 gpm

The predicted TCE concentrations in the pumped water, the mass removed, and the mass removal rate by CW-1 under this alternative are shown in Figure 6. At this pumping rate, the TCE concentrations in the water pumped from the well [Figure 6 (a)] are predicted to reach the MCL of 5 μg/L in the year 2020, and the DL of 1 μg/L near the end of 2023. Thus, the water pumped by the well after 2020 would meet, without treatment, the water-quality requirements of the discharge permit for the infiltration gallery. The well continues to pump until it meets the one-acre termination criterion. This occurs during 2027 (see Figure 7) and the well is shut down at the end of that year. The only plume that remains at that time (Figure 8) is that associated with the silt/clay unit leakage.

3.2 Alternative 2 - Well CW-1 Pumping at 450 gpm

The predicted TCE concentrations in the pumped water, the mass removed, and the mass removal rate by CW-1 under this alternative are shown in Figure 9. At this pumping rate, the TCE concentrations in the pumped water are predicted to reach the MCL in the year 2019, and the DL near the end of 2022. The termination criterion is met during 2025 (see Figure 10) and the well is shut down at the end of that year. The plume extent at that time is shown in Figure 11; again, the only plume that remains at that time is that associated with the silt/clay unit leakage.

3.3 Alternative 3 – Add Center-of-Mass Well CW-3

In this alternative, the off-site containment well CW-1 continues to pump at its original design rate of 225 gpm; a new center-of-mass well, CW-3, located as shown in Figure 5 begins pumping, also at a rate of 225 gpm, at the beginning of 2011. The predicted TCE concentrations in the pumped water, the mass removed, and the mass removal rate by CW-1 and CW-3 under this pumping conditions are shown in Figures 12 and 13, respectively. The mass removed by both wells and the combined mass removal rate is shown in Figure 14. Well CW-1 reaches the MCL during 2019 and the DL during 2021. Well CW-3 also reaches the MCL during 2019 but continues to pump water with concentration above the DL until near the end of 2023. The two-well system also meets the termination criterion during that year (see Figure 15) and it is shut down at the end of 2023. The extent of the plume at the time of the shutdown is shown in Figure 16. Note that besides the plumes associated with the leakage along the edge of the silt/clay unit there is also a small off-site plume between the two extraction wells, CW-1 and CW-3; this plume is due to the stagnation point that was present in this area when both wells were pumping. The total TCE mass the remains within all these plumes less than 0.04 kg and would not impact any other users of groundwater.

Section 4
Comparison of Existing and Alternative Extraction Systems

The existing containment system is capturing the contaminant plume that originated from the Sparton site and will eventually restore the aquifer in the off-site area; however, the evaluation of its performance indicates that it would take several decades to achieve this goal. The evaluation of the system also indicates that the source containment well CW-2 may need to be operated for a long time, even after the off-site area has been restored, depending on the mass of contaminants that are present in the 4970-foot silt/clay unit underlying the site and the rate at which these contaminants are released into the more permeable sands and gravels within the capture zone of the well.

The three other off-site extraction alternatives that were evaluated are also all capable of restoring the aquifer in the off-site area downgradient from the Sparton site, with a relatively small difference in the time each one would achieve this goal. The times at which the existing system and these three alternatives will meet different water-quality milestones and the selected termination criterion of a plume area of less than acre are summarized on Table 1; also shown on this table are the calculated plume areas and the mass of TCE that remains within the plumes at the time of termination.

Note that an increase in the pumping rate of CW-1 by 75 gpm (Alternative 1) appears to reduce considerably the time that would be required to meet the termination criterion. Additional reductions in the restoration time are achieved with a higher pumpage by CW-1 (Alternative 2) or by the addition of a new center-of-mass well (Alternative 3), although these reductions are rather modest, two years each.

In terms of reducing restoration time, Alternative 3 is the best of the evaluated alternatives, but an analysis of the costs for operating the existing system and of implementing and operating the alternatives is necessary to determine whether any of these alternatives is cost-effective for implementation. There are no capital improvement costs that have to be incurred to continue with the existing system. The infiltration gallery, which was installed in 1999, is estimated to have a life of 20 years at the current operating rate and is, therefore, assumed that will need to be replaced in 2019; for alternatives with higher operating rates the gallery life was assumed to reduce in proportion to the operating rate. Implementation of Alternative 1 has only one capital improvement cost which is associated with replacing the pump in CW-1 with a larger pump that can handle 300 gpm; the existing treatment system had been designed for 300 gpm and can treat the water pumped under this alternative. The pump has also to be replaced for Alternative 2, but this alternative will also require an additional air stripper to increase the treatment capacity to 450 gpm. Finally, Alternative 3 will require buying a residential lot, obtaining permits and easements for installing the new well, installing and equipping the well, installing a double-containment pipeline to the location of the CW-1 treatment facility,[4] and also adding an air stripper to the treatment facility.

Operation and Maintenance (O&M) for the existing system were based on the average actual O&M costs incurred for operating the system during the last five years, excluding costs associated with the operation of CW-2. For the alternative extraction systems, O&M costs were increased to include estimated additional power and other O&M costs that would be incurred after their implementation. For all four options, O&M costs also include other costs that are attributed to the operation of the off-site systems; for example, these costs include the costs of collecting, evaluating, and reporting the data collected from these systems, and of administrative costs associated with the operation of the systems. Also, for all four options, the treatment plant was assumed to be operating until termination although the discharge permit requirements will be met at an earlier date by the untreated influent to the plant.

The capital improvement, replacement, and O&M costs discussed above, and their present values are summarized on Table 2.[5] The results of this cost analysis indicate that Alternative 1, that of increasing the pumping rate of CW-1 to 300 gpm, is a cost-effective alternative that may reduce the aquifer restoration time by about 8 years, and which will cost less than the existing system. The present value of the costs for Alternatives 2 and 3 is about one-half to one million dollars more than that of the cost for Alternative 1, and they provide only modest additional reductions in restoration time that do not justify their higher costs. Based on these results of the cost analysis, it is proposed that Alternative 1 be implemented.

It should be noted that the model analysis that forms the basis of these evaluations assumes that, except for the 4,970-foot silt/clay unit, the underlying aquifer materials do not retard the migration of TCE. This is a good assumption if the aquifer materials consist solely of sands and gravels, but it would be expected that the aquifer also contains some finer-grained materials that would retard the migration of TCE and result at longer times for meeting the termination criteria. However, this would a factor in the evaluation of both the existing and of the alternative extraction systems and would be expected to affect similarly the results of each evaluation; therefore, the results of the comparative analysis presented above would not be expected to be significantly different.

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[4] Conveying the water pumped from CW-3 to the on-site CW-2 treatment facility was also considered, but this was more costly than conveying the water to the CW-1 facility.

[5] Cost data for this analysis were provided by Metric Corporation (personal communication, Gary Richardson, November 2009)

Section 5
Evaluation of Alternative Technologies

An evaluation of alternative remedial technologies was conducted to determine their applicability to the Sparton site. Only technologies that have demonstrated effectiveness in remediating groundwater contaminated with chlorinated hydrocarbons were considered in this evaluation. These technologies were evaluated based on their potential for meeting site remediation goals, feasibility of implementation, anticipated costs, and other factors.

5.1 Selected Alternative Technologies

The remedial technologies selected for evaluation were identified from the Federal Remediation Technologies Roundtable, Remediation Technologies Screening Matrix and Reference Guide, Version 4.0 (http://www.frtr.gov) and the Environmental Security Technology Certification Program (ESTCP) (http://www.estcp.org/Technology/ER-Chlorinated-Solvents.cfm). The selection process focused on in-situ technologies that potentially can be used to replace or supplement the existing containment systems.

Potential in-situ remediation technologies fall into two categories: (1) biological treatment, and (2) physical/chemical treatment. In-situ biological treatment technologies include enhanced bioremediation, monitored natural attenuation, and phytoremediation. Dissolved oxygen (DO) and oxidation/reduction potential (ORP) data collected in past years from site monitoring wells indicate that natural attenuation is unlikely to occur in the groundwater environment underlying the site and concentrations of TCE degradation products indicate that biodegradation is not occurring [see 2007 Annual Report (SSP&A, 2008), Section 5.2.2]. Also the depth to the water table (100-200 feet) precludes phytoremediation. Thus, of the three biological treatment technologies, only enhanced anaerobic bioremediation is appropriate for consideration at the Sparton site. The physical/chemical treatment technologies that were considered as potentially applicable to the Sparton site are air sparging, chemical oxidation, and in-well air stripping.

To summarize, the following four alternative remedial technologies were reviewed for this screening-level evaluation:

1. Enhanced anaerobic bioremediation;
2. Air sparging;
3. Chemical oxidation; and
4. In-well air stripping.

Brief descriptions of these selected four technologies are presented in the section that follows.

5.2 Description of Selected Technologies

5.2.1 Enhanced Anaerobic Bioremediation

Enhanced anaerobic bioremediation involves the delivery of electron donors into the subsurface for the purpose of stimulating microbial growth and development. The electron donors are generally organic compounds that are added to create anaerobic groundwater treatment zones and to generate hydrogen through fermentation reactions, thereby creating conditions conducive to the anaerobic biodegradation of chlorinated solvents dissolved in groundwater. One of the primary mechanisms for the breakdown of chlorinated solvents is anaerobic reductive dechlorination. Some of the organic compounds that have been used for Enhanced anaerobic bioremediation include soluble substrates (molasses, lactate, cheese whey), vegetable oil (soybean, corn, etc.) and oil emulsions, and proprietary polymerized organics (HRC). Key design parameters include existing geochemical conditions, substrate selection, injection /methods, and projected subsurface distribution.

5.2.2 Air Sparging

Air sparging is an in-situ technology in which air is injected through a contaminated aquifer. Injected air traverses horizontally and vertically in channels through the soil column, creating an underground treatment zone that removes contaminants by volatilization. This injected air helps to flush (bubble) the contaminants up into the unsaturated zone where a vapor extraction system is usually implemented in conjunction with air sparging to remove the generated vapor phase contamination. Factors that may limit the applicability and effectiveness of the process include:

1. Air flow through the saturated zone may not be uniform, with preferential flow along narrow vertical paths;
2. Depth of contaminants and specific site geology must be considered; and
3. Soil heterogeneity may cause some zones to be relatively unaffected.

5.2.3 Chemical Oxidation

Chemical oxidation involves the injection of chemicals into the impacted groundwater zone to oxidize hydrocarbon contaminants. The chemical oxidants most commonly employed include peroxide, ozone and permanganate. These oxidants cause the rapid chemical destruction of many toxic organic chemicals; other organics are amenable to partial degradation as an aid to subsequent bioremediation. Key design parameters include matching the oxidant and *in situ* delivery system to the contaminants of concern (COCs) and the site conditions. The rate and extent of degradation of a target COC are dictated by the properties of the chemical itself and its susceptibility to oxidative degradation as well as the matrix conditions, most notably, pH, temperature, the concentration of oxidant, and the concentration of other oxidant-consuming substances such as natural organic matter. One institutional limitation of the technology is the requirement for handling large quantities of hazardous oxidizing chemicals.

5.2.4 In-Well Air Stripping

In-well air stripping involves injecting air into a vertical well that has been screened at two depths. The lower screen is set near the bottom groundwater zone to be treated, and the upper screen is set near the water table. Pressurized air is injected into the well just above the lower well screen, aerating the water. The aerated water rises in the well and flows out of the system at the upper screen. Contaminated groundwater is drawn into the system at the lower screen. The volatile organic compounds transfer from the groundwater to the air as the air bubbles rise within the well. The vapors are drawn off the top of the well by a vapor extraction system for treatment and venting. The partially treated ground water is never brought to the surface; it is moved from the bottom of the treatment zone to the water table by the rising bubbles, then circulates through the aquifer to the lower screen. The process is repeated as water follows a hydraulic circulation pattern or cell that allows continuous cycling of ground water. Because ground water is not pumped above ground, pumping costs and permitting issues are reduced. Limitations include potential fouling of the system by precipitation of oxidized constituents and short circuiting at sites with heterogeneous conditions and/or strong natural flow patterns. This technology is considered to be still in the demonstration phase of development.

5.3 Applicability to the Sparton Site

Each of the four in-situ technologies described above is a promising candidate for the remediation of chlorinated hydrocarbons under the appropriate hydrogeologic conditions. These technologies are particularly well-suited for the remediation of "source" areas and/or of plumes of limited extent in relatively shallow groundwater.

At the Sparton site, sources in the unsaturated zone and within the saturated sands and gravels above the 4,970-foot silt/clay unit have been remediated through the past operation of a soil vapor extraction (SVE) system and the increased groundwater flow induced by infiltration from the ponds that receive the treated groundwater from the source containment system. The current sources of contaminants at the on-site area are within the 4,970-foot silt/clay unit. This presents significant mass transfer limitations for these technologies because chlorinated hydrocarbons tend to adsorb on the silt and clay particles. Furthermore, due to the low permeability and heterogeneity of the unit most of the contaminants in the source areas would not be accessible to the biological, chemical, or physical treatment media. Thus, these technologies are not applicable to the on-site area because they would not be effective in remediating the contaminant sources present in the silt/clay unit that underlies this area.

