Response to Regulatory Comments
for
Final Focused Feasibility Study/TI Waiver for MARBO Groundwater
Andersen Air Force Base, Guam

Item	Page	Section	Comments	Response to Comments
Comments provided by EPA Region IX RPM (M Ripperda) in 7/24/08 email				
Focused Feasibility Study Comments				
1	4, last bullet		Please avoid phrases like "conditions are far too toxic…" Either explain the geochemical problems or delete this sentence. Likely "conditions are not favorable" is better	The last bullet point in section 3.0, page 5 now reads "Groundwater geochemical conditions are *not favorable* for biological reductive dehalogenation."
2		2	Please include a short description of island groundwater lenses, particularly vertical chloride gradients and the transition zone. A more detailed explanation also needs to go in the TI Waiver Justification, Section 7. as part of the conceptual site model	An additional bullet point was added to section 2.0, page 3 to provide additional description of freshwater lenses. Cross-sectional diagrams illustrating the relationship between lens thickness, time, chloride concentration, and contaminant concentrations were incorporated. (Figures 3 and 5)
3		3	This section mentions that the contamination is in the deeper portion of the lens, but please make it more clear that this is in the transition zone which has brackish water.	Section 3.0 has been modified throughout to address the comment.
4		4	Chapter 3 had a good description of the hydrodynamics and the differences between the upper and lower portions of the lens. However, this hasn't been presented in terms of its impact on the potential changes in remedy. Please start Section 4.0 with a statement that the original remedy of natural attenuation was successful in the upper and main part of the lens, that no downgradient drinking water wells are impacted, and that the new proposed remedy is only necessary for the deeper, brackish portion of the lens.	The introductory paragraph to Section 4.0, page 5 now reads, "As discussed in Section 3.0 above, the original remedy of natural attenuation was successful in the upper and main part of the freshwater lens in that that no downgradient drinking water wells are impacted. The new proposed remedy therefore is only necessary for the deeper, brackish portion of the lens. Several remedial alternatives have been identified to address dissolved-phase PCE and TCE in groundwater at the MARBO OU. Remedial alternatives considered within this FFS are:
5		4	I think that it's a good idea to introduce the concept of the TI waiver here. The recommended alternative should be listed here as Alternative 6 – ICs and Contingency for Wellhead Treatment. This would include a description of the TI Waiver.	A bullet listing Alternative 6 – ICs and Contingency for Wellhead Treatment has been added to the list (page 12, section 4.2), and an evaluation of the Alternative has been added to Section 4.2.
6			Please add an **ARARs discussion section**, which, after all, is the reason for the TI Waiver. This should include the SDWA reg for MCLs, along with the **NCP references for TI Waivers**. Some of the other alternatives may have ARARs as well.	A paragraph on ARARs and a paragraph on NCP references for TI waivers were added to the introduction section (1.0).
TI Waiver Comments				
7		4.2	Most of the items we need are provided but it would be neater if they followed the TI guidance specifically, see Section 4.3 TI components. Each item should be clearly identified, such as ARAR to be waived, spatial area(plume volume) for the TI decision. The conceptual model does not mention how the TCE and PCE were transported to the transition zone (how did they get there?)…	A paragraph was added to the background section (3.0) that outlines the location of TI evaluation components within the report. ARAR to be waived and plume volume are also mentioned. Density mechanism of TCE/PCE transport to transition zone has been added to the conceptual model section.
8	A-1		Please remove the words 'prepared and' from the last sentence of the third paragraph.	The last sentence of the 3rd paragraph, section 1.0 on page A-1 has been changed to read, "Since this does not appear to be possible and other alternatives do not appear to be feasible, this document is being submitted with a Focused Feasibility Study (FFS) to support a ROD amendment invoking a TI Waiver for MARBO Annex groundwater."

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9	A-1		Please remove the last paragraph. EPA and GEPA do not concur until the ROD Amendment. The purpose of this document is to provide the justification for our concurrence.	The last paragraph on Page A-1 has been removed.
10	A-3, 4th paragraph		Wells IRP 29 and 31 are defined as being screened within the lower portion of the aquifer. Please i**dentify where GPA 1 and 2** are screened and show in cross section	A figure demonstrating GPA 1 and 2 screening in cross-section has been added (Figure 3-2). In addition, a description of their locations has been added to page A-3, paragraph 4.
11	A-5	5	The second paragraph states that the area around **IR Site 20** will be retained to maintain the site cover and ICs. A site may be transferred with ICs including a requirement that a site remain open space and that cover integrity is maintained. There is not a CERCLA reason for the AF to retain IR Site 20.	Acknowledged, the institutional controls near IRP Site 20 will be maintained although IRP Site 20 may be eventually transferred out of the IRP Program. This has been stated in Section 5.0, page A-5, paragraph 2, sentence 4.
12	A-6	7	The list of bullets is a nice summary of conditions. However, a separate and more detailed description of the nature of island fresh water lens would be helpful, especially since the upwelling of salt water during pump and treat is one of the major reasons for the TI waiver. Please also add a cross-sectional schematic depicting the island fresh water lens, transition zone, etc. agree but we should be more specific and define etc. the cross-section should include variable water levels and thicknesses of the lens, time vs concentration and salinity, the TI zone	An additional bullet point (#4) was added to section 7.0 to provide added description of the freshwater lenses. The bullet reads " Though some infiltrating precipitation is captured as storage in vadose zone primary porosity, the vast majority of infiltration percolates through the vadose secondary porosity and – due to density effects - creates a freshwater lens that floats atop a transition zone underlain by a marine water." In addition, clarification was made to other bullets relating to the transition zone and marine layer. Lastly, cross-sectional diagrams illustrating the relationship between freshwater lens thickness, time, chloride concentration, and contaminant concentrations were incorporated. (Figures 8 and 9)."
13	A-7	8	Need to explain why low levels of dissolved TCE and PCE occur in the deep portion of the lens.	The following sentence was added to Section 8.1, page A-8, paragraph 2 "This is likely due to past density driven flow of dense non-aqueous phase liquid (DNAPL) and indicates that the deep groundwater of the freshwater lens is significantly more static and less mobile than shallow groundwater."
14	A-10	10.1	The second paragraph is somewhat confusing and needs editing for clarity. Also, this paragraph is about the areal extent of the plume and should be moved to a more appropriate location.	The second paragraph of Section 10.1 (page A-10 and A-11) was not relocated. However, the paragraph now reads: Concentrations of dissolved-phase TCE above the MCL have been observed in the deep freshwater in the vicinity of IRP-31 at downgradient locations GPA-1 and GPA-2. Similarly, dissolved-phase PCE has been observed in the deep freshwater at the downgradient location of IRP-62. These locations serve to delineate the downgradient areas of the respective TCE and PCE plumes (Figure 8) and, therefore, limit the extent of the TI Waiver to areas defined within, or along the boundaries of, the MARBO Annex.

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15	A-10	10.2	Please move the third paragraph to the start of this section. It makes the argument about sources stronger. Also state that no source, or even traces, of VOCs have been found in the vadose zone. Please remove the last two sentences "It is presumed that …" and "TCE and PCE would not ..." These statements are already obvious from earlier sentences.	What was formerly the third paragraph of Section 10.2 (page A-11) is now the first paragraph of that same section and has been modified to read: "The strong lateral flow component in the shallow aquifer has served to remove the source of dissolved phase PCE (and presumably TCE) from the shallow zone; thus, relegating continued sources to within the deep portion of freshwater lens. Long-term monitoring of shallow (IRP-14) versus deep (IRP-29) PCE concentrations in groundwater surrounding the MARBO Laundry substantiates this deduction. No source and no traces of VOCs have been found in the vadose zone. TCE has not been identified in shallow groundwater in the vicinity of IRP-31 and, presumably has attenuated prior to the LTGM program or simply cannot be found."
16	A-14	12	should mention that after the ROD Amendment a long term monitoring plan will be submitted. Monitoring is required until the original ARARs are met as well as five year reviews.	The last paragraph of Section 12.0 has been modified to read, "The proposed TI Waiver is for the area covered by the MARBO Annex and the region of the TCE plume (5µg/L limit) extending off of MARBO in a northwest direction toward wells GPA-1 and GPA-2 (Figure 8). The estimated volume of groundwater within the spatial limits of the TI waiver for TCE and PCE is 3.4E08 gal and 2.8E08 gal, respectively. After the ROD Amendment, a long term monitoring plan will be submitted. Monitoring and 5-year reviews are required until the original ARARs are met. The USAF will continue to monitor and to provide the contingency of wellhead treatment as long as the contaminant plumes exist."
17	A-14	13	Please rewrite the first sentence to: "A TI Waiver for the MARBO Annex is appropriate because …"	The first sentence of section 13.0 (page A-15) has been modified to read, "A TI Waiver for the MARBO Annex is appropriate because it is not feasible or practicable from an engineering and technological viewpoint to remediate the dissolve-phase TCE or PCE or to remediate the sources."
18		Figures	Please add concentration versus time graphs for the deep wells and any key shallow monitoring wells and production wells.	Attachment 1 contains well graphs of contaminant concentration versus time for shallow and deep wells in the vicinity of the TCE and PCE occurrences. Reference to Attachment 1 was made in the second paragraph of Section 8.1.
19		Figure 8	does not show the TI zone..should be depicted here and in cross-section	Acknowledged. Figure 8 was corrected to indicate spatial limits of TI waiver and is now entitled Figure 8-1. Additionally a cross section was added (Figure 10-1).

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS, 36TH WING (PACAF)
UNIT 14007, APO AP 96543-4007

21 November 2008

36 CES/CEVR
Unit 14007
APO AP 96543-4007

Mr. Mark Ripperda
Project Manager
U.S. Environmental Protection Agency
75 Hawthorne St., H-9-4
San Francisco, CA 94105-3901

Dear Mr. Ripperda

Attached are two copies of the *Final Focused Feasibility Study to Support a Record of Decision Amendment with a Technical Impracticability Waiver for the MARBO Annex Operable Unit,* Andersen Air Force Base, Guam.

This letter supersedes the previous issued letter dated 17 September 2008 with attached Focused Feasibility Study documents (dated 12 September 2008).

Should you have any questions concerning these reports, please feel free to contact me at (671) 366-4692.

Sincerely

GREGG N. IKEHARA
IRP Program Manager

Attachment:
FFS (2 copies)

cc:
Mr. Michael S. Cruz, GEPA

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS, 36TH WING (PACAF)
UNIT 14007, APO AP 96543-4007

21 November 2008

36 CES/CEVR
Unit 14007
APO AP 96543-4007

Mr. Michael Cruz
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RECEIVED NOV 24 2008 Guam Environmental Protection Agency

Dear Mr. Cruz

Attached are two copies of the *Final Focused Feasibility Study to Support a Record of Decision Amendment with a Technical Impracticability Waiver for the MARBO Annex Operable Unit,* Andersen Air Force Base, Guam.