Aquifer permeability and heterogeneity is less of a problem in the off-site plume area. However, there are no off-site source areas where these treatment technologies could be focused. The off-site plume extends about 2,700 feet downgradient from the site boundary and is more than 1,000 feet wide. To obtain adequate distribution of biological, chemical, or physical treatment media for remediating this plume several "injection" or treatment points would be required in either a barrier formation across the plume or in a matrix covering the plume area. The depth to water table in the off-site plume area ranges from about 100 feet immediately downgradient of the site to more than 200 feet near the leading edge of the plume, and the aquifer thickness is about 160 feet. Furthermore, most of the off-site plume is under a residential area. Besides the difficulty of finding appropriate locations for installing injection points in a residential area, the costs for installing and maintaining these injection points, even for just a barrier across the approximately 1000-foot wide plume, would be prohibitive. The implementation of these in-situ technologies to remediate the off-site plume is not, therefore, cost-effective because of the size of the plume, the depth to the water table, and the thickness of the impacted aquifer.

Section 6
Conclusions and Recommendations

The evaluation of the existing containment system that controls impacted groundwater at the Sparton site, of three alternative extraction systems that could be implemented at the site, and of four alternative technologies that have demonstrated effectiveness in remediating groundwater contaminated with chlorinated hydrocarbons leads to the following conclusions:

- The current sources of contaminants at the Sparton site are at the on-site area and within the low permeability silts and clays of the 4,970-foot silt/clay unit that underlies this area;
- The source containment well of the existing system may have to be operated for an indefinite period to contain contaminants that are originating from these sources;
- To restore the aquifer in the off-site area to beneficial use would require the operation of the existing system for a relatively long period of time, possibly as much as 25 years or more;
- The three alternative groundwater extraction systems that were evaluated may reduce the restoration time by 8 to 12 years;
- Only one of the three alternatives that were evaluated, that of increasing the pumping rate of the off-site containment well to 300 gpm, is cost-effective for implementation at the site; and
- None of the alternative technologies that were evaluated at a screening level are viable options for expediting aquifer restoration at the Sparton site because of the nature of the sources, the size of the plume, the depth to the water table, and the thickness of the impacted aquifer.

Based on these conclusions, it is recommended that:

- Data from on-site monitoring wells completed below the 4,970-foot silt/clay unit and from the source containment well be monitored during the next few years to assess whether the assumptions concerning the magnitude of the sources within this unit need to be revised; and
- The pumping rate of the off-site containment well is increased to 300 gpm, upon approval by USEPA and NMED and the implementation of the necessary changes to the containment system.

Section 7
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FIGURES

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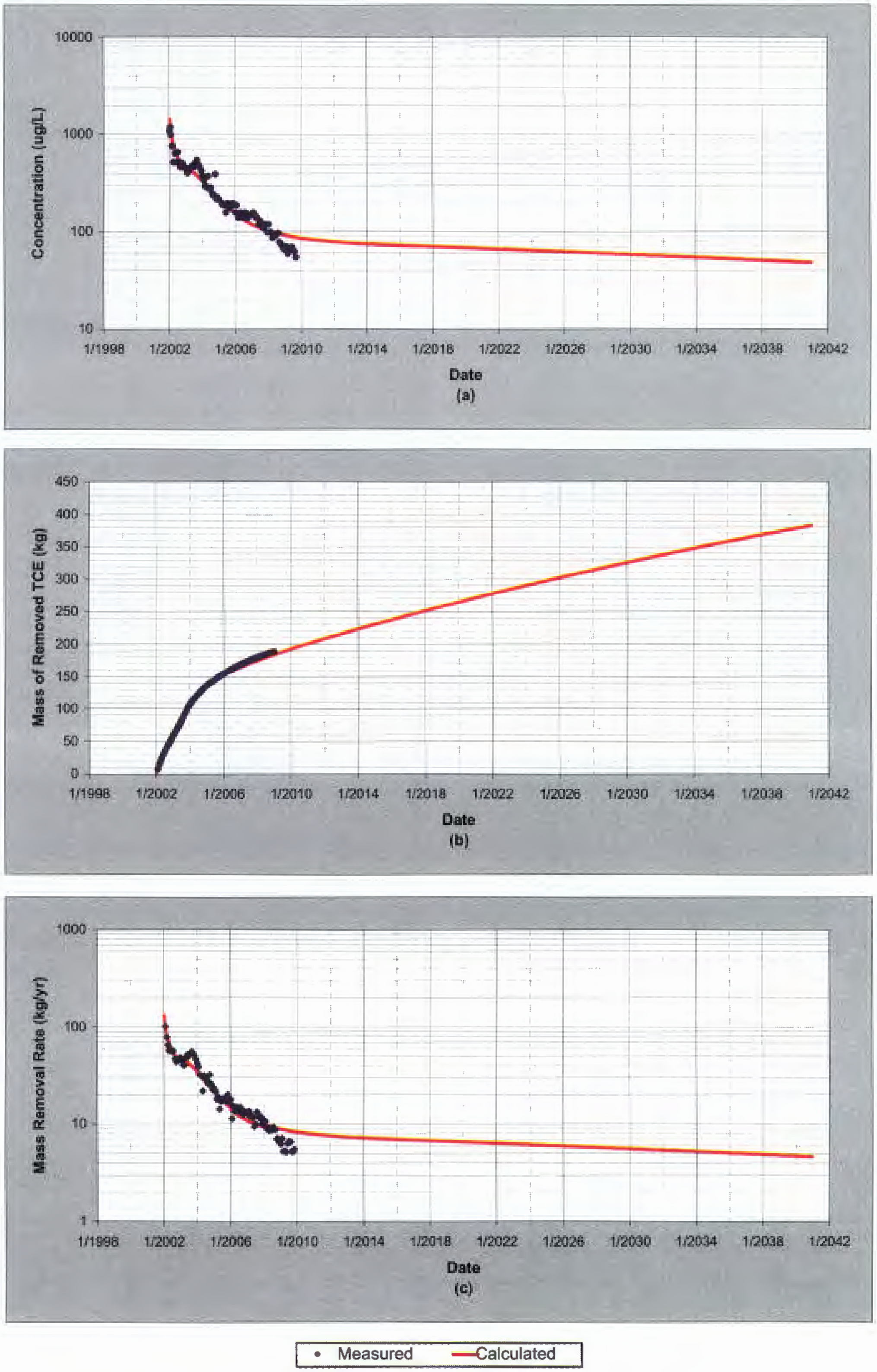


Figure 1 Existing System - Predicted Concentration, Mass Removal, and Mass Removal Rate for Source Containment Well CW-2

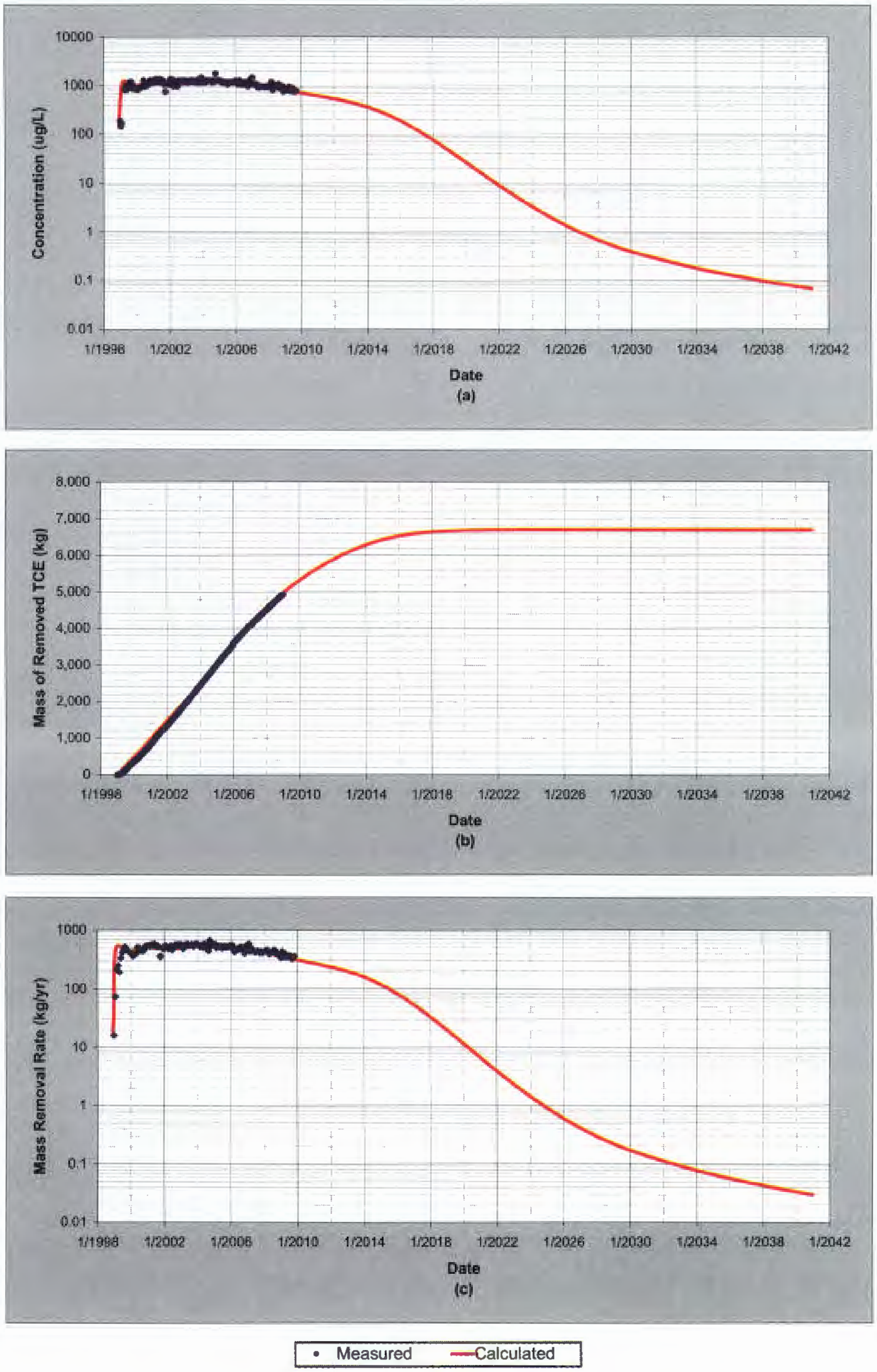


Figure 2 Existing System - Predicted Concentration, Mass Removal, and Mass Removal Rate for Off-Site Containment Well CW-1

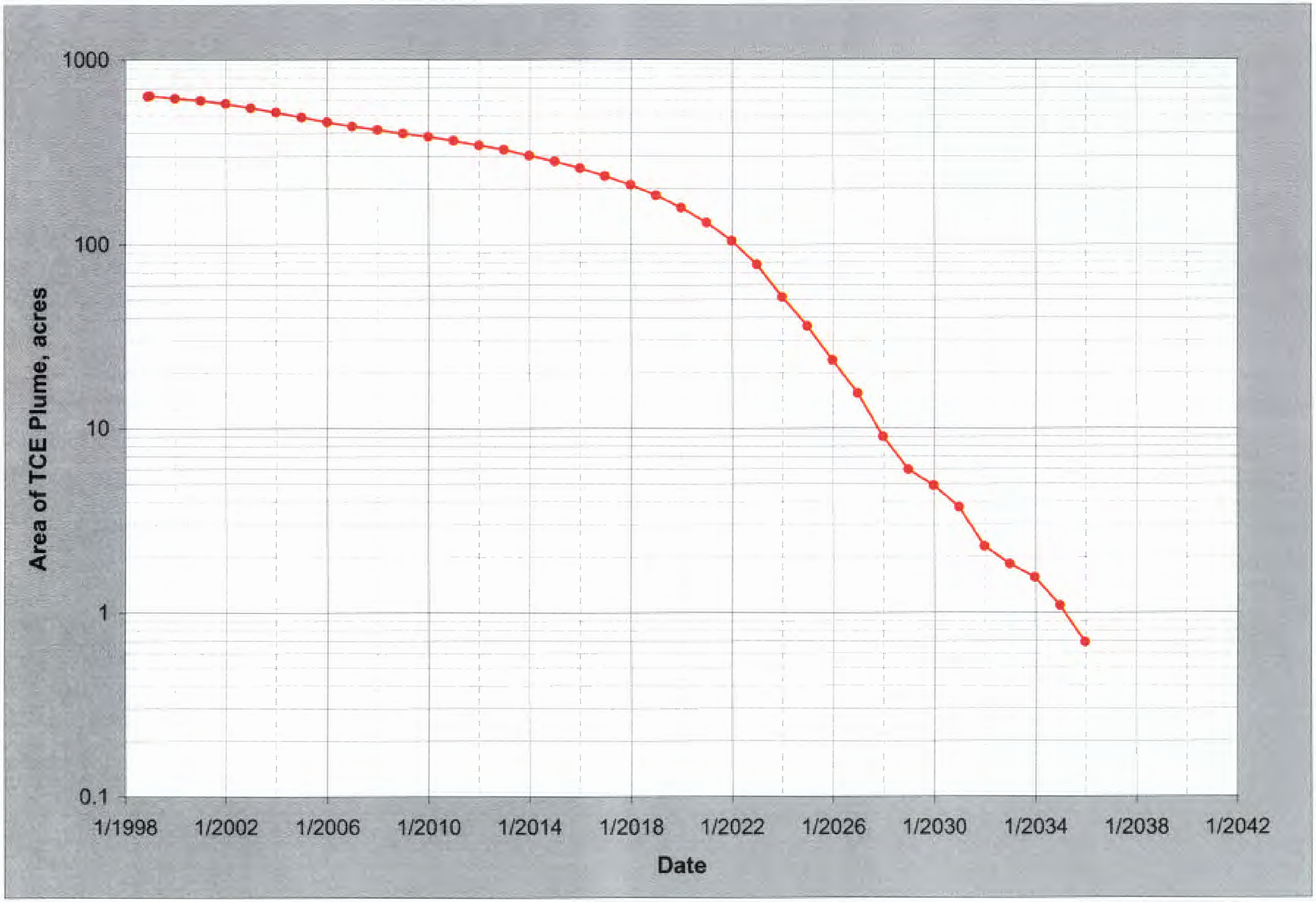


Figure 3 Existing System - Variation of the Area of the TCE Plume Outside the Capture Zone of CW-2

Figure 4 Existing System - Predicted Extent of TCE Plume Outside the Capture Zone of CW-2 when CW-1 is Shut Down (end of 2035)

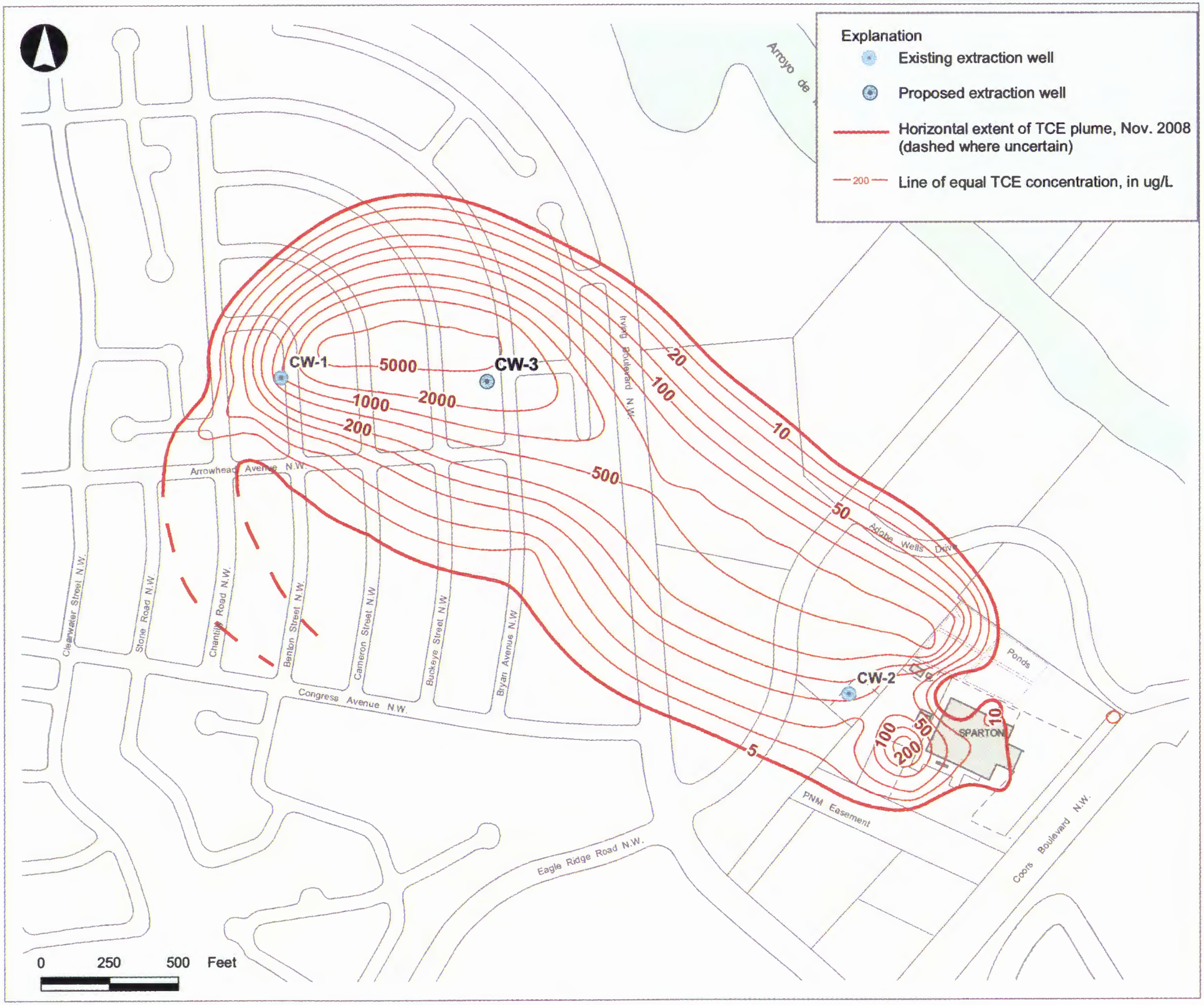


Figure 5 Proposed Location of Center-of-Mass Well CW-3 for Alternative 3

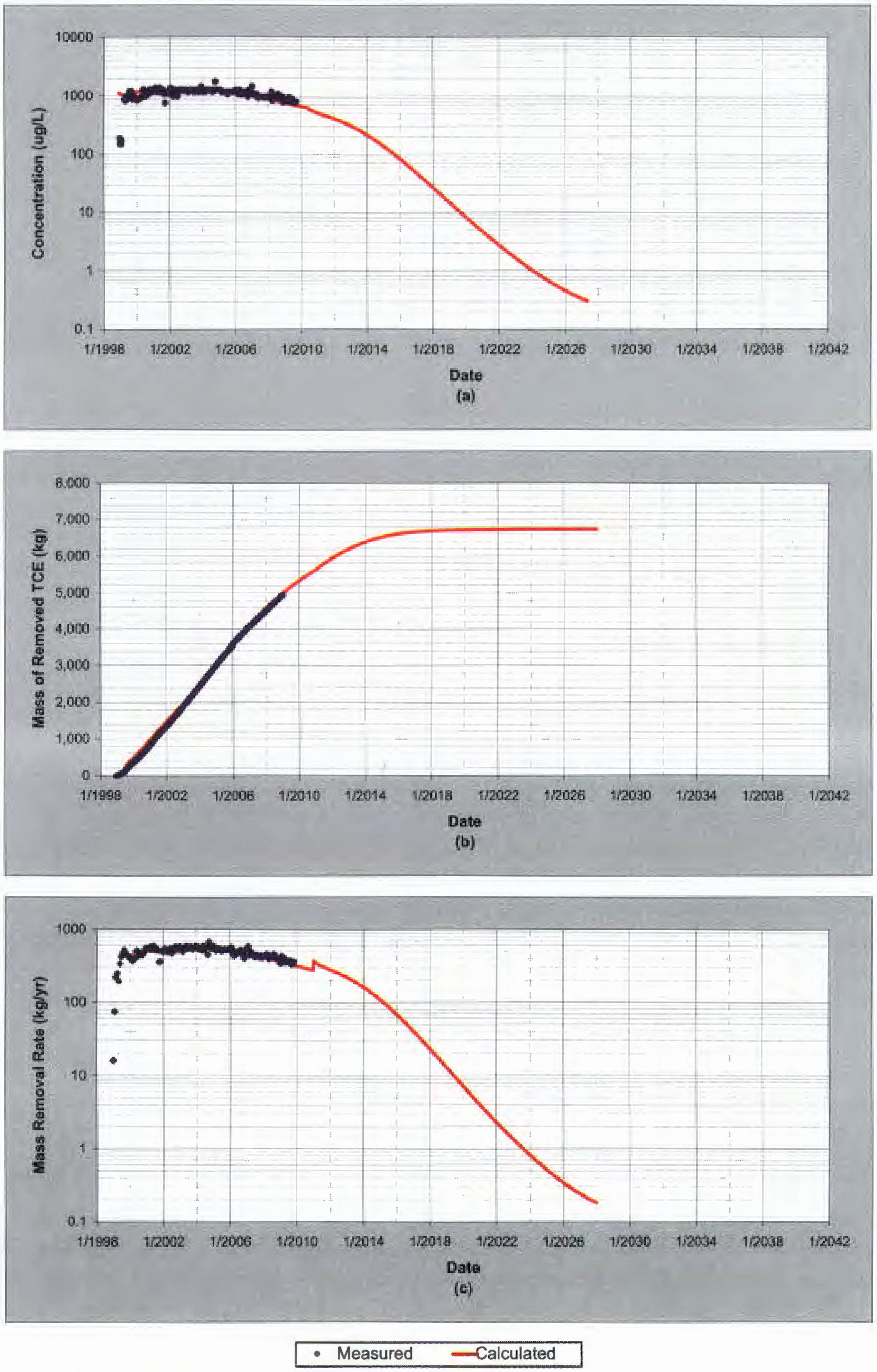


Figure 6 Alternative 1 - Predicted Concentration, Mass Removal, and Mass Removal Rate for Off-Site Containment Well CW-1

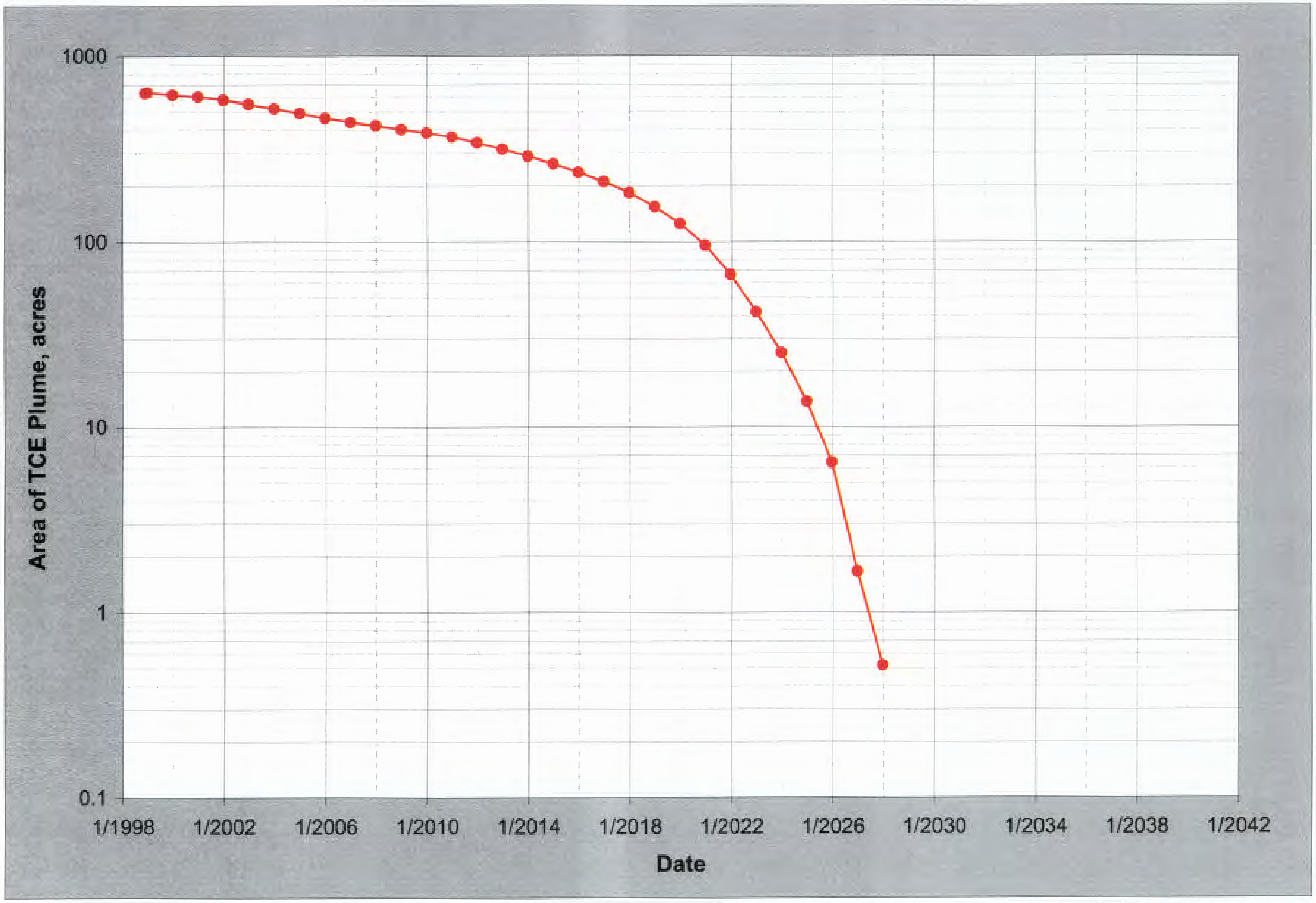


Figure 7 Alternative 1 - Variation of the Area of the TCE Plume Outside the Capture Zone of CW-2