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Sincerely

GREGG N. IKEHARA
IRP Program Manager

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21 November 2008

Mark Richter, Maj.
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AFCEE
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SUBJECT: Final Focused Feasibility Study to Support a Record of Decision Amendment with a Technical Impracticability Waiver for the MARBO Annex Operable Unit Andersen Air Force Base, Guam

PROJECT: F41624-03-D-8596, Delivery Order 0076
Project No. AJJY20077001C (CDRL A001D)

Dear Maj. Richter:

Please find enclosed one electronic copy of the Final *Focused Feasibility Study to Support a Record of Decision Amendment with a Technical Impracticability Waiver for the MARBO Annex Operable Unit Andersen Air Force Base, Guam*. This document was prepared in accordance with the Statement of Work for Task Order 0076. Eight (8) copies for Andersen AFB (including two (2) copies for the information repositories and one (1) copy for the administrative record), two (2) copies for USEPA, and two (2) copies for Guam EPA are being hand-delivered to Mr. Gregg Ikehara. Additional copies have been distributed as indicated below. A copy of this transmittal (w/o enclosures) will also be forwarded to AFCEE/MSCD.

If you have any questions or comments, please contact me at your convenience. We appreciate the opportunity to provide these services to AFCEE.

Sincerely,

[signature] for

Robert Shambach.
EA Guam Manager

cc: Mr. Gregg Ikehara, Andersen AFB (8 copies)
Ms. Judith Keith, HQ AFCEE/CMS, Brooks City-Base, TX (1 copy)
Ms. Cathy Dolan, Booz Allen Hamilton (1 electronic copy)
Mr. Brian Thomas, P.G., Booz Allen Hamilton (1 copy)
Mr. Mark Ripperda, USEPA Region 9 (2 copies)
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AFCEE/MSCD (w/o enclosures)
AFCEE Project File, Guam (1 electronic copy)

THE UNITED STATES AIR FORCE

INSTALLATION RESTORATION PROGRAM

FINAL

FOCUSED FEASIBILITY STUDY
TO SUPPORT A
RECORD OF DECISION AMENDMENT
WITH A
TECHNICAL IMPRACTICABILITY WAIVER
FOR THE MARBO ANNEX OPERABLE UNIT
ANDERSEN AIR FORCE BASE, GUAM

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13. ABSTRACT *(Maximum 200 words)*

This Focused Feasibility Study (FFS) presents a Technical Impracticability (TI) Waiver to address trichloroethene (TCE) and tetrachloroethene (PCE) contaminated groundwater at MARBO Annex Operable Unit, Andersen Air Force Base, Guam. The TI Waiver is to replace the existing monitored natural attenuation solution, which is the operating remedial action for TCE and PCE in groundwater at MARBO Annex according to the 1998 Record of Decision (ROD). This FFS will be presented as an amendment for the upcoming second five-year review of ROD for MARBO Annex Operable Unit due in 02 March 2009.

14. SUBJECT TERMS

- *Andersen AFB*
- *TI Waiver*
- *PCE*
- *Groundwater Monitoring*
- *TCE*
- *MARBO Annex*

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LIST OF ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
ARARs	Applicable or Relevant and Appropriate Requirements
bgs	below ground surface
COC	contaminant of concern
DNAPL	Dense non-aqueous phase liquid
DO	Dissolved Oxygen
EA	EA Engineering, Science, and Technology, Inc.
ENSO	El Nino/Southern Oscillation
ft	feet
FFA	Federal Facility Agreement
FFS	Focused Feasibility Study
Guam EPA	Guam Environmental Protection Agency
IC	Institutional Control
IRP	Installation Restoration Program
MARBO	Marianas Bonins
MCL	Maximum Contaminant Level
µg/L	micrograms per liter
mg/L	milligrams per liter
MNA	monitored natural attenuation
mV	millivolts
NGL	Northern Guam Lens
NPL	National Priorities List
O&M	Operation and Maintenance
ORP	Oxidation-Reduction Potential
OSWER	Office of Solid Waste and Emergency Response (USEPA)
OU	Operable Unit
PCE	tetrachloroethene
RAO	Remedial Action Objective
RI	Remedial Investigation
ROD	Record of Decision
TCE	trichloroethene
TI	Technical Impracticability

USAF	United States Air Force
USEPA	United States Environmental Protection Agency
ZVI	zero valent iron

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1.0 Introduction

This Focused Feasibility Study (FFS) was prepared to address trichloroethene (TCE) and tetrachloroethene (PCE) contaminated groundwater at the Marianas Bonins (MARBO) Annex Operable Unit (OU). MARBO is located adjacent to Andersen Air Force Base (AFB) on the north central karst limestone plateau of Guam (Figures 1-1 and 1-2). This FFS has been prepared as a primary deliverable required under the Federal Facility Agreement (FFA) finalized on 30 March 1993 by the United States Air Force (USAF), the United States Environmental Protection Agency (USEPA) Region 9, and the Guam Environmental Protection Agency (Guam EPA). Andersen AFB, inclusive of the MARBO Annex, is listed on the National Priorities List (NPL).

This FFS evaluates a limited number of remedial alternatives and/or presumptive remedies that could address groundwater contamination and serve to replace monitored natural attenuation (MNA), the implemented remedy resulting from the Record of Decision (ROD) (EA Engineering, Science, and Technology, Inc. [EA], 1998). The ROD selected an operating Remedial Action of MNA with Institutional Controls (ICs) (EA, 1998; EA, 2004), including the contingency for wellhead treatment of water supply wells that are contaminated by the plume. Since 1998, residual TCE and PCE concentrations in the deep aquifer have persisted and will not allow for unrestricted use of the property within an acceptable timeframe, as presented in Section 4 of this document. Because groundwater MNA is not proceeding within a reasonable timeframe, as defined in the ROD, MNA has been deemed a failed remedy. As such, this FFS is provided in support of a ROD amendment prior to the next 5-year ROD review in 02 March 2009 (EA, 2004).

In light of recent technology developments, this FFS reevaluates some of the alternatives presented in the previous FFS (EA, 1997) as well as evaluating some additional alternatives in light of the applicable or relevant and appropriate requirements (ARARs) and remedial action objectives (RAOs). As discussed in the 1997 Focused Feasibility Study, these requirements and objectives include:

- Maintaining the human health risk associated with the presence of PCE and TCE within groundwater at the MARPO Annex at or below a technically practical level that is within the EPA's target risk range of 10^{-4} to 10^{-6};
- Preventing ingestion of water having concentrations of PCE/TCE exceeding the Federal Maximum Contaminant Level (MCL) for PCE and TCE, which is 5 micrograms per liter (µg/L);
- Establishing a means to monitor and confirm that the human health risks associated with the presence of PCE and TCE within the groundwater at MARBO Annex do not exceed established acceptable levels;
- Restoring the groundwater underlying the MARBO Annex to concentrations below the Federal MCL for TCE and PCE (5 µg/L);

As discussed in this document, the hydrogeologic conditions and contaminant distributions at the MARBO Annex present unique challenges to the existing and applicable remedial technologies.

Due to the complexities of the underlying vadose zone and aquifer, technologies that might be considered under more conventional subsurface conditions (i.e., shallower occurrence, smaller volume of groundwater contamination, absence of secondary solution channeling, lower aquifer transmissivities, greater definition of contaminant distribution and migration pathways) do not show promise with respect to implementability, effectiveness, or restoration potential.

According to the National Contingency Plan (NCP) and Section 121 (d) of the Superfund Amendments and Reauthorization Act (SARA), Federal ARARs must be attained upon completion of remedial action taken under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) unless specified waivers are granted. Thus, in light of the site constraints, the USAF has prepared a Justification for a Technical Impracticability (TI) Waiver, which is provided as Appendix A of this document. This FFS includes a screening of alternatives in order to satisfactorily evaluate the technology performance required of a TI Waiver (Directive 9234.2-25) and is not intended as a comprehensive feasibility study with a detailed analysis of alternatives (EPA/540/G-89/004).

The site location, background, physical characteristics, land use, and general geology of the MARBO Annex are discussed in Appendix A (Justification for a TI Waiver). The hydrogeology of the MARBO Annex and occurrence, fate, and distribution of TCE and PCE in groundwater are summarized in Sections 2 and 3, respectively. The reasons for the failing of the original prescribed remedy are presented in Section 4. A detailed discussion of the screening of remedial alternatives is provided in Section 5.

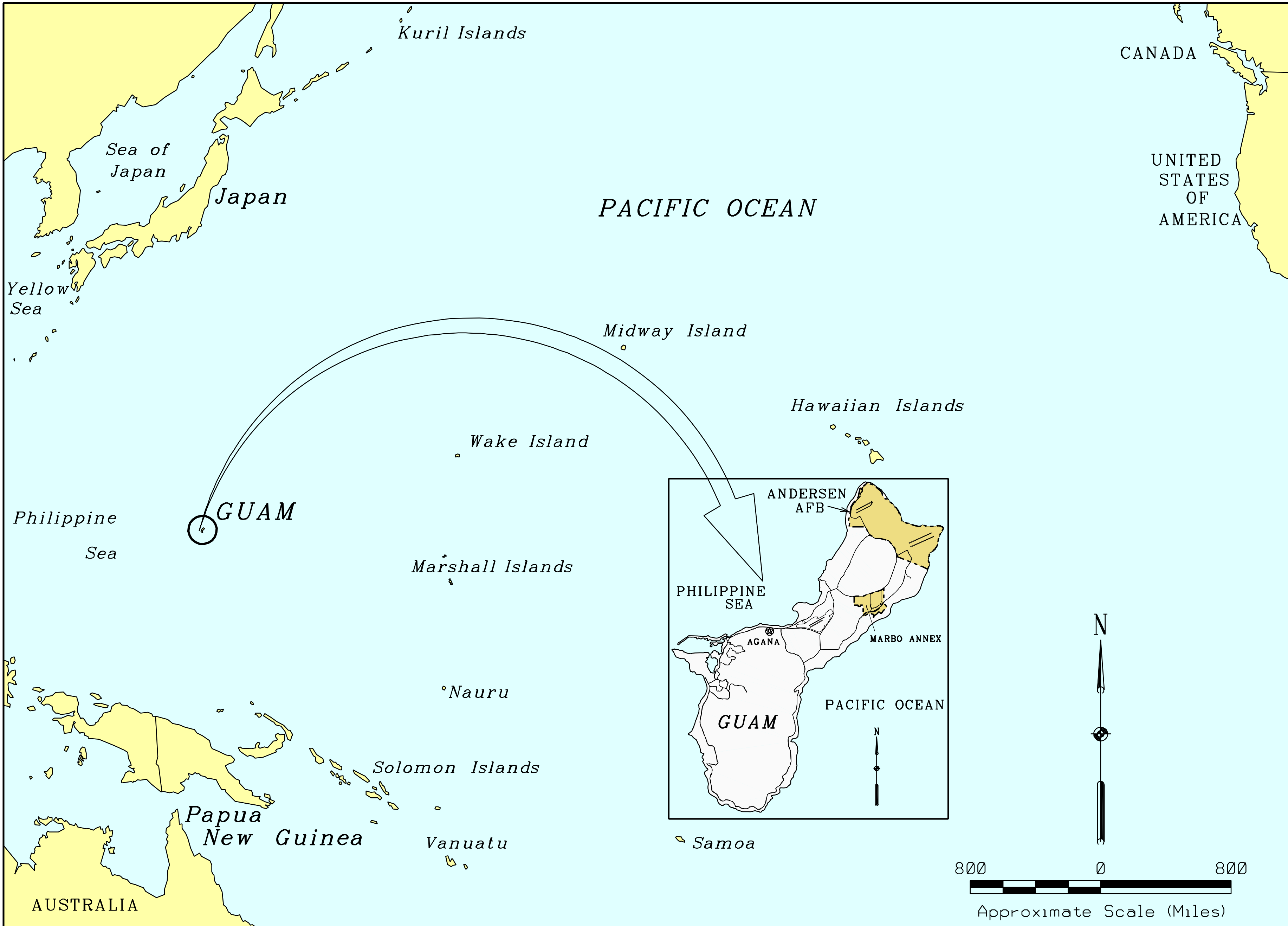


Figure 1-1. Location Map of Guam.

Figure 1–2. Location Map of Andersen Air Force Base on Guam.

2.0 Hydrogeology of the MARBO Annex

The northern half of Guam exhibits characteristics of a Simple Carbonate Island, a Carbonate-Cover Island, and a Composite Island according to the type of Carbonate Island Karst Model (Mylroie et al., 2001). Although a freshwater lens (overlying marine water) exists in the subsurface for all model types observed on Guam, the types differ by location of the limestone-volcanics contact relative to the elevation of the water table and relative to the elevation of the ground surface. The volcanics act as an aquaclude to groundwater flow. As discussed in Section 4.0, the two volcanic peaks, Mount Santa Rosa and Mataguac Hill, control this relationship and, therefore, affect the distribution and migration of groundwater in the vicinity of these features, and result in a channeling of flow of groundwater within the limestone toward Tumon Bay.

Groundwater is the principal source of drinking water for Guam and is the source of fresh water for other uses. The karst limestone of the Northern Guam Lens (NGL) produces approximately 40 million gallons of fresh water per day for these uses. Even though Guam receives approximately 100 inches per year of rainfall, surface water does not exist on northern Guam due to the highly permeable, eogenetic, karst limestone. The general hydrogeology of the NGL is summarized below:

- The Barrigada and Mariana limestone formations are the primary groundwater aquifers underlying the MARBO Annex.
- Groundwater flow (and contaminant migration) at MARBO Annex is very complex due to karstic geologic features, secondary solution channelizing, and production well pumping.
- The vadose zone consists of approximately 400 feet (ft) of coralline-reef limestone, which has a heterogeneous porosity distribution with diffuse groundwater flow within primary porosity and discrete, channelized groundwater flow in secondary, dissolution-enhanced porosity.
- Though some infiltrating precipitation is captured as storage in vadose zone primary porosity, the vast majority of infiltration percolates through the vadose secondary porosity and – due to density effects - creates a freshwater lens that floats atop a transition zone underlain by marine water.
- This freshwater aquifer is approximately 100 ft thick and is highly conducive to groundwater flow. Hydraulic conductivities as high as 20,000 ft per day were observed during the MARBO OU Remedial Investigation (RI) (ICF Technology, Inc., 1997) and during dye trace studies conducted on the Main Base during the MARBO OU RI field work.
- A brackish transition zone (mixing zone), approximately 20 ft in thickness, exists between the freshwater lens and the underlying marine water.
- The rapid infiltrating recharge to the upper portion of the freshwater lens propagates quickly (weeks to months) to coastal discharge areas (seeps and/or large-scale dissolution features).
- The rapidly infiltrating recharge has created strongly oxidized groundwater conditions throughout the fresh water lens, as evidenced by shallow and deep dissolved oxygen

(DO) concentrations generally ranging from 5 to 8 milligrams per liter (mg/L) and oxidation-reduction potential (ORP) ranging from 100 to 500 millivolts (mV).

- The strong lateral flow component that is observed in the upper portion of the freshwater lens is not evident (based on contaminant trends) in the basal portion of the lens.
- The elevation of the water table and thickness of the freshwater lens vary in response to rapid stimuli (large short-term rain events), moderate-term stimuli (seasonal rainfall and monsoonal wind effects on sea level), and long-term stimuli (precipitation fluctuations due to El Nino/Southern Oscillation events and eustatic sea level rise).
- The effect of short- and long-term stimuli on the thickness of the freshwater lens has lead to cyclic variation on the observed chloride levels in deep groundwater when observed at a vertically fixed sampling point (Figure 2-1). For example, chloride levels in groundwater at Installation Restoration Program (IRP)-29 and IRP-31 have cyclically varied between approximately 20 and 200 mg/L.

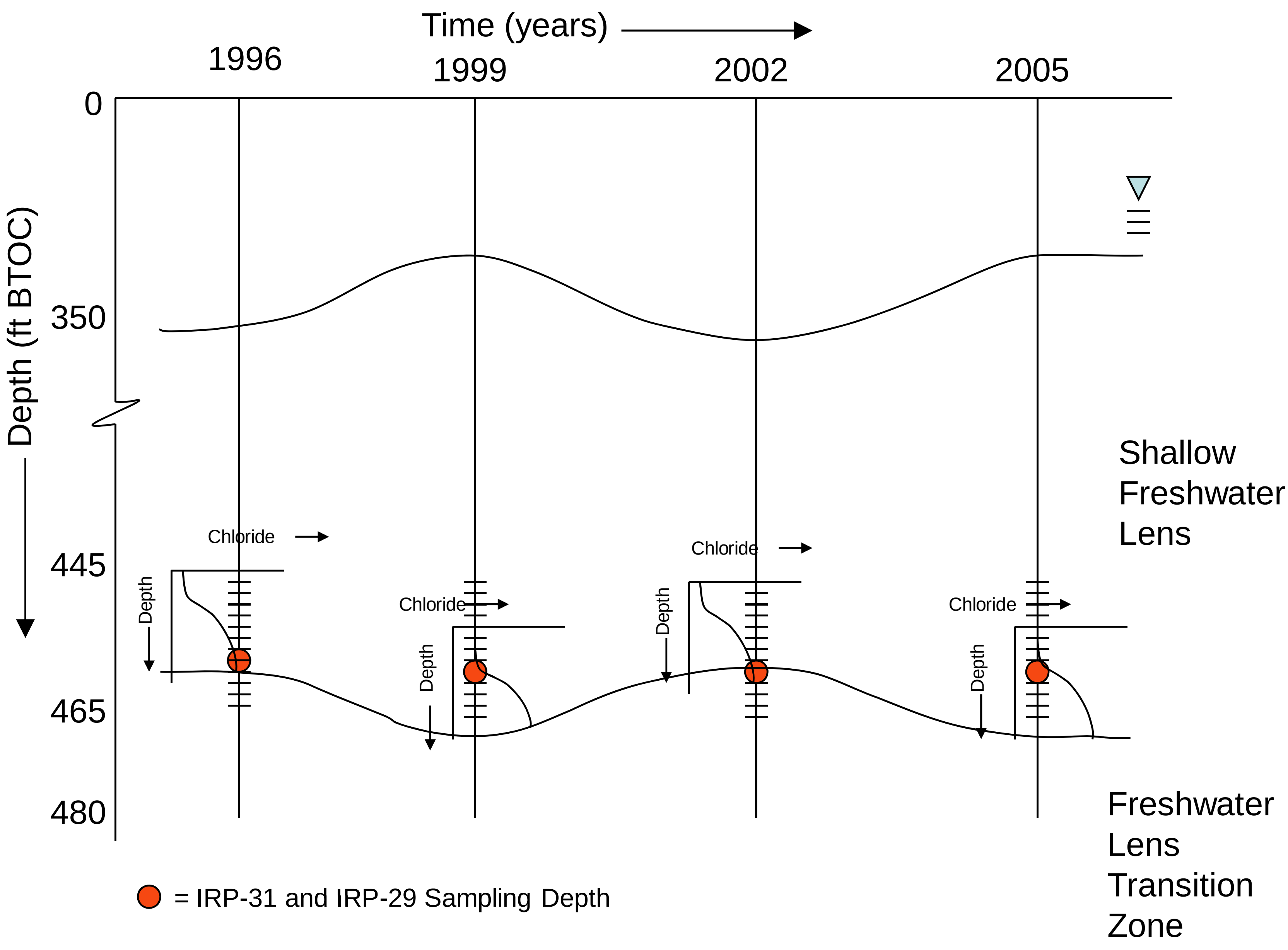


Figure 2-1. Conceptual Model of Chloride Concentration Cyclicity Versus Time at IRP-31 and IRP-29.

3.0 Occurrence, Fate, and Transport of TCE and PCE within MARBO Annex Groundwater

Two geographic areas within the deep portion of the freshwater lens have been identified as having dissolved TCE and PCE exceeding Maximum Contaminant Levels (MCLs). Of the most likely contaminant source areas within the MARBO Annex, based on soil sampling and analysis conducted at MARBO, none were confirmed as continuing sources of TCE or PCE. Also, the fact that the shallow freshwater lens has shown a consistent decline in TCE and PCE concentrations over time is indicative that there is not continued contaminant sourcing from the vadose zone. The following findings regarding the nature and extent of TCE and PCE occurrence provide the basis for the conceptual site model of groundwater contamination at the MARBO Annex.

Based on historical results (RI and the Long-term Groundwater Monitoring program), two potential contaminants of concern (COCs) have been identified: PCE and TCE. These COCs have historically been detected in deep groundwater samples collected from IRP-29 and IRP-31 at concentrations above their respective MCLs (5 micrograms per liter [µg /L], each). The historic distribution of PCE and TCE concentrations in groundwater exceeding the MCL are depicted on Figure 3-1.