Figure 8 Alternative 1 - Predicted Extent of TCE Plume Outside the Capture Zone of CW-2 when CW-1 is Shut Down (end of 2027)

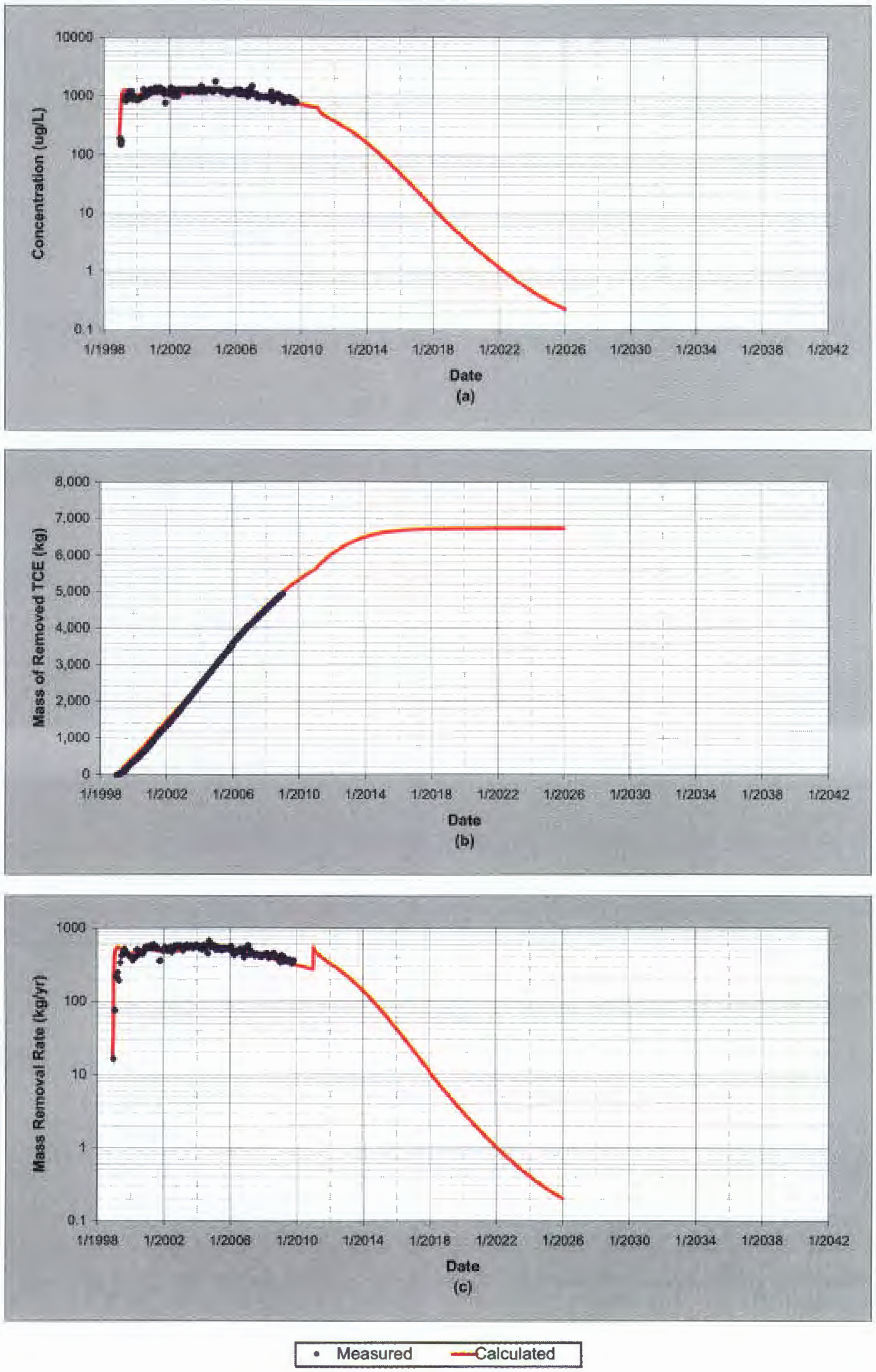


Figure 9 Alternative 2 - Predicted Concentration, Mass Removal, and Mass Removal Rate for Off-Site Containment Well CW-1

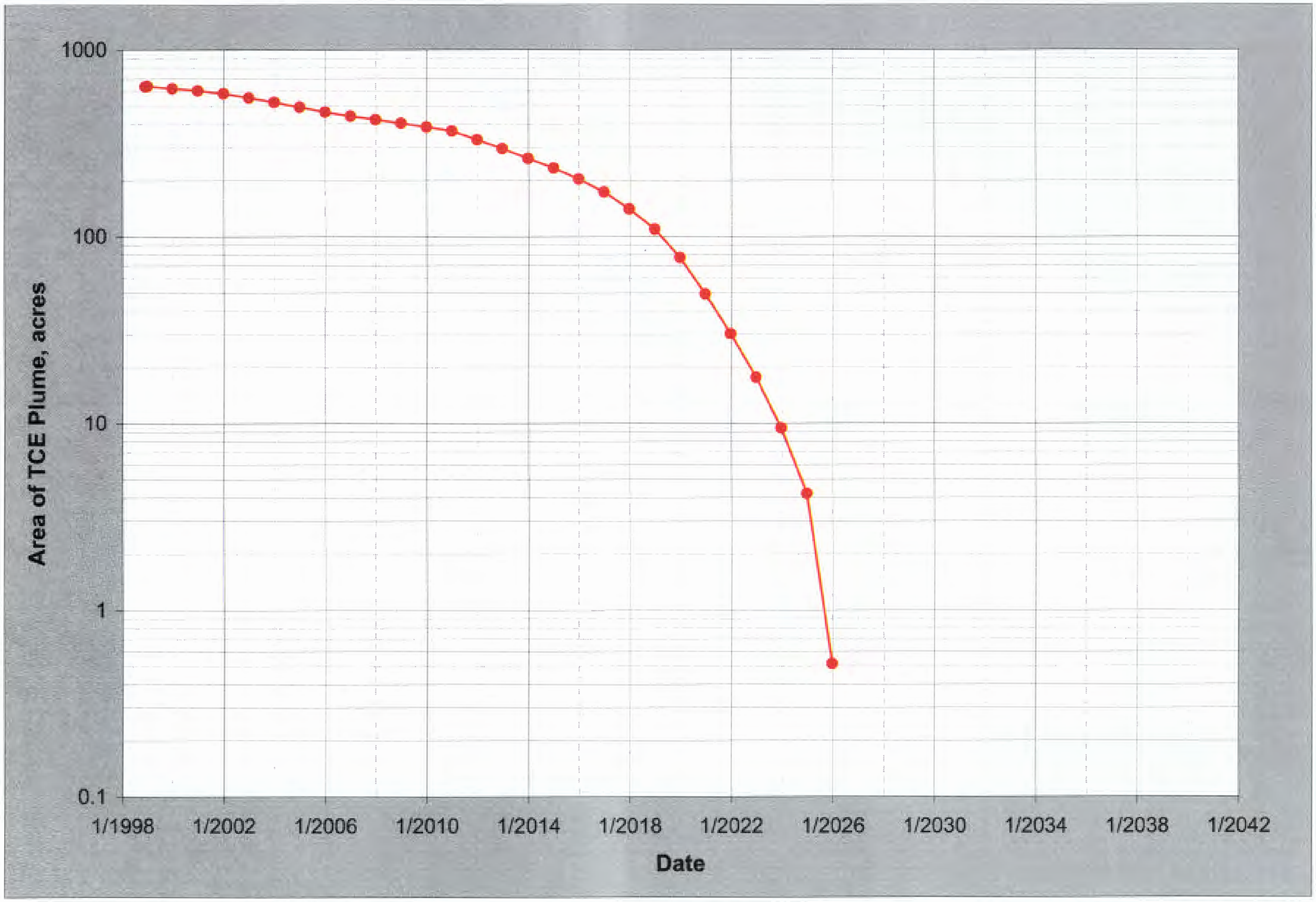


Figure 10 Alternative 2 - Variation of the Area of the TCE Plume Outside the Capture Zone of CW-2

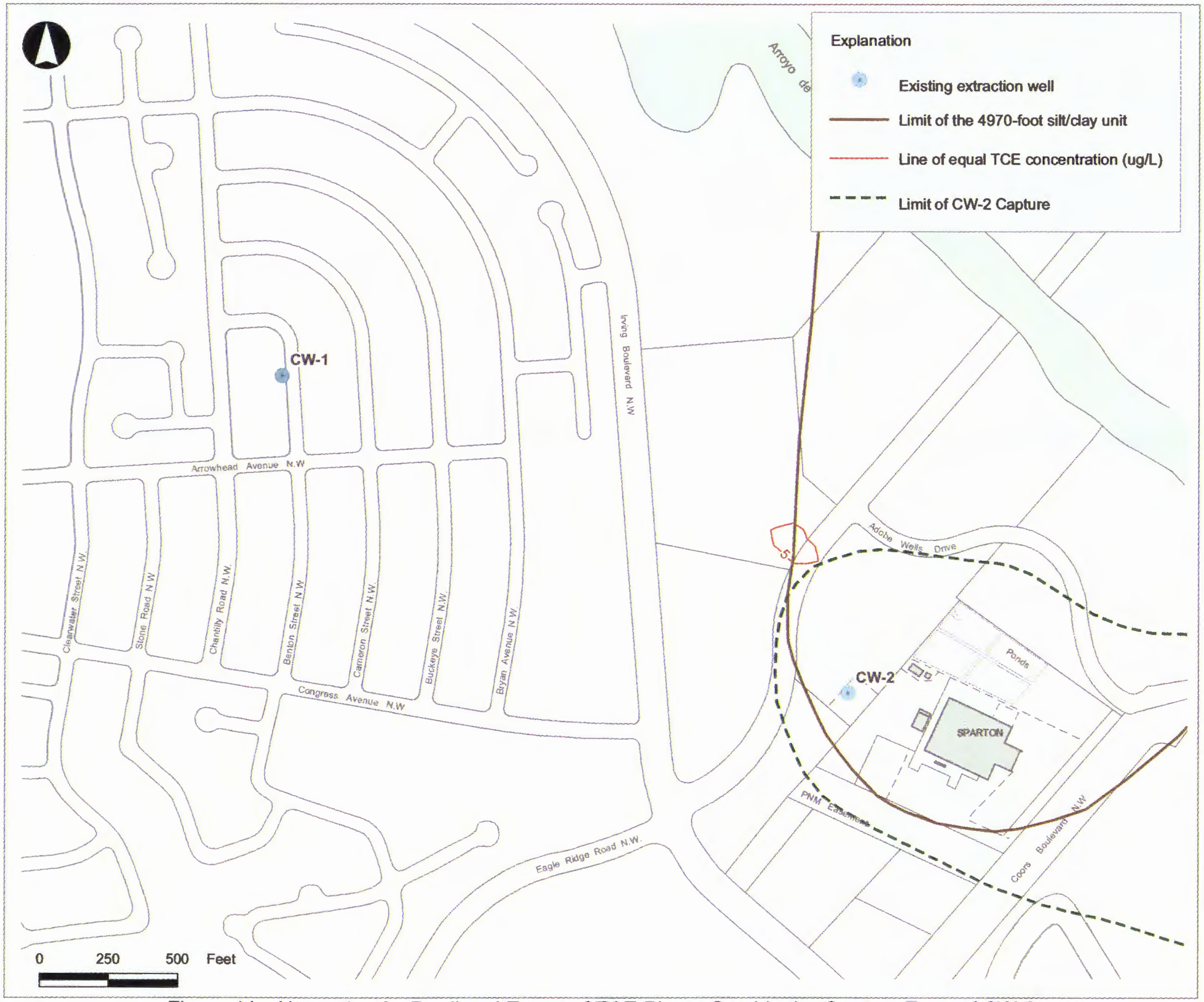


Figure 11 Alternative 2 - Predicted Extent of TCE Plume Outside the Capture Zone of CW-2 when CW-1 is Shut Down (end of 2025)