TCE and PCE have either been non-detect or detected at concentrations below the MCL in all shallow monitoring wells, except IRP-14. PCE concentrations have decreased over time in groundwater samples collected from IRP-14. The linear decline in PCE concentrations within shallow groundwater at IRP-14 over the past 11 years suggests that PCE in the shallow aquifer is being attenuated through the physical process of hydrodynamic dispersion. This is likely due to strong horizontal flow components in the shallow portion of the freshwater lens that result in rapid turnover rates.

The data from the shallow freshwater lens (and other findings) indicate the following:

- There is no indication of a continued shallow contaminant source of PCE or TCE in the MARBO area.
- The PCE concentrations observed in the shallow freshwater lens in the vicinity of the former MARBO Laundry has been decreasing linearly over time.
- The physical processes (strong horizontal flow) operating in the shallow freshwater lens have attenuated the dissolved PCE to levels below the MCL.

TCE and PCE concentrations in groundwater samples collected from deep wells IRP-31 and IRP-29 are one to two orders of magnitude higher than in shallow wells. This is likely due to past density driven flow of dense non-aqueous phase liquid (DNAPL) and indicates that the brackish water transition zone in the deep part of the freshwater lens is significantly more static and less mobile than the shallow part of the freshwater lens. TCE and PCE concentrations observed in the deep freshwater transition zone over time show cyclical increases and decreases that appear to coincide with changes in the elevation of the water table and thickness of the freshwater lens and inversely correlate to choride concentration (Figure 3-2). These variations in the configuration of the freshwater lens appear to be influenced by short term and long term variations in precipitation and sea level. The historical data indicate that the overall freshwater lens has gotten thicker and thinner in response to long term variations in precipitation while the vertical horizon of the groundwater sampling points of MARBO monitoring wells have remained static. More specifically, with an increase in precipitation there is a corresponding rise in the top of the freshwater lens that is coupled with a lowering in the base of the freshwater lens.

Historical data also suggest that the processes operating deep in the transition zone of the freshwater lens are not as dynamic as in shallow groundwater. The cyclical PCE and TCE trends in the deep freshwater transition zone indicate the following:

- The highest concentrations of PCE and TCE (detected at IRP-29 and IRP-31, respectively) have been observed in groundwater samples collected near the base of the freshwater lens, where these contaminants appear to be trapped within the karst limestone matrix.
- There is a much weaker lateral flushing (and thus hydrodynamic dispersion) in the deep portion of the freshwater lens than shallower in the lens.
- The TCE and PCE contamination may be from relatively "old" sources.
- The TCE and PCE observed in IRP-31 and IRP-29, respectively, appear to have resulted from separate sources (Figure 3-1).
- PCE and TCE concentrations have cyclically fluctuated over time in relation to changes in the lens thickness in response to intense rain events, seasonal rainfall, and long term El Nino/Southern Oscillation (ENSO) effects, but have stayed within an established concentration range and show no appreciable increase or decrease, on average, over the past 11 years.
- Neither physical (e.g., dilution) nor biological processes (e.g., reductive dehalogenation) are operating to significantly attenuate TCE or PCE in the deep part of the freshwater lens. Groundwater geochemical conditions are not favorable for biological reductive dehalogenation.

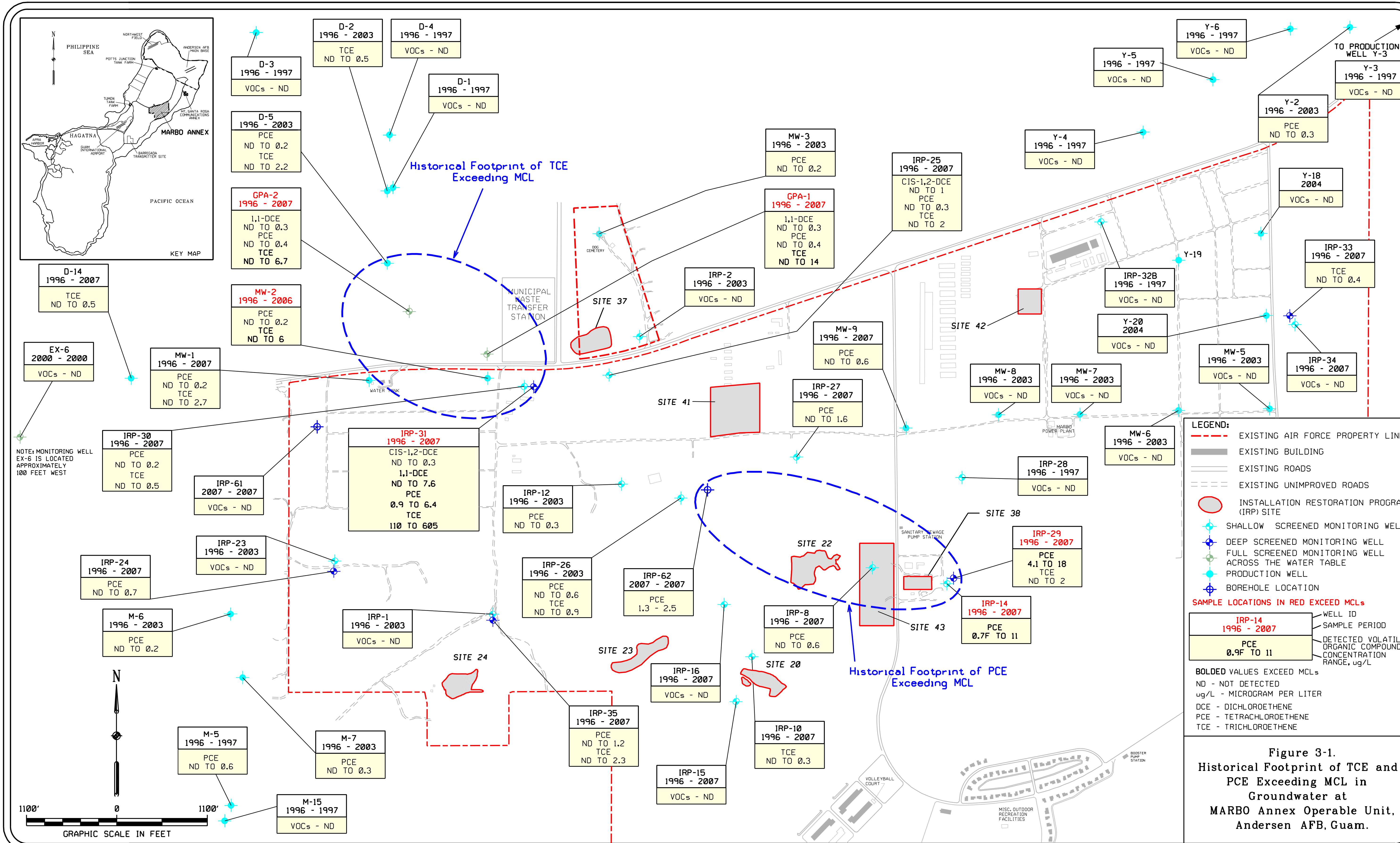


Figure 3-1.
Historical Footprint of TCE and PCE Exceeding MCL in Groundwater at MARBO Annex Operable Unit, Andersen AFB, Guam.

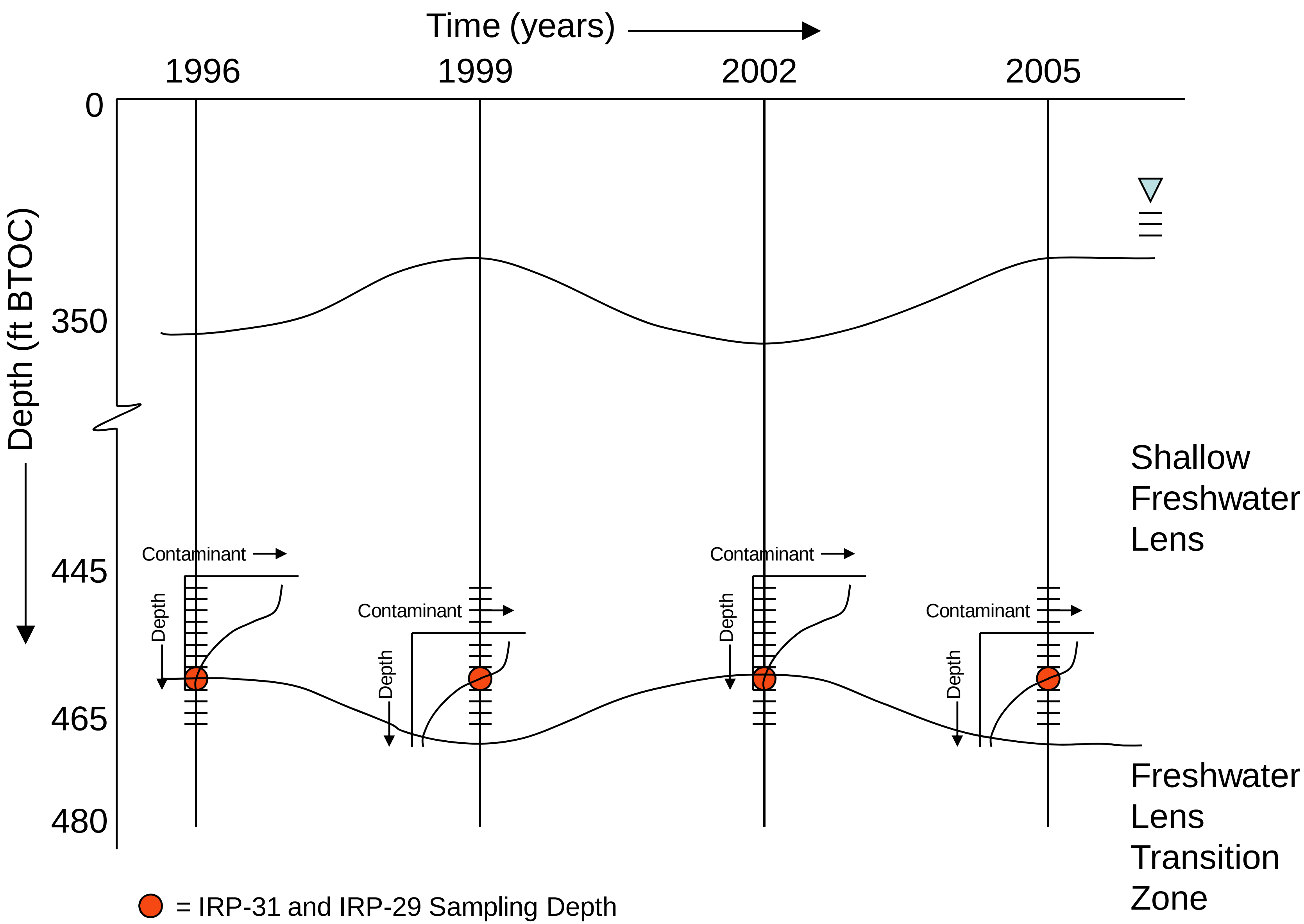


Figure 3-2. Conceptual Model of TCE (IRP-31) and PCE (IRP-29) Concentration Cyclicity Versus Time.

4.0 Performance of Original Prescribed Remedy

According to the 1998 MARBO OU ROD, a combination of MNA and ICs were prescribed as the remedy to address the presence of TCE and PCE in MARBO groundwater (EA, 1998). The performance of this remedy is evaluated in the following two sections.

4.1 Performance Evaluation of Original Prescribed Remedy

Since the issuance of the 1998 MARBO OU ROD, the original sources of the PCE and TCE in MARBO groundwater still remain unknown. Additionally, no new sources of TCE or PCE have been identified at MARBO Annex. According to semi-annual sampling and monitoring of the groundwater at MARBO Annex, MNA has been successful in attenuating the presence of TCE and PCE in the shallow portion of the aquifer (overlying deeper groundwater contamination) due to rapid flushing of the fresh water. As presented in Figure 4-1, the shallow PCE occurrence observed at well IRP-14 has shown marked decline, to below the 5 µg/L MCL level, in the past 11 years of monitoring. The rapid flushing of the fresh water in the upper portion of the groundwater lens has provided a dynamic combination of physical processes (i.e., dilution and dispersion) that have lead to attenuation of PCE and TCE.

However, the MNA remedy has not been successful in attenuating the presence of PCE and TCE in deep wells IRP-29 and IRP-31, respectively. The reasoning for the failure of MNA, as shown in Figures 4-2 and 4-3, is that the PCE and TCE concentrations in IRP-29 and IRP-31, respectively, have been highly variable over the last five years, indicating slight overall increases. The conceptual model is that TCE is trapped in the transition zone limestone matrix and releases very slowly into a karst-dominated system that is static with respect to lateral flow. The concentration variability results from the frequent changes in the karst-flow dynamics from intense rain events, seasonal rainfall, long term ENSO effects, and resulting changes in the transition zone depth. There is no evidence that the TCE and PCE bound to the limestone matrix are decreasing. According to the 1998 ROD, MNA was intended to achieve TCE and PCE reductions to levels below the 5 µg/L MCL in an estimated 10 to 40 years. However, based on 11 years of historical groundwater data at MARBO Annex (as shown in Figure 4-2, 4-3, and Attachment A of Appendix 1), the TCE and PCE concentrations in the deep portion of the groundwater lens have remained cyclical and for all practical purposed unchanged. Therefore, MNA is considered a failed remedy in addressing the presence of the TCE and PCE in the deep portion of the MARBO Annex groundwater lens.

4.2 Compliance of Original Prescribed Remedy with Respect to ARARs

Considering that 11 years of historical groundwater data support the evidence for the failure of MNA to attenuate TCE and PCE in the deep portion of MARBO Annex groundwater lens, the compliance of any alternative remedy with respect to Federal and Territorial (Guam) ARARs should be reevaluated in accordance with CERCLA Section 121 (d). This comparison is presented in Section 5.3 of this document.

Additionally, any selected remedy must be protective of human health and the environment. The remedial action objective (RAO) with respect to the TCE and PCE in the aquifer is to ensure that no drinking water is available for public use with these contaminants present at concentrations above MCLs. According to CERCLA, the point of compliance is in the aquifer, even though the MCLs are Safe Drinking Water Act (SDWA) promulgation with compliance at the point of use. Possible general approaches to achieve the RAO include in situ treatment that destroys the contaminants, pump and treat to remove the contaminants, wellhead treatment, or restrictions against use. Specific remedial alternatives are evaluated and compared in Section 5.

According to CERCLA, any remedy must comply with ARARs, unless a waiver for technical impracticability is invoked. As presented in the earlier sections, the MNA failed to achieve TCE and PCE concentrations below MCLs. As presented in Appendix A of this document, it is technically impractical for MNA to meet MCLs with respect to TCE and PCE due to the hydrogeologic complexities of MARBO Annex OU. However, ICs including potential wellhead treatment will be continued to ensure that no drinking water from MARBO Annex groundwater is impacted above contaminant MCLs. Under the ICs, Guam's Wellhead Protection Program and Guam's Water Resource and Development Operating Regulations will remain in effect to monitor the installation of extraction/pumping wells in or adjacent to impacted areas of MARBO Annex. The Guam EPA has the authority to deny well installation in compromised portions of the aquifer. Andersen AFB will continue to work closely with Guam EPA to supply all groundwater quality data collected as part of the IRP program, so that Guam EPA can maintain an adequate database for their Wellhead Protection Program.

In Section 5 below, other alternatives will be evaluated to achieve the RAO, including in-situ and ex-situ treatment technologies. Additionally, an analysis of the proposed remedy's compliance with ARARs is presented in Section 5.3.