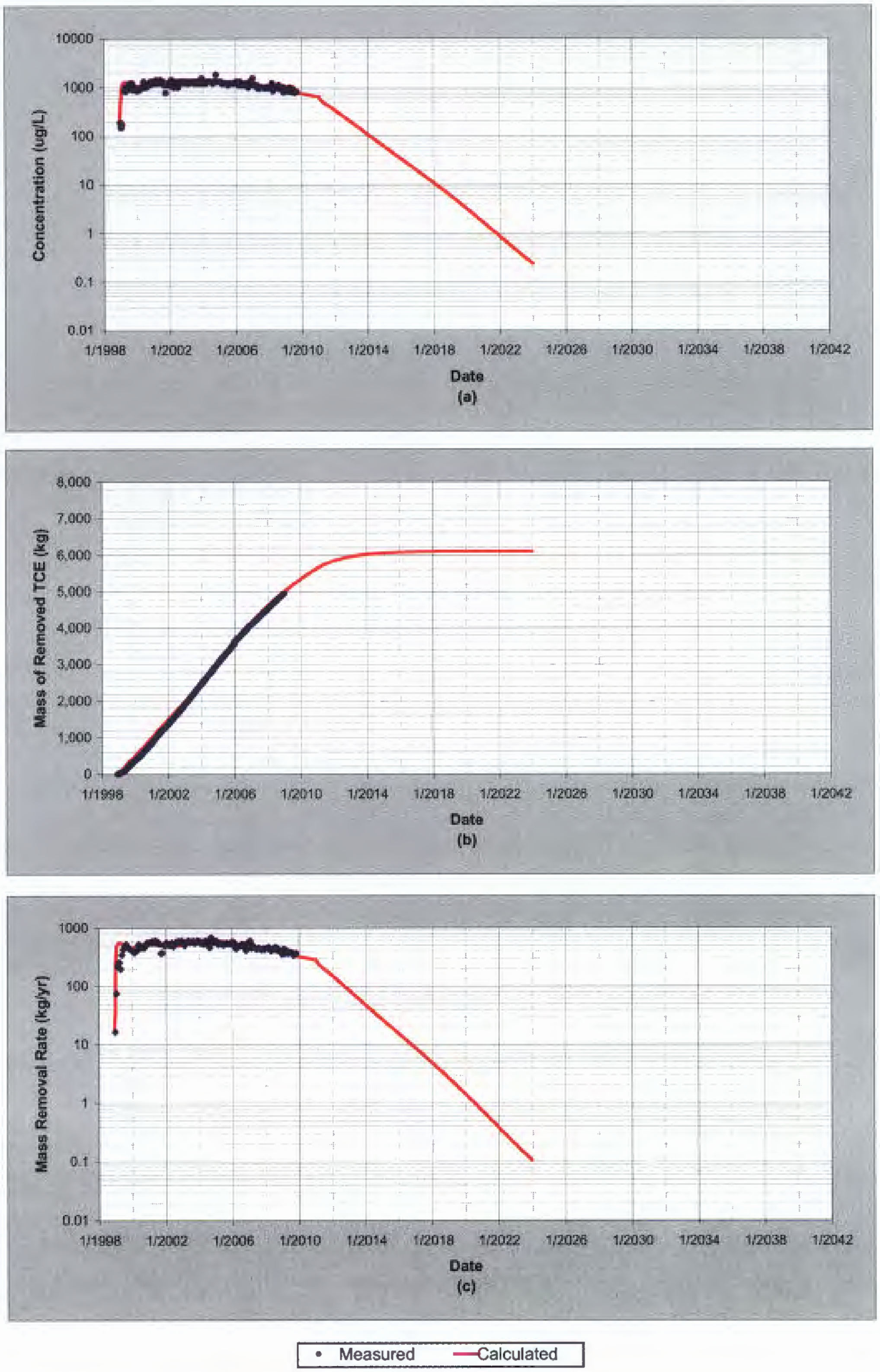
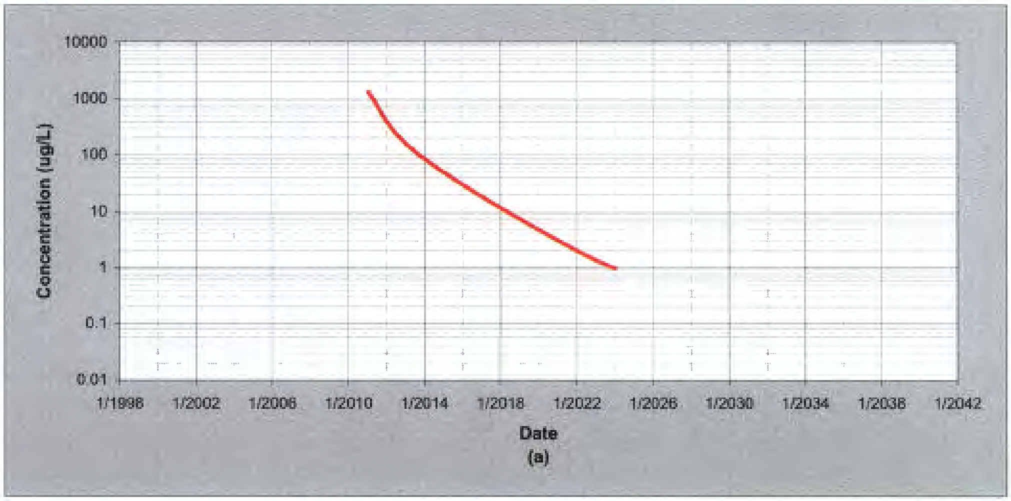
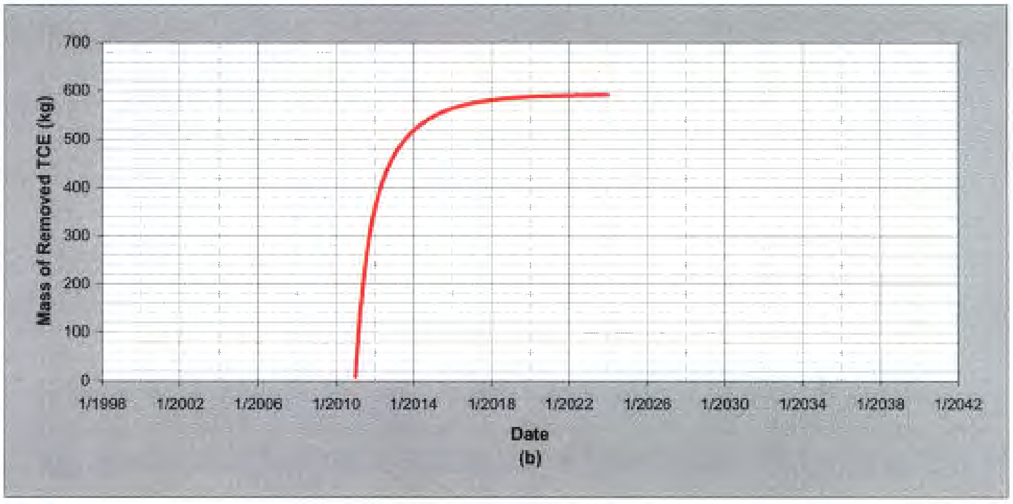


Figure 12 Alternative 3 - Predicted Concentration, Mass Removal, and Mass Removal Rate for Off-Site Containment Well CW-1





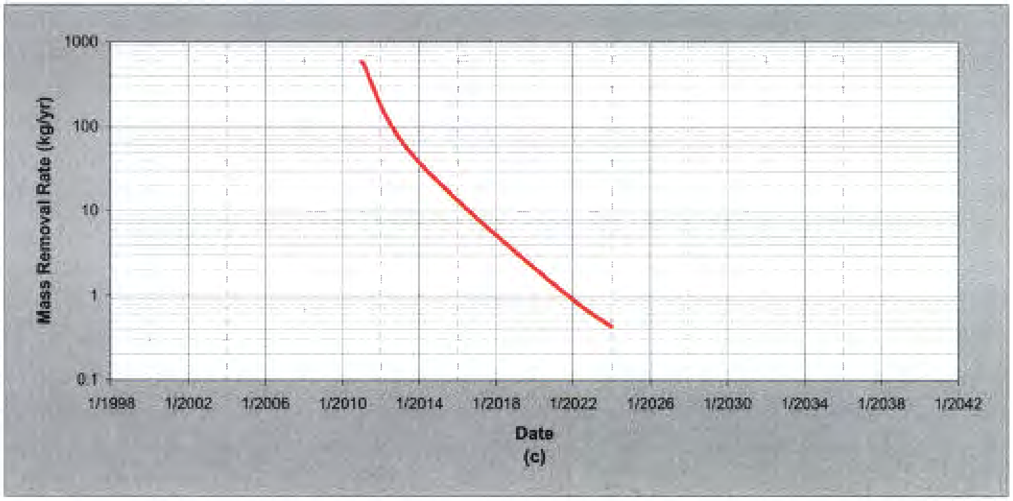


Figure 13 Alternative 3 - Predicted Concentration, Mass Removal, and Mass Removal Rate for Center-of-Mass Well CW-3

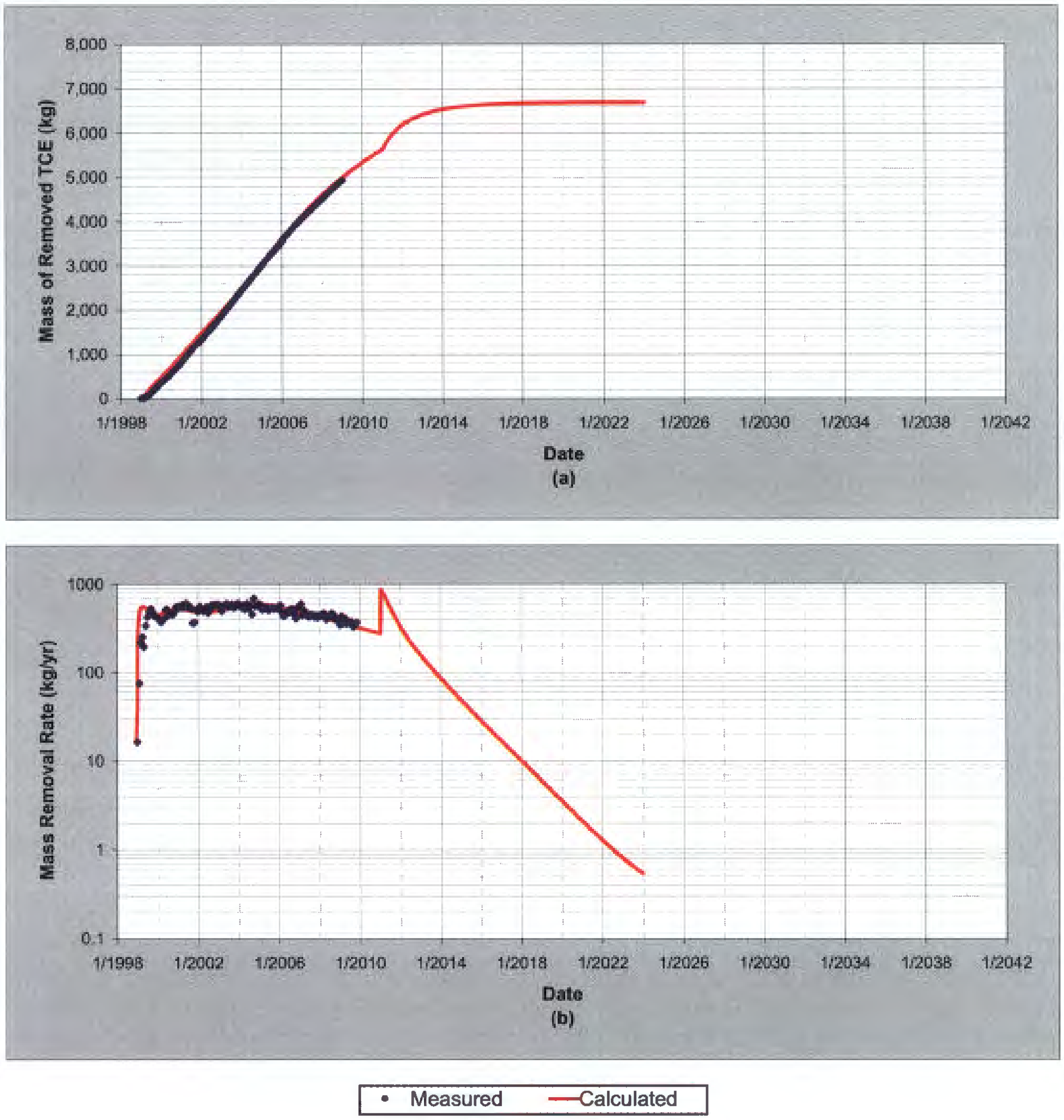


Figure 14 Alternative 3 - Predicted Combined Mass Removal and Mass Removal Rate for Wells CW-1 and CW-3