Figure 4-1 Historical PCE Concentration in Well IRP-14

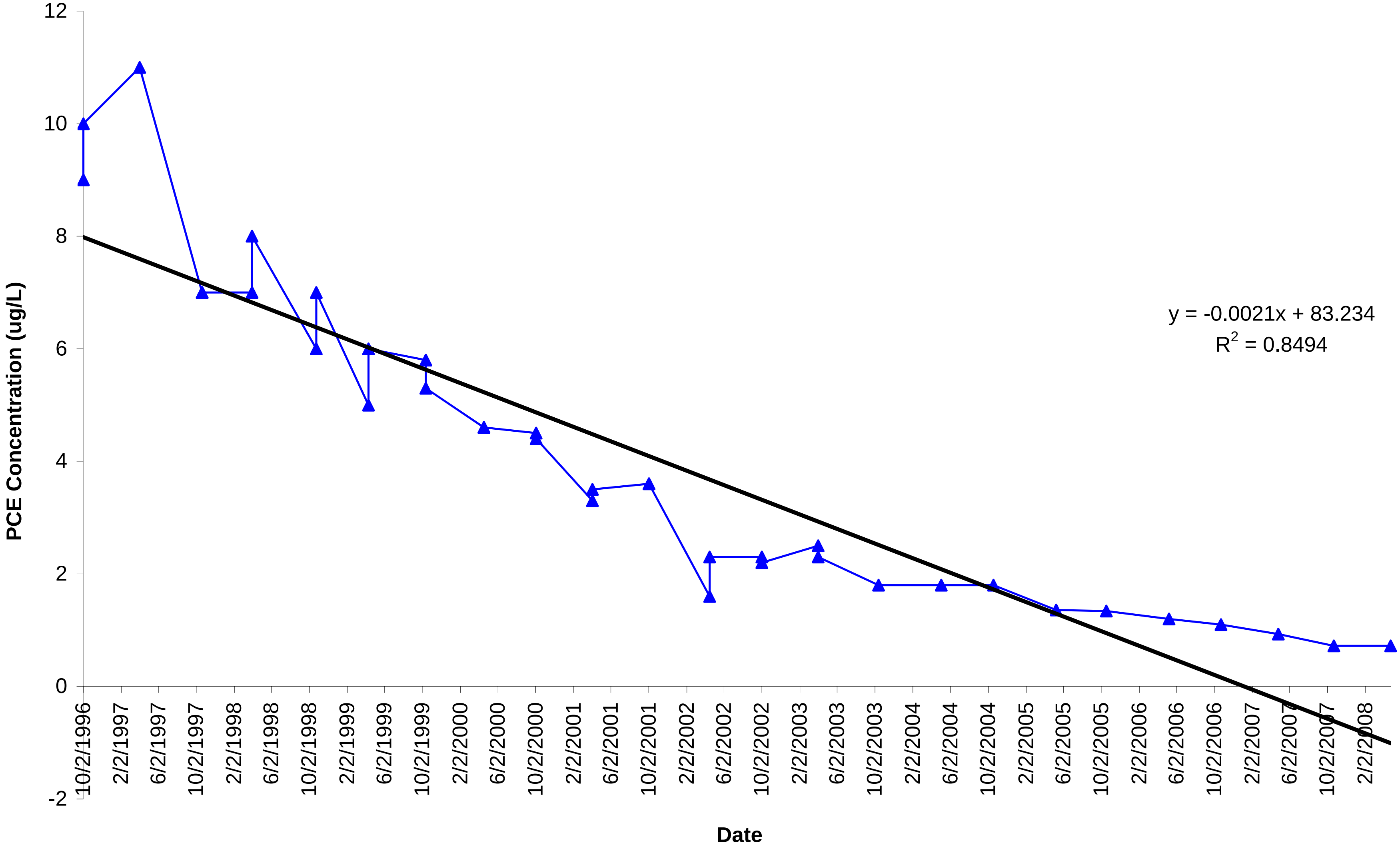


Figure 4-2 Historical PCE Concentration in Well IRP-29

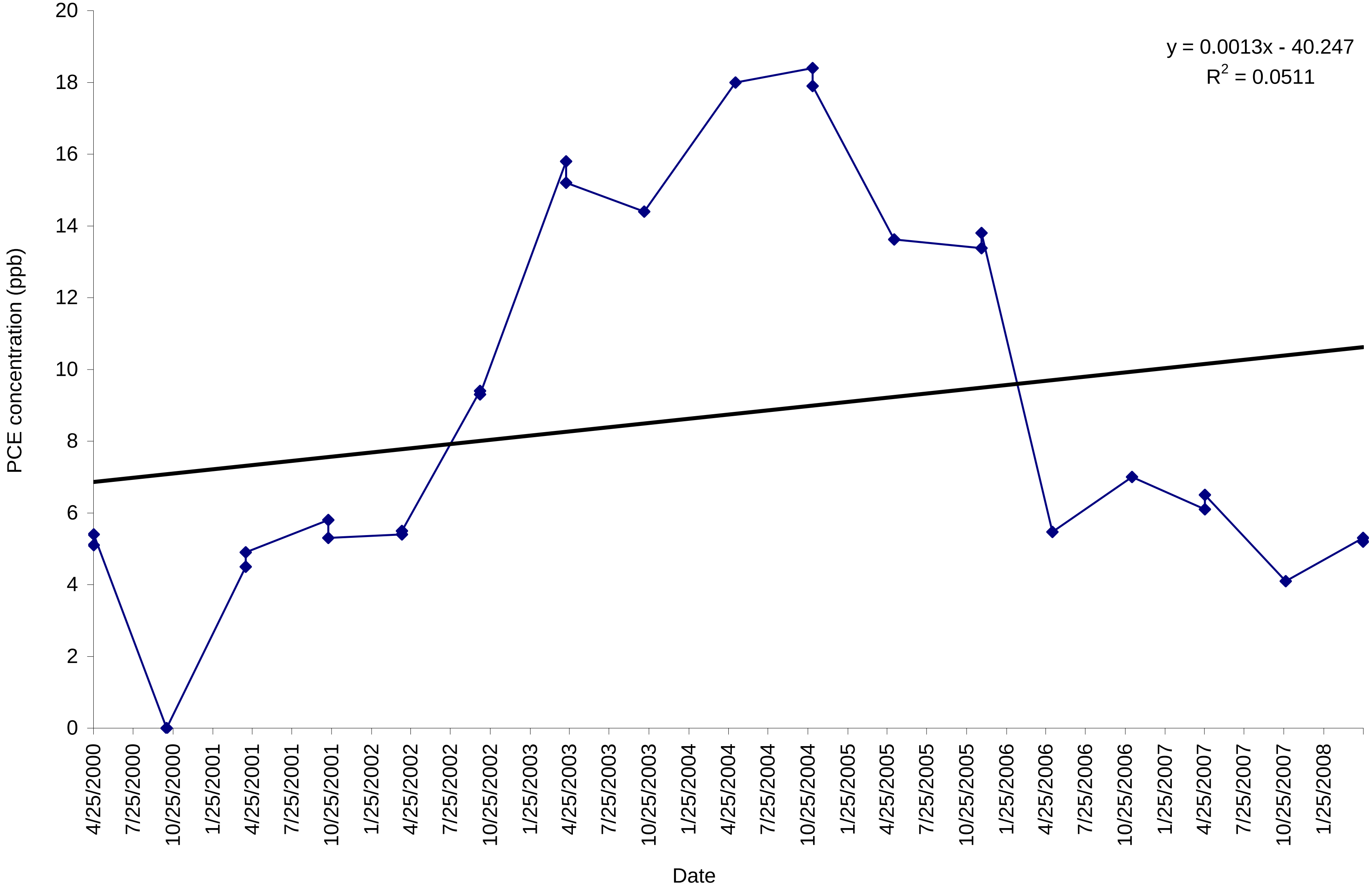
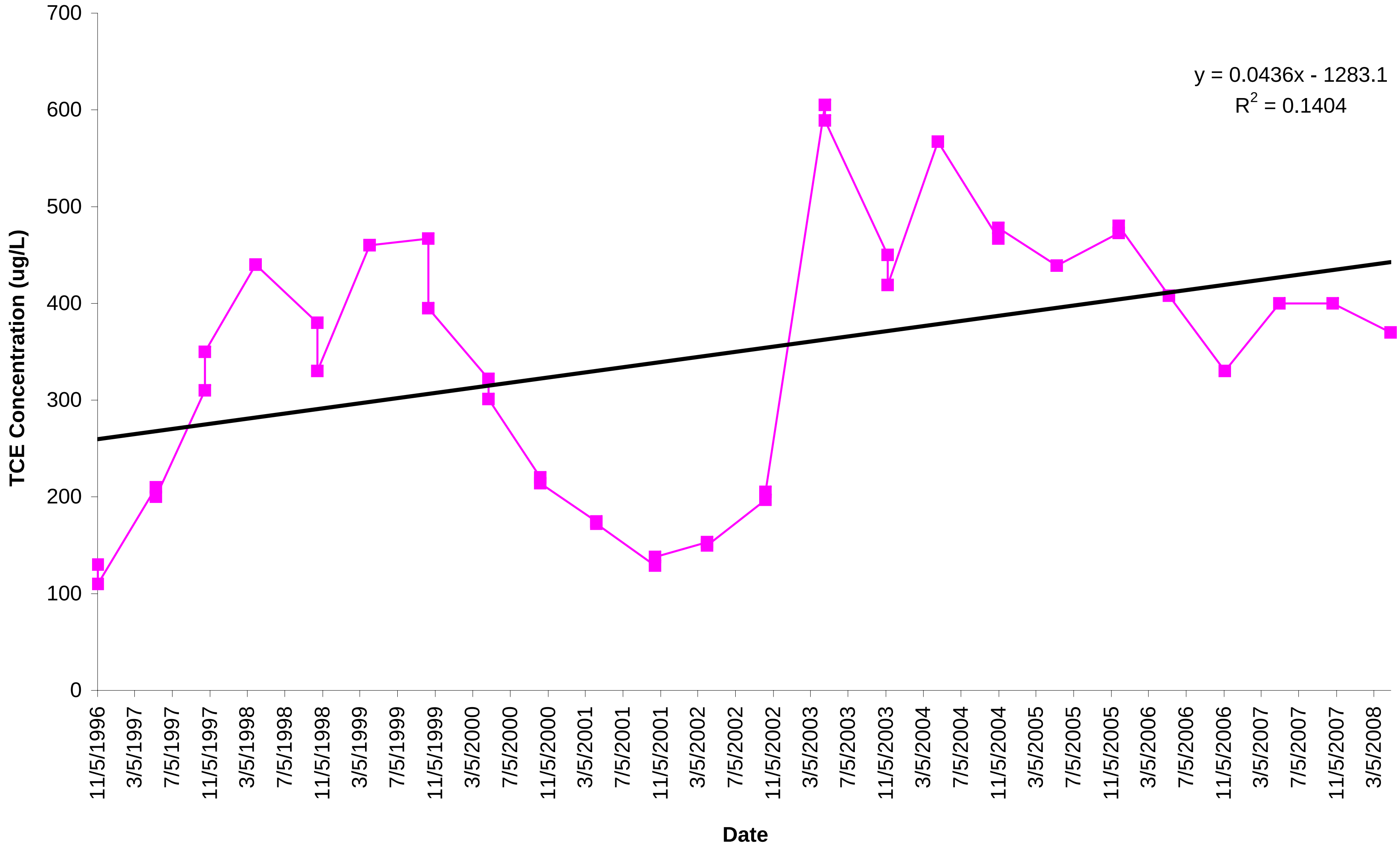


Figure 4-3 Historical TCE Concentration in Well IRP-31



5.0 Remedial Alternatives to be Considered

As discussed in Section 4.0 above, the original remedy of natural attenuation was successful in the upper and main part of the freshwater lens in that that no downgradient drinking water wells are impacted. The new proposed remedy therefore is only necessary for the deeper, brackish portion of the lens. Several remedial alternatives have been identified to address dissolved-phase PCE and TCE in groundwater at the MARBO Annex OU. Remedial alternatives considered within this FFS are:

- Alternative 1—Enhanced Anaerobic Bioremediation (*In-Situ*)
- Alternative 2—Chemical Oxidation (*In-Situ)*
- Alternative 3—Micro-Scale Zero Valent Iron (*In-Situ*)
- Alternative 4—In-Well Air Stripping (*In-Situ*)
- Alternative 5—Pump and Treat (*Ex-Situ*)
- Alternative 6—ICs and Contingency for Wellhead Treatment

5.1 Description of Evaluation Criteria

The following criteria were used to evaluate the remedial alternatives that were carried forward:

1. Implementability
2. Restoration Potential (or Effectiveness)
3. Cost

The factors and elements used in the FFS are as follows:

Implementability

The implementability evaluation focuses on the technical feasibility of implementing each alternative such as:

- Ability to construct, operate, or apply the technology
- Availability and reliability of equipment and skilled workers to implement the technology
- Logistical issues and special considerations
- Ability to monitor effectiveness of remedy

Restoration Potential

The evaluation of restoration potential focuses on the following elements:

- Potential effectiveness for destruction or removal of PCE and TCE in the estimated impacted areas or volume of media
- Ability to achieve the MCL (5 μg/L) for TCE and PCE in groundwater
- The reliability and proven effectiveness of the process with respect to dissolved-phase PCE and TCE in groundwater and the site-specific conditions

Cost

The purpose of the cost evaluation is to screen out technologies that would be cost prohibitive in relation to the benefits obtained. Cost evaluation is preliminary, based on qualitative information and published unit costs, and is not intended to be considered as a firm price for implementing a given technology. The cost evaluation (including assumptions for unit costing) is summarized in Table 5-1. The cost for the continued implementation of ICs, including the contingency for wellhead treatment at any water supply wells impacted by the plume, has not been included within this evaluation.

5.2 Individual Evaluations of Remedial Alternatives

Alternative 1—Enhanced Anaerobic Bioremediation (*In-Situ)*

Enhanced bioremediation entails changing the aerobic or anaerobic conditions within the subsurface to facilitate biological activity and accelerate natural attenuation. Aerobic conditions generally are achieved through introduction of oxygen via bioventing, biosparging, or slow-release oxidation reagent. Anaerobic conditions generally are enhanced by injecting substrate for biological activity, which includes edible oils, edible oil emulsions, or slow-release introduction of hydrogen. Effective bioremediation of PCE and TCE requires stable anaerobic conditions and the presence of appropriate microbial populations within the targeted area.

***Implementability*—**Logistical problems associated with the successful implementation of this technology are practically insurmountable. The depth to groundwater is such that each substrate injection point would require a considerable drilling effort (i.e. a large drill rig with skilled operators and the tools and supplies to reach the required depth). Installation of a sufficient number of tightly spaced injection points (i.e. 10 ft on center) across the area of the PCE and TCE plumes is extremely difficult and certainly is not practical. Accurate placement of injection points at a depth of approximately 400 ft below ground surface (bgs) is extremely difficult because the depth and geology (e.g., cavernous features) causes deflection of drill strings in unpredictable ways. Substrate delivery would require large injection pressures assuming injection points could be properly installed. Even if accurate placement of substrate amendments or introduced microbial communities were possible, it would be unlikely that a sufficient number of microbes could grow due to insufficient surface area of the limestone exposed to groundwater.

Site characterization is limited (due to logistics as discussed above), but the subsurface characteristics that are known indicate that the aquifer is not amenable to treatment using enhanced anaerobic bioremediation. Monitoring the effectiveness of the remedy would require installing and sampling wells in addition to those used for substrate injection.

Attainment of highly anaerobic conditions in the aquifer would require significant reduction of DO, ferrous iron, nitrate, and sulfate prior to reaching the methanogenic conditions that are favorable for reduction of PCE and TCE. The natural conditions of the aquifer are such that excessive amounts of substrate would be required to substantially reduce the level of DO, attain methanogenic conditions, and maintain strongly reducing conditions for even a short time. Transient flow conditions (e.g., input of water during large or sustained rain events) existing within the vadose and saturated zones produce an oxidation-reduction environment that is nearly always oxidized, which means that anaerobic microbes would have little chance of surviving and almost no chance to degrade the PCE and TCE. Even if an anaerobic environment could be generated locally, it is unlikely that it could be sustained, particularly during large infusions of infiltrating water.

High chloride levels observed within the transition zone may be an additional obstacle that must be overcome. High chloride levels (>1000 mg/L) could be biologically inhibitory under temporally transient conditions when lens thinning occurs in response to long term stimuli.

Restoration Potential—Although the effectiveness of enhanced anaerobic bioremediation for the *in-situ* treatment of TCE and PCE has been demonstrated in shallow unconsolidated aquifers where injection is relatively easy and contact with the contaminants is good, none of these ideal conditions exist in the MARBO Annex.

Assuming a sufficient number of injection points could be installed to treat the impacted area, delivery of the injectable substrate also would be inhibited by the dual porosity of the limestone, the rapid flushing of the aquifer, and low surface area to which the substrate could adsorb. In addition, installing an effective permeable reactive barrier would be extremely difficult under these conditions.

For the reasons described above, the potential for PCE and TCE destruction by enhanced bioremediation in groundwater at the MARBO Annex is low enough to be considered not feasible with current and foreseeable bioremediation technologies.

Estimated Cost—$92,200,000 (Table 5-1)

Alternative 2—Chemical Oxidation (*In-situ*)

In-situ chemical oxidation injection is a method used to chemically break the bonds within hydrocarbon compounds (including chlorinated hydrocarbons like PCE and TCE), which effectively destroys them, leaving behind innocuous by-products such as hydrogen, carbon dioxide, and chloride ions. Additional by-products (e.g., magnesium) may result depending on the type of oxidizer used. The method generally is effective in remediation of dissolved-phase constituents, but the stoichiometry between the hydrocarbons and oxygen can be prohibitive for destruction of non-aqueous phase liquid. Effective remediation with this method requires delivery of sufficient amounts of chemical oxidizer and sufficient physical contact and contact time between the oxidizer and the dissolved hydrocarbon compounds.

Implementability—Logistical problems with the successful implementation of this technology are much the same as those for enhanced *in-situ* bioremediation. The depth to groundwater is such that each injection point would require a considerable drilling effort (i.e. a large drill rig with skilled operators and the tools and supplies to reach the required depth). Installation of a sufficient number of tightly spaced injection points (i.e. 10 ft on center) across the area of the PCE and TCE plumes may be extremely difficult and certainly is not practical. Accurate placement of injection points at a depth of approximately 400 ft bgs is extremely difficult because the site geology causes deflection of drill strings in unpredictable ways. Chemical oxidizer delivery would require large injection pressures assuming injection points could be properly installed. Commingling of the oxidant and potential activation agents (e.g., with modified Fenton's or activated persulfate, percarbonate, or peroxygen) would be problematic as well. In addition, those oxidants requiring acidic conditions for reaction optimization would not be implementable in a limestone aquifer, where significant pH buffering would occur and alkaline conditions would prevail irrespective of the amount of acid added to optimize the oxidant reaction.

Site characteristics indicate that physical contact between the oxidizer and the PCE and TCE in groundwater would not be adequate due to the dual porosity and extremely high permeability of the aquifer. Monitoring the effectiveness of the remedy would require installing and sampling of wells that are not used for chemical oxidation injection, adding to the logistical issues.

***Restoration Potential*—**Although the effectiveness of *in-situ* chemical oxidation for the destruction of PCE and TCE has been demonstrated in locations with simpler hydrogeological characteristics, the technology is unlikely to be effective at the MARBO Annex, primarily due to delivery problems mentioned above.

For the reasons described above, the potential for PCE and TCE destruction by *in-situ* chemical oxidation injection at the MARBO Annex is extremely low and not feasible with current and foreseeable oxidation technologies.

***Estimated Cost*—**$57,418,000 (Table 5-1)

Alternative 3—Micro-Scale Zero Valent Iron (*In-Situ*)

Micro-scale zero valent iron (ZVI) is a proven technology that destroys chlorinated hydrocarbons (e.g., PCE and TCE) through abiotic reduction induced by oxidation of the ZVI. As with the previous discussed alternatives, ZVI requires contact with the chlorinated hydrocarbons for these reactions to take place. A common method of *in-situ* groundwater remediation with ZVI involves the "funnel and gate" approach, which sets up an impermeable barrier that funnels groundwater through a permeable reactive barrier filled with a ZVI mixture. Additionally, ZVI can be injected as a slurry mixture into an aquifer in the same way as described in the previous alternatives.

***Implementability*—**Logistical problems with successful implementation of this technology are much the same as those for enhanced *in-situ* bioremediation and chemical oxidation injection. The use of a funnel and gate approach in conditions such as those present at the MARBO Annex is impossible.

The depth to groundwater is such that each injection point would require a considerable drilling effort (i.e. a large drill rig with skilled operators and sufficient tools and supplies to reach the required depth). Installation of a sufficient number of tightly spaced injection points (i.e. 10 ft on center) across the area of the PCE and TCE plumes may be extremely difficult and certainly is not practical. Accurate placement of injection points at a depth of approximately 400 ft bgs is extremely difficult because the site geology causes deflection of drill strings in unpredictable ways. Delivery of a ZVI slurry mixture would require large injection pressures assuming injection points could be properly installed.

Site characteristics indicate that physical contact between the ZVI slurry and the PCE and TCE in groundwater would not be adequate due to the dual porosity and extremely high permeability of the aquifer. Monitoring the effectiveness of the remedy would require installing and sampling of wells that are not used for chemical oxidation injection, adding to the logistical issues.

***Restoration Potential*—**Although the effectiveness of ZVI slurry injection for the destruction of PCE and TCE has been demonstrated in locations with simpler hydrogeological characteristics, the technology is unlikely to be effective at the MARBO Annex, primarily due to delivery problems mentioned above. In addition, oxidation of the ZVI will cause carbonate precipitation on ZVI surfaces, which would significantly decrease the efficiency and lifecycle of the ZVI, leading to frequent ZVI replacement for sustained treatment.

For the reasons described above, the potential for PCE and TCE destruction by ZVI injection at the MARBO Annex is extremely low and not feasible with current and foreseeable ZVI technologies.

***Estimated Cost*—**$57,790,000 (Table 5-1)

Alternative 4—In-Well Air Stripping (*In-Situ*)

In-well stripping is a technology that provides *in-situ* treatment of the vadose and the saturated zones, as well as the capillary fringe. The collection and treatment well is specially designed to create a circular groundwater flow current between an upper screen (typically located at the upper portion of the aquifer) and a lower screen. Water is drawn in from the lower screen and infused with air prior to discharge back into the aquifer through the upper screen. The infused air is compressed in from the surface and acts as an air stripper. The hydrocarbon-laden air is brought to the surface and treated with an *ex-situ* treatment technology such as carbon adsorption.

***Implementability*—**Logistical problems with successful implementation of this technology are much the same as those discussed for prior technologies. The depth to groundwater is such that each well would require a considerable drilling effort (i.e. a large drill rig with skilled operators and tools and supplies to reach the required depth). Installation of a sufficient number of tightly spaced stripper wells (i.e. 20 ft on center) across the area of the dissolved-phase PCE and TCE plumes may be extremely difficult and certainly is not practical. Accurate placement of wells at a depth of approximately 400 ft bgs is extremely difficult because the site geology causes deflection of drill strings in unpredictable ways.

Monitoring the effectiveness of the remedy would require installing and sampling of wells that are not used for in-well stripping, adding to the logistical issues. Additional implementation problems include the need for extensive testing of the system to develop an accurate design. In-well stripping requires that the groundwater extraction rate from the lower screen be balanced with the vapor flow rate and achievable infiltration rate from the upper screen. If these parameters do not coincide, in-well stripping will not be effective. Groundwater recharge conditions in the aquifer are highly unstable, making system balance operations unreasonably complex.

Operation and maintenance (O&M) of in-well stripper systems can be very complicated due to carbonate fouling of well screens and the associated changes the system balance and the inability to produce or inject sufficient water. O&M of in-well stripper systems with a large number of extremely deep wells like the ones required for the MARBO Annex would be extremely difficult.

At the MARBO Annex, TCE has been detected at depth, creating the potential to extract TCE-impacted groundwater and discharge insufficiently treated groundwater to the upper portion of the aquifer. This would result in cross contaminating a sectional volume of the aquifer. A similar problem could occur if saline water were extracted from the lower part of the aquifer and injected into the upper part of the aquifer as well; increasing saline contamination in the upper portion of the aquifer.

Restoration Potential**—**In-well stripping is a demonstrated technology, but its effectiveness can be limited due to the presence of preferential pathways within karst limestone formations or the mass transfer limitations in moving contaminants from diffuse primary porosity to channelized flow in secondary porosity. At the MARBO Annex, creation of an adequate circulation cell between the upper and lower screens will be very difficult because of preferential pathways inherent in the dual porosity and the high flow characteristics of the aquifer. For these reasons and the implementability issues stated above, effective use of this method for aquifer and groundwater restoration is not considered feasible.

Estimated Cost**—**$55,992,000 (Table 5-1)

Alternative 5—Pump and Treat (*Ex-Situ*)

Pump and treat was one of the first technologies that was widely used for remediation of groundwater. In some cases it has not been fully effective in obtaining site closure due to the kinetics of diffusion from contaminant sources into groundwater, but it can be useful for hydraulic control of groundwater plumes. The approach is used to remove contaminated groundwater, treat it using an *ex-situ* technology such as air stripping or carbon adsorption, and discharge the water as appropriate.

Implementability**—**Although logistical problems associated with successful implementation of this technology are formidable, they may be lower than those discussed for the other discussed technologies. As with the other technologies, the depth to groundwater is such that each well would require a considerable drilling effort (i.e. a large drill rig with skilled operators and sufficient tools and supplies to reach the required depth). Pumping tests would be required to determine the well spacing, and as with the other technologies the installation of a sufficient number of wells across the extent of the PCE and TCE plumes may be very difficult or highly impractical. Accurate placement of wells at a depth of approximately 400 ft bgs is extremely difficult because the site geology causes deflection of drill strings in unpredictable ways. Monitoring the effectiveness of the remedy may require installing and sampling wells that are not used for groundwater extraction, adding to the logistical issues.