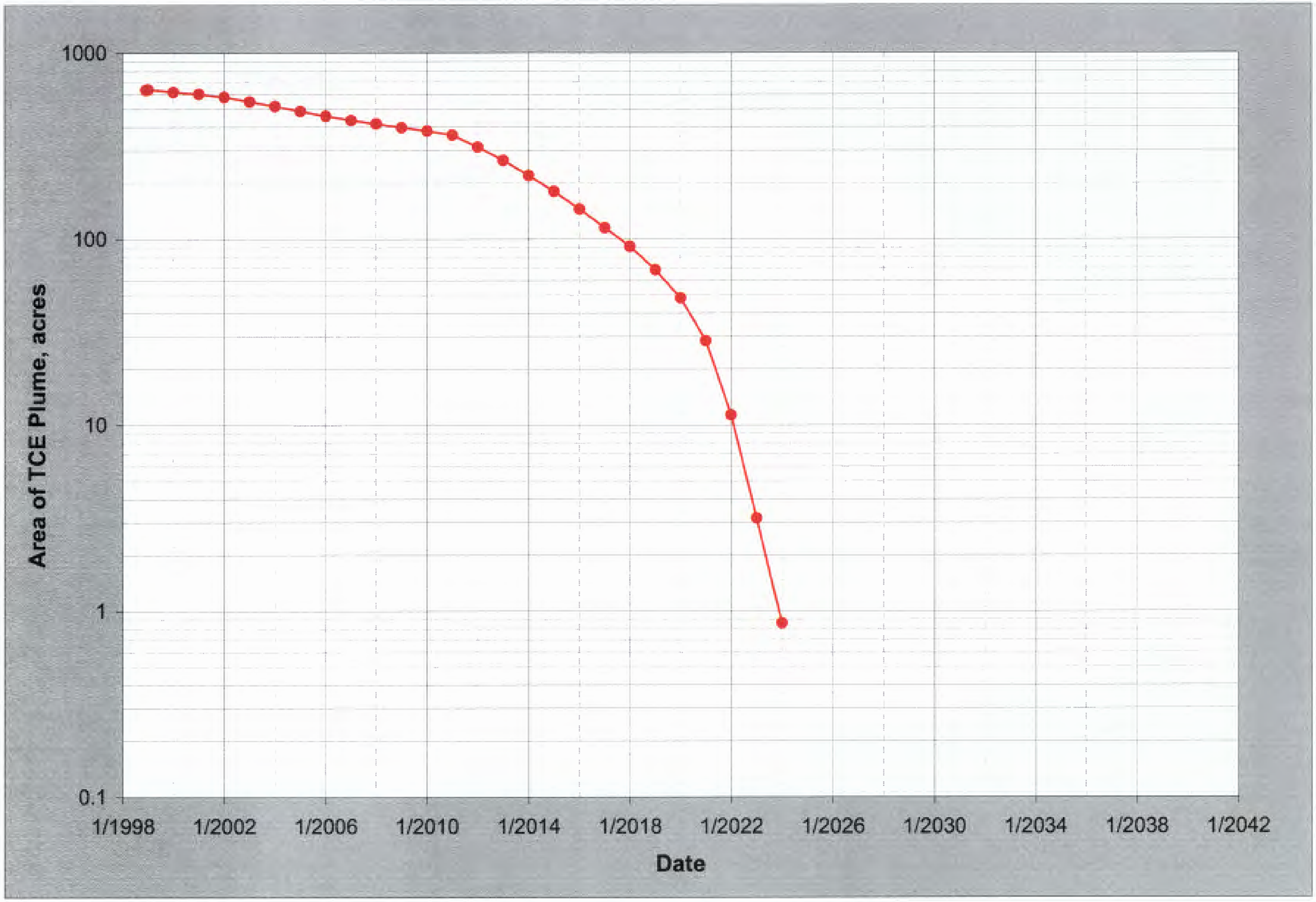


Figure 15 Alternative 3 - Variation of the Area of the TCE Plume Outside the Capture Zone of CW-2

Figure 16 Alternative 3 - Predicted Extent of TCE Plume Outside the Capture Zone of CW-2 when both CW-1 and CW-3 are Shut Down (end of 2023)

TABLES

TABLES

Table 1

Comparison of Existing and Alternative Extraction Systems

Option		Year of Reaching			TCE Plume at Termination	
		Pumped Water Criteria		Termination Criterion	Area (acres)	Mass (kg)
		MCL	DL			
Existing System		2023	2026	2035	0.69	0.020
Alternative 1		2020	2024	2027	0.52	0.016
Alternative 2		2019	2022	2025	0.52	0.018
Alternative 3	CW-1	2019	2021	2023	0.86	0.038
	CW-3		2023			

Table 2

Cost Analysis of Existing and Alternative Groundwater Extraction Systems

Option	Time to Shutdown (yrs)	Time to Gallery Replacement (yrs)	Costs in $ for		Present Value of Costs in $ for			Total Present Value in $
			Capital Improvements	Annual O&M	Capital Improvements	Gallery Replacement	Annual O&M	
Existing System	25	8	0	175,000	0	220,814	2,039,377	2,260,191
Alternative 1	17	6	14,000	186,500	14,000	252,810	1,820,841	2,087,651
Alternative 2	15	4, 14	148,500	214,000	148,500	436,580	1,949,094	2,534,174
Alternative 3	13	4	679,000	241,500	679,000	289,442	2,018,373	2,986,815

Notes:

1. Gallery life is assumed to be 20 years at 225 gpm, and proportionally reduced at higher flow rates.
2. Capital improvement costs for Alternative 1 are associated with pump replacement to accommodate the flow rate.
3. Capital improvement costs for Alternatives 2 and 3 include costs of the treatment facility expansion to accommodate the higher flow rates.
4. Capital improvement cost for Alternative 3 assume double-containment piping from CW-3 to CW-1 with treatment at an expanded CW-1 facility.
5. Annual O&M costs for existing system are based on the average costs for the past 5 years. They exclude O&M for CW-2 but include other annual costs associated with the evaluation and administration of the off-site sytems.
6. Gallery replacement cost is estimated to be $379,400, including permits, engineering, and construction.
7. Present values are calculated as of the beginning of the year 2011, using an interest rate of 7 percent, based on Sparton's current costs for credit.

APPENDIX A

APPENDIX A

Appendix A

Recalibration of Flow and Transport Model

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Attachment I
Groundwater Flow and Transport Model – Model Modifications

The groundwater flow and transport model for the Sparton site and its vicinity is described in detail in the 2008 Annual Report (SSP&A, 2009). This model was developed following the general outline described in Task 3 of the "Work Plan for the Assessment of Aquifer Restoration" which is incorporated as Attachment D in the Consent Decree. The initial version of the model was described in the 1999 Annual Report (SSP&A 2001) and the model has been updated and recalibrated several times since then as described in the 2008 Annual Report. The model is a reliable tool for evaluating groundwater flow and contaminant transport in the vicinity of the Sparton site and is an appropriate tool for evaluating the future performance of the containment systems and alternative groundwater extraction schemes.

The transport component of the groundwater flow and transport model has been recalibrated each year since 1999 as additional data on groundwater quality has been obtained, except for 2006, by adjusting the initial TCE concentration distribution in the aquifer in a manner consistent with available data until a reasonable match was obtained between the calculated and measured TCE concentrations. Subsequent to the completion of the 2008 Annual Report, the transport component was recalibrated once again and the method of simulating the containment wells was modified to provide a better model for evaluating the future performance of the existing containment systems and for evaluating alternative containment systems. The transport component of the model was recalibrated because even though the model as described in the 2008 Annual Report simulated TCE concentrations and TCE mass removal at the containment wells that were in excellent agreement with measured concentrations and mass removal from 1999 through 2008, calculated TCE concentrations at some key monitoring wells differed significantly from measured concentrations.

Previously the two containment wells, CW-1 and CW-2, were simulated using the MODFLOW well package. These wells are screened over multiple model layers, including the layer containing the water table, and when using the well package it is necessary to specify at the beginning of the simulation the amount of extracted water that is coming from each model layer. As the water table within the model domain is declining with time as the result of regional groundwater pumping, the amount of flow extracted from each aquifer layer for extraction wells that are completed over multiple model layers is dynamically changing with time. It is not straightforward, therefore, to simulate dynamically changing extraction rates from model layers for wells screened in multiple layers with the well package. To overcome the limitations of the well package, the MODFLOW multi-node well package (MNW2)[1] was used to simulate the containment wells. The pumping rate at each well simulated with the multi-node well package

[1] Konikow, L., G. Hornberger, K. Halford, and R. Hanson, 2009. Revised Multi-Node Well (MNW2) Package for MODFLOW Ground-Water Flow Model. U.S. Geological Survey, Techniques and Methods 6-A30.

extraction (SVE) system that was operated at the site, and the infiltration of clean water from the ponds where the water pumped from CW-2 is discharged after treatment have drastically reduced the concentration of contaminants in on-site monitoring wells completed above the 4,970-foot unit. The source containment well, however, continues to produce water with TCE concentrations in the 50-100 µg/L range, and some of the on-site monitoring wells completed below the silt/clay unit (MW-19, MW-42, and MW-72) continue to have TCE concentrations greater than 100 µg/L. This indicates that while the more permeable sands and gravels above the silt/clay unit may now be free of sources of contamination, the silt/clay unit continues to have such sources; downward leakage through the unit and these sources slowly carries contaminants into the underlying aquifer mostly within the capture zone of CW-2. To simulate this process, the initial (November 1998) TCE concentration distribution that was used as the starting point for the model simulations was assumed to have significant concentrations of TCE within the 4,970-foot silt/clay unit. The amount of TCE that currently remains in the silt/clay unit is poorly defined by available data. The amount of TCE extracted from CW-2 in the future will provide better data to estimate the magnitude of the amount of TCE remaining in the silt/clay unit. The amount of TCE that is specified in the recalibrated model results in calculated TCE concentrations at CW-2 that decline very slowly with time. If observed concentrations at CW-2 in the future are lower than model calculated concentrations, this will indicate that the amount of TCE remaining in the silt/clay unit is smaller than specified in the recalibrated groundwater model.

The total estimated initial mass of TCE in November 1998 is 7381 kg. This estimate of the initial mass is about twelve percent higher than was described in the 2008 Annual Report. This estimate of the initial mass is similar to the magnitude of initial masses estimated in previous years, which are listed below.

	Year									
	1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Estimated Initial Mass (kg)	2178	3097	3295	4647	7342	6638	6908	6908	6881	6601

The initial TCE mass by model layer is listed on Table A-2.

Once the model was recalibrated the model was used to evaluate the long-term operation of the existing containment wells at design extraction rates and to evaluate alternative extraction scenarios. For purposes of these evaluations, the groundwater flow and transport model was run in transient mode from 1998 until the attainment of aquifer restoration. The model boundary conditions and pumping rates for period 1998 through 2008 were identical to those described in the 2008 Annual Report. For the period 2008 through 2010 the pumping rates of the containment wells were specified at the observed average 2008 rates and the water levels along the constant head boundaries were specified to decline at an average rate of 0.4 feet per year as the result of regional groundwater production. For the period from 2011 until achievement of

Figure A-1a Locations of Monitoring Wells and Pilot Points used to Define Initial TCE Concentration Distribution