Extraction of large amounts of water from the freshwater part of the aquifer at the MARBO Annex could cause significant problems with saltwater intrusion, which is highly undesirable. Groundwater recharge conditions in the aquifer are highly unstable, which could require significant effort by operators to avoid over pumping (exacerbating saltwater intrusion) or under pumping (with the associated loss of sufficient capture and/or hydraulic control of the plume).

***Restoration Potential*—**As mentioned above, pump and treat technology has not always been effective for obtaining sufficient mass removal to attain site closure. For this reason and the implementability issues stated above, effective use of this method for aquifer and groundwater restoration is not practical or feasible.

***Estimated Cost*—**$55,992,000 (Table 5-1)

Alternative 6—ICs and Contingency for Wellhead Treatment

The high cost and significant logistical issues associated with Alternatives 1 through 5 necessitate the Justification for a TI Waiver in the form of institutional controls with a contingency for wellhead treatment. Institutional controls can take many forms, including deed restrictions, fencing and signage, limitations on issuance of permits, etc. Alternative 6 includes the use of ICs restricting groundwater extraction from the transitional zone in the deep part of the freshwater lens, but it also adds the option of groundwater treatment at the wellhead if extracted groundwater exceeds the limitations set forth in the TI waiver.

***Implementability*—**Alternative 6 is readily implementable. GEPA regulates well drilling and well operating through a permit process, which can be used to prevent water withdrawal from the deeper part (transitional zone) of the freshwater lens. *Ex situ* groundwater treatment for VOCs such as PCE and TCE is readily implemented using technologies such as granular activated carbon (GAC) and/or air stripping if wellhead treatment is required. There are active production wells in certain areas of MARBO Annex. These productions wells are regularly tested for SDWA parameters and should there be any TCE or PCE, the wellhead treatment will be implemented, if necessary, to protect human health and the environment as stipulated in 1998 ROD (EA, 1998).

***Restoration Potential*—**Institutional controls with a wellhead treatment contingency will not be effective in restoring the deeper zones of the aquifer to pristine conditions.

***Estimated Cost*—**$992,000 (Inclusive of contingency wellhead treatment) (Table 5-1)

5.3 ARARs Analysis

As shown in Table 5-1 only ICs and Contingency for Wellhead Treatment meets all the screening criteria and is retained as remedial alternative. An evaluation of whether eliminated alternative met ARARs analysis is not necessary since they would only achieve the ARARs if they were successfully implemented and in each case the FFS and Appendix A show that their implementation is impracticable. An analysis of whether the alternative proposed remedy, a TI Waiver and ICs with a contingency for wellhead treatment will satisfy the ARARs and To Be Considered Criteria guidance is presented in Tables 5-2 through 5-3.

The main point of comparison between the previous preferred remedial alternative, MNA, and the proposed alternative preferred remedy is that MNA cannot meet the MCLs as discussed in previous sections, where ICs and Wellhead Treatment is able to achieve the RAO and satisfy all chemical-, action-, and location-specific ARARs/TBCs provided that requirement to achieve MCLs in the drinking water aquifer is waived.

TABLE 5-1. FOCUSED FEASIBILITY STUDY REMEDIAL TECHNOLOGY SCREENING MATRIX

REMEDIAL ALTERNATIVE[1]	TARGETED MEDIA	UTILIZATION STATUS	RELATIVE EFFECTIVENESS	IMPLEMENTABILITY
BIOLOGICAL TREATMENT				
Enhanced Anaerobic Bioremediation (In-Situ)	Deep Groundwater (450 to 500 feet bgs)	Available	Low	Difficult
CHEMICAL TREATMENT				
Chemical Oxidation (In-Situ)	Deep Groundwater (450 to 500 feet bgs)	Available	Low	Difficult
Micro-Scale Zero Valent Iron (In-Situ)	Deep Groundwater (450 to 500 feet bgs)	Available	Low	Difficult
PHYSICAL TREATMENT				
In-Well Air Stripping (In-Situ)	Deep Groundwater (450 to 500 feet bgs)	Available	Low	Difficult
Pump and Treat (Ex-Situ)	Deep Groundwater (450 to 500 feet bgs)	Available	Low	Difficult
ICs and Contingency for Wellhead Treatment	Deep Groundwater (450 to 500 feet bgs)	Available	High	Implementable

TABLE 5-1. FOCUSED FEASIBILITY STUDY REMEDIAL TECHNOLOGY SCREENING MATRIX

REMEDIAL ALTERNATIVE[1]	ESTIMATED CONSTRUCTION COST[2]	OVERALL RESTORATION POTENTIAL	SCREENING	TI WAIVER RATIONALE[3]
BIOLOGICAL TREATMENT				
Enhanced Anaerobic Bioremediation (In-Situ)	$92,200,000	Low	Eliminate	• Insufficient aquifer surface area in karst setting for colonization of degrading microorganisms • Inaccurate or insufficient spatial delivery of biostimulants and/or degrading microorganisms at depth of contamination • High oxygen levels in groundwater and transient, episodic flow conditions will disallow stable, reducing conditions required for biological reductive dechlorination
CHEMICAL TREATMENT				
Chemical Oxidation (In-Situ)	$57,418,000	Low	Eliminate	• Inaccurate or insufficient spatial delivery at depth of contamination in complex geologic setting • Optimization of pH-dependent oxidants (e.g., Fenton's, activated persulfates/peroxygens) not possible due to carbonate buffering in karst setting
Micro-Scale Zero Valent Iron (In-Situ)	$57,790,000	Low	Eliminate	• Inaccurate or insufficient spatial delivery at depth of contamination in complex geologic setting • Significant decrease in zero valent iron reactivity in short time frames due to carbonate scaling in karst setting
PHYSICAL TREATMENT				
In-Well Air Stripping (In-Situ)	$55,992,000	Low	Eliminate	• High volume of pumping required • Short circuiting due to directional flow from secondary porosity conduits • Mass transfer limitations from primary diffuse porosity
Pump and Treat (Ex-Situ)	$55,992,000	Low	Eliminate	• High volume of pumping required • Potential for upwelling of marine water • Mass transfer limitations from primary diffuse porosity • carbonate scaling of treatment system
ICs and Contingency for Wellhead Treatment	$992,000	Low	Retain	• Remedial alternative would be implemented under a TI waiver determination

TABLE 5-1. FOCUSED FEASIBILITY STUDY REMEDIAL TECHNOLOGY SCREENING MATRIX

Notes:
bgs = below ground surface
IC = institutional control
TI = technical impracticability

1. No Action was not evaluated because it did not meet Remedial Action Objectives as specified in ROD (EA, 1998), and it was eliminated as an alternative in previous FFS (EA, 1997). Remedial alternatives evaluated within this FFS were selected on the basis of: A) currently applicable technologies (including presumptive remedies), B) findings of previous FFS (EA, 1998), and C) 2006-2008 RPM meeting correspondence.
2. Estimated construction costs based on well installation costs and technology unit costs to treat entire plume (3 Pore Volumes for physical treatments). System O&M costs not included. Estimated costs based on the following assumptions:
   -Spatial extent of PCE exceedance in area of IRP-29
   Length of PCE plume: 2500 ft
   Width of PCE plume: 1000 ft
   Height of PCE plume: 50 ft
   Volume of aquifer treatment: 4.6E06 cu yds
   Volume of groundwater with PCE above 5 ug/L: 2.8E08 gal
   -Spatial extent of TCE exceedance in area of IRP-31
   Length of TCE plume: 3000 ft
   Width of TCE plume: 1000 ft
   Height of TCE plume:50 ft
   Volume of aquifer treatment: 5.6E06 cu yds
   Volume of groundwater with TCE above 5 ug/L: 3.4E08 gal
   -Estimated number of required injection or extraction wells (@$100,000 each) per technology:
   In-Well Air Stripping (In-Situ): 550 (based on 100 ft well spacing)
   Pump and Treat (Ex-Situ): 550 (based on 100 ft well spacing)
   Chemical Oxidation (In-Situ): 550 (based on 100 ft well spacing)
   Zero-Valent Iron (In-Situ): 550 (based on 100 ft well spacing)
   Enhanced Anaerobic Bioremediation (In-Situ): 550 (based on 100 ft well spacing)
   -Average Unit Treatment Cost (EPA Clu-In; http://www.frtr.gov/matrix2/section4/4_2.html) per technology for large scale, difficult sites:
   In-Well Air Stripping (In-Situ): $4/10,000 gal
   Pump and Treat (Ex-Situ): $4/10,000 gal (for air ex-situ air stripping)
   Chemical Oxidation (In-Situ): $39/10,000 gal
   Zero-Valent Iron (In-Situ): $45/10,000 gal
   Enhanced Anaerobic Bioremediation (In-Situ): $60/1000 gal
3. Rationale relating to the performance potential of the remedial alternatives evaluated. The low performance potential support the justification for a TI Waiver (Appendix A).
4. The cost for continued promotion of ICs, including the contingency for wellhead treatment at any water supply wells impacted by the plume, has not been included within this evaluation.

TABLE 5-2. CHEMICAL-SPECIFIC APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS AND TO-BE-CONSIDERED GUIDANCE FOR THE PROPOSED REMEDY

Source or Authority	Requirement, Standard, or Criterion	Type	Description	Remarks
Federal				
Safe Drinking Water Act	40 CFR 141.11 to 141.16	Relevant and Appropriate	Enforceable standards for public water systems. Identifies Maximum Contaminant Levels.	Meets the MCL at point of use using wellhead treatment if necessary.
Clean Water Act, National Pollutant Discharge Elimination System (NPDES)	40 CFR 122 and 125	Applicable	Regulates the discharge of treated effluent and storm water runoff. Substantive provisions of a NPDES permit for discharges to a state body of water	Meets discharge requirements by restricting extraction form the transitional zone and by using appropriate treatment technologies if necessary.
Guam				
Guam Safe Drinking Water Act	10 GCA, Chapter 53	Relevant and Appropriate	Establishes primary and secondary standards and MCL.	Meets the MCL at point of use using wellhead treatment if necessary.
Revised Guam Water Quality Standards, Adopted 7/18/87 and 1/2/92	Public Law 26-32	Applicable	Restricts, controls, and permits pollutant discharges, and defines water quality criteria.	Meets discharge requirements by restricting extraction form the transitional zone and by using appropriate treatment technologies if necessary.
Water Pollution Control Act	10 GCA, Chapter 47	TBC	Determines ways and means of eliminating and/or preventing pollution to surface waters and groundwaters.	Meets regulatory requirements restricting extraction form the transitional zone and by using appropriate treatment technologies if necessary.
Air Pollution Control Act	10 GCA, Chapter 49	Applicable[1]	Establishes air quality criteria; sampling, testing, monitoring, record keeping requirements, source permitting system; and specific