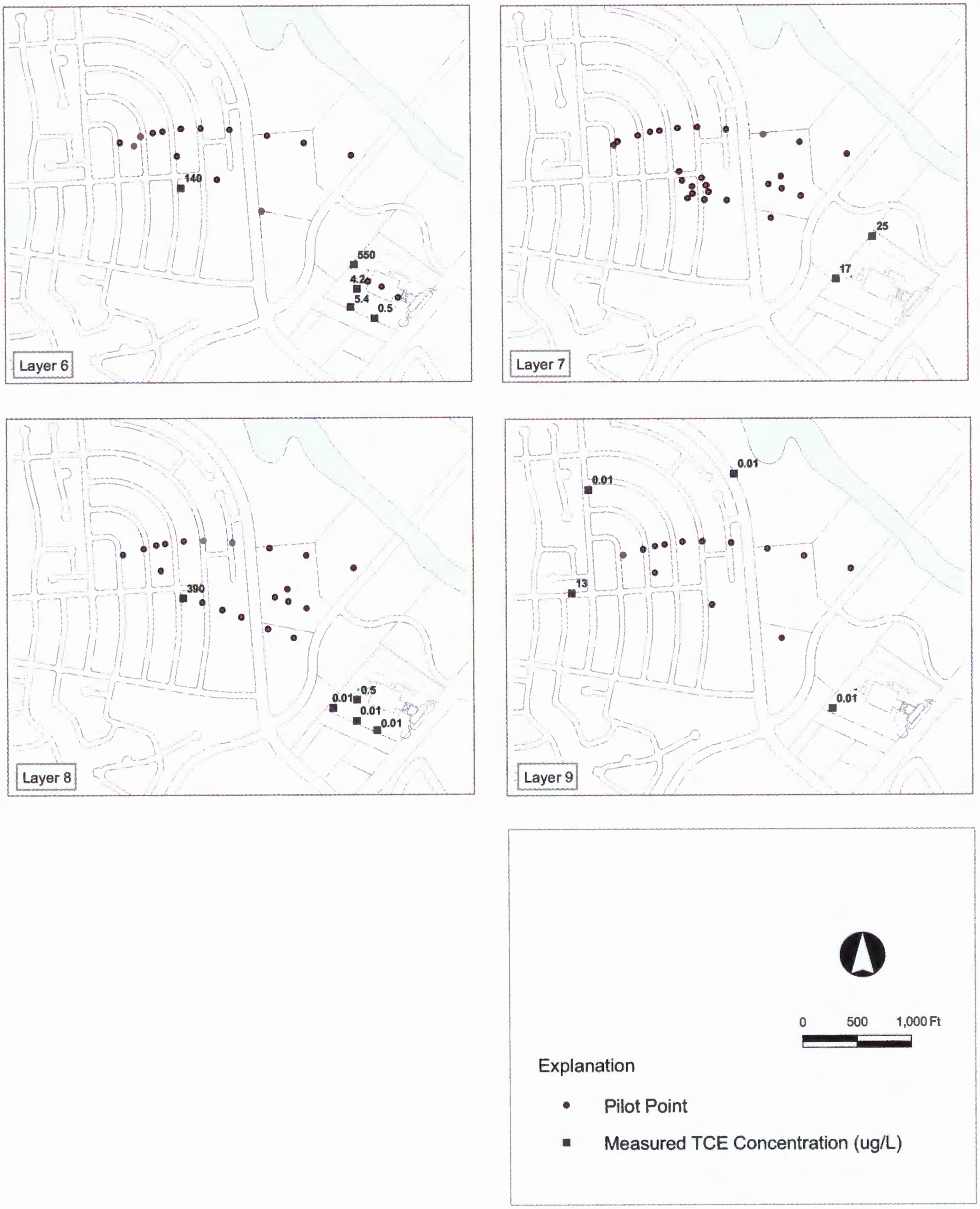
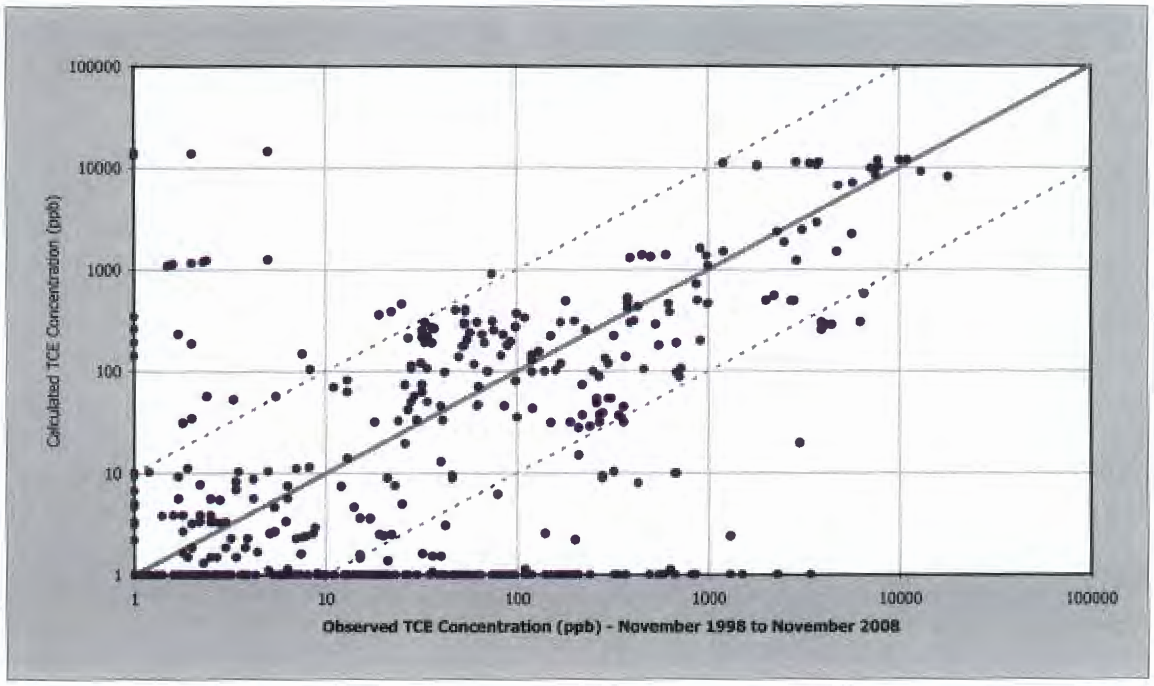


Figure A-1b Locations of Monitoring Wells and Pilot Points used to Define Initial TCE Concentration Distribution



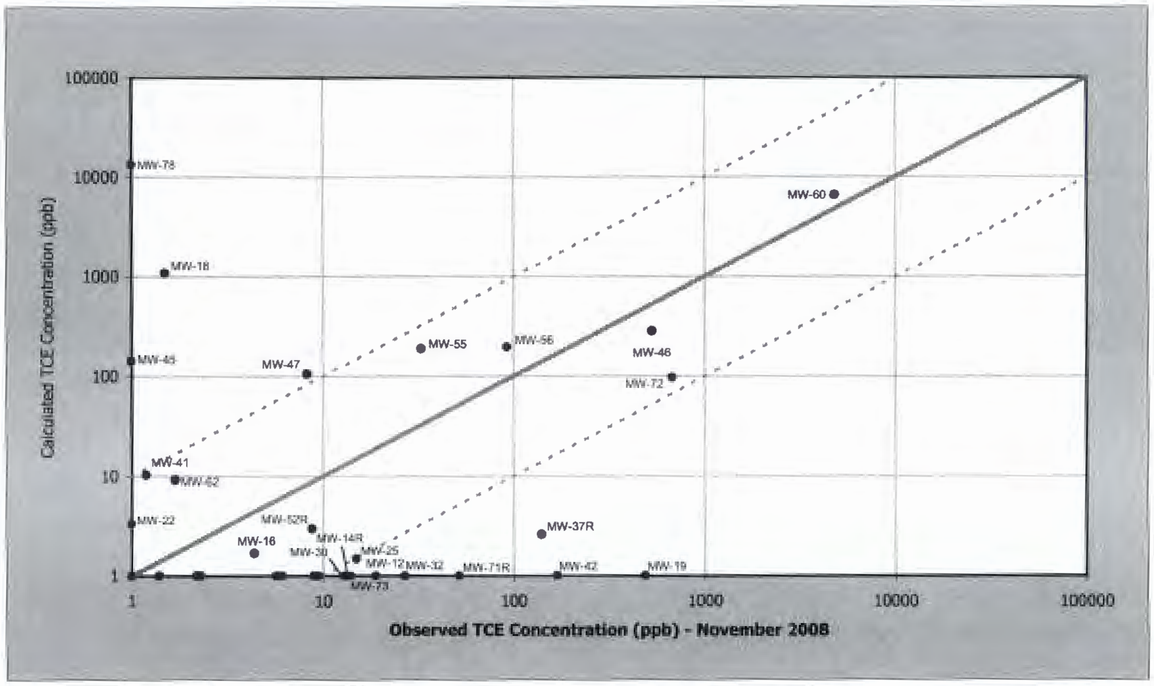


Figure A-2 Comparison of Calculated to Observed TCE Concentrations in Monitoring Wells

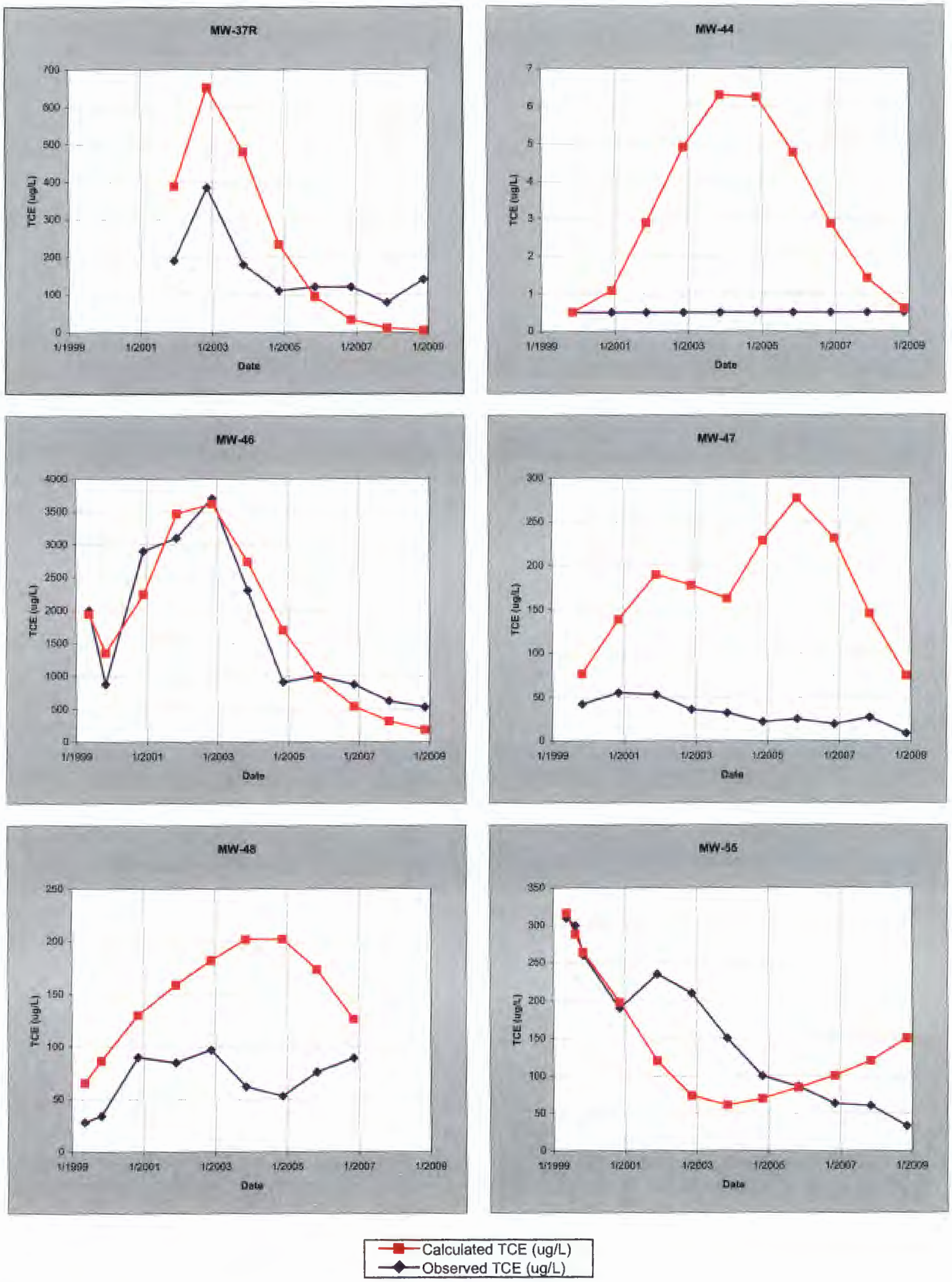


Figure A-3a Comparison of Calculated to Observed TCE Concentrations at Selected Monitoring Wells

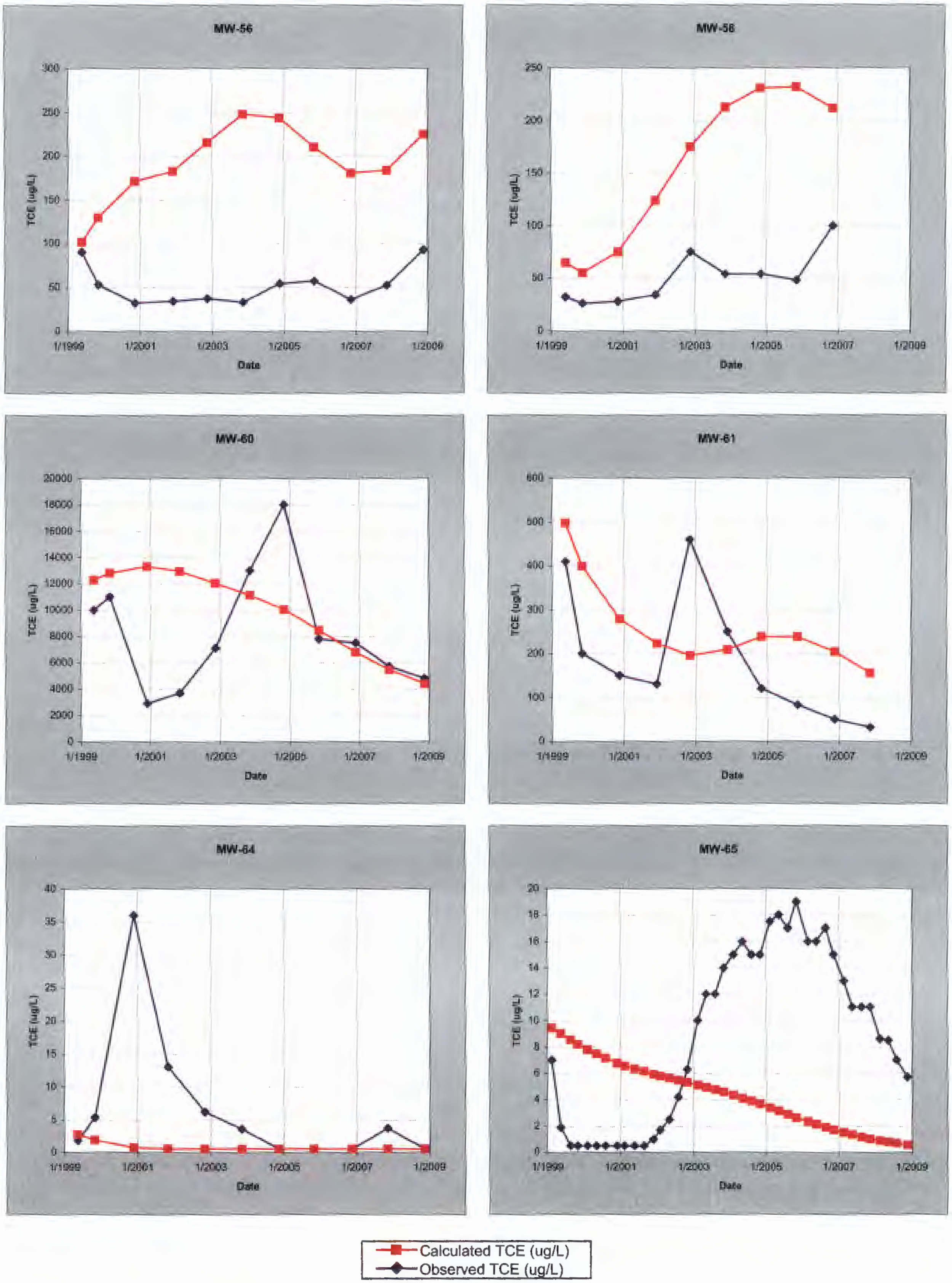
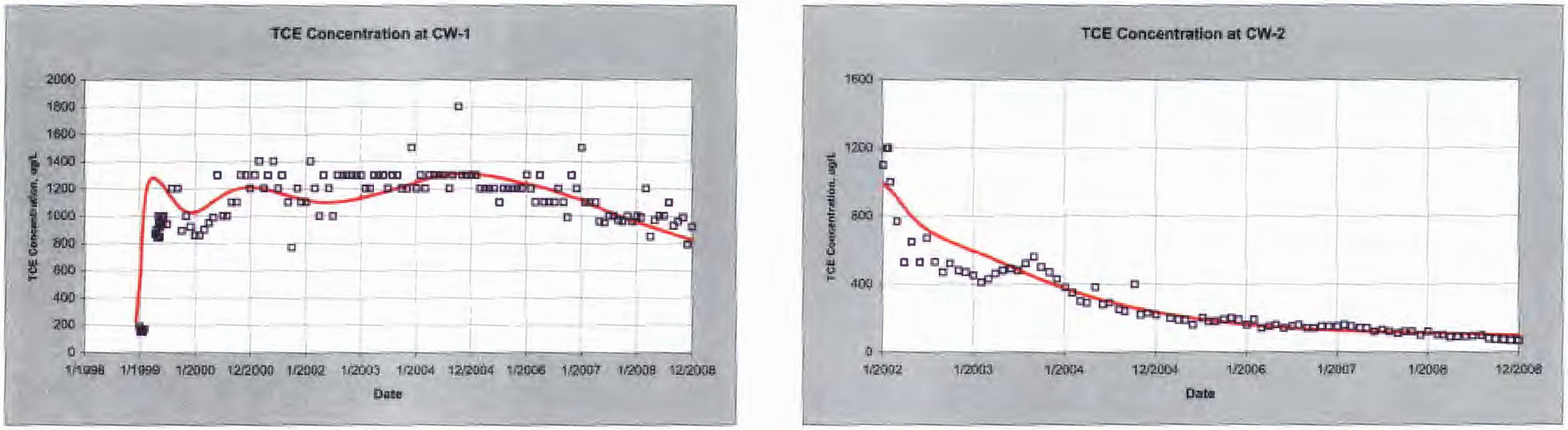


Figure A-3b Comparison of Calculated to Observed TCE Concentrations at Selected Monitoring Wells

a) TCE Concentrations



b) Mass Removal

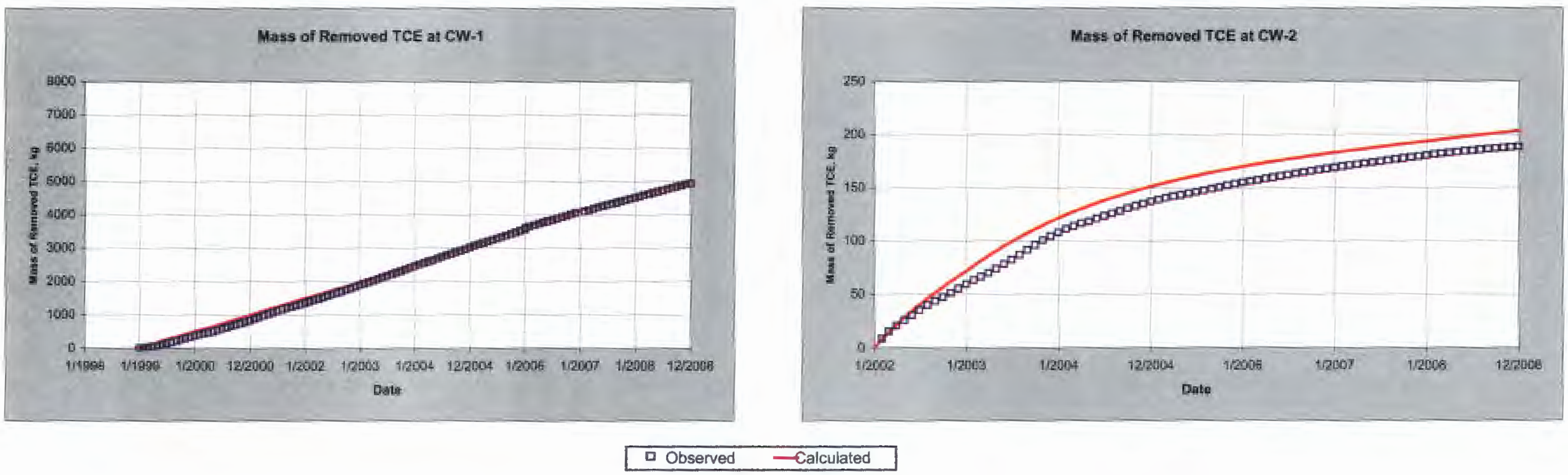


Figure A-4 Comparison of Calculated to Observed TCE Concentrations and Mass Removal at CW-1 and CW-2

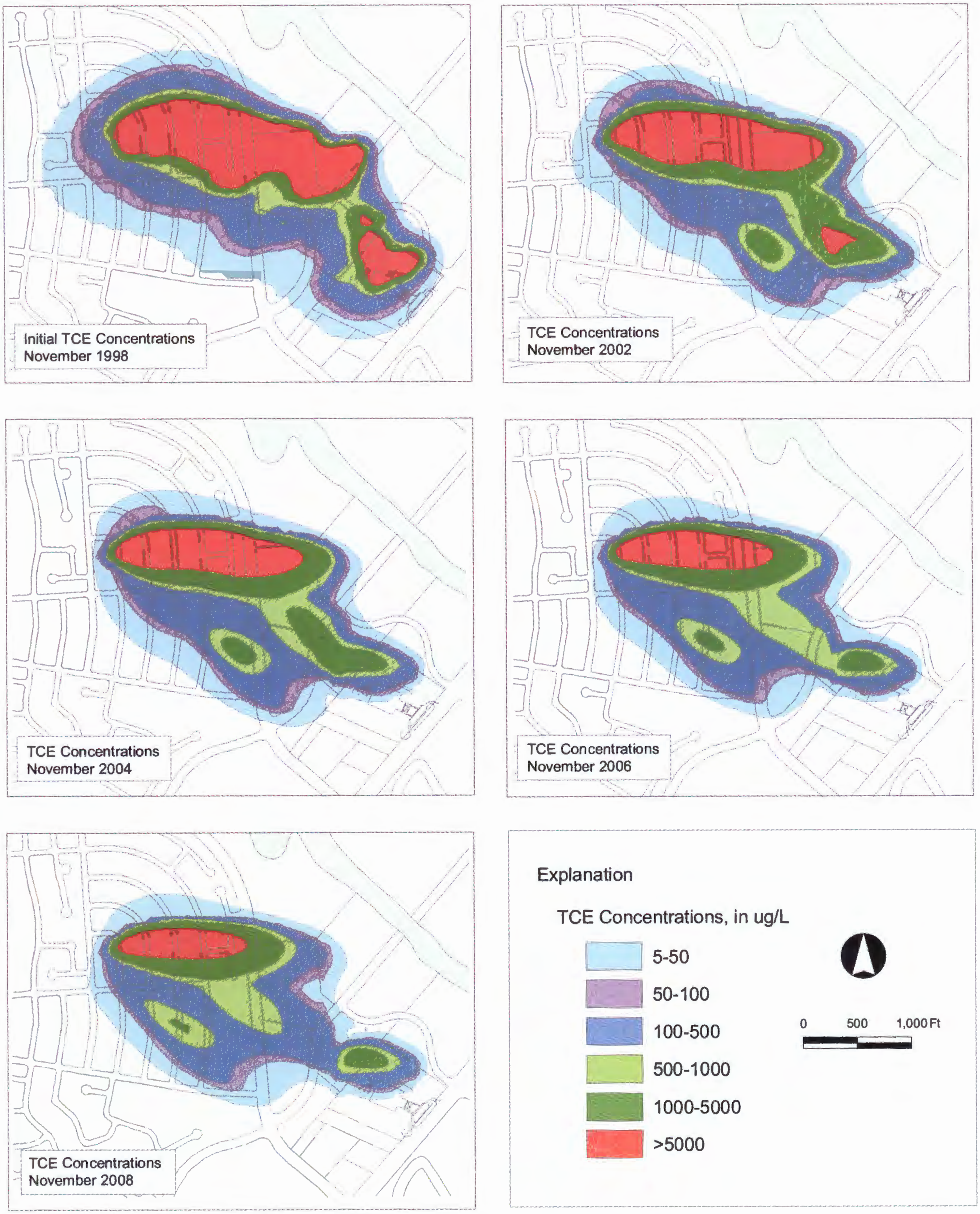


Figure A-5 Model Calculated TCE Concentrations

Table A-1

Observed and Calculated TCE Concentrations and Mass removal at CW-1 and CW-2						
Year	Cumulative TCE mass removed by both wells through end of year (kg)		Average Concentration at CW-1 (µg/L)		Average Concentration at CW-2 (µg/L)	
	Measured	Calculated	Measured	Calculated	Measured	Calculated
1999	359	482	829	1114		
2000	822	979	1,055	1,136		
2001	1,340	1,476	1,205	1,167		
2002	1,944	1963	1,225	1,107	723	749
2003	2,560	2,492	1,275	1,183	473	485
2004	3,156	3,054	1,317	1,291	301	298
2005	3,714	3,618	1,217	1,277	191	195
2006	4,225	4,121	1,166	1,181	153	142
2007	4,692	4,578	1,050	1,032	130	117
2008	5,130	4970	982	889	90	104

Table A-2

Initial Mass and Maximum Concentration of TCE in Model Layers			
Model	Approximate Mass		Maximum Concentration
Layer	(kg)	(lbs)	(µg/L)
1	0.5	1.2	989.3
2	42.2	93.1	10,002.5
3	580.6	1,280.1	149,995.7
4	706.4	1,557.3	24,896.8
5	1,118.0	2,464.8	39,862.0
6	978.6	2,157.5	39,874.6
7	864.7	1,906.3	29,939.1
8	1,525.6	3,363.3	34,857.1
9	1,283.1	2,828.8	24,922.1
10	236.5	521.5	1,600.4
11	1.4	3.2	7.2
12	0.0	0.0	0.0
13	0.0	0.0	0.0
14	0.0	0.0	0.0
15	0.0	0.0	0.0
Total Mass	7381.1	16,273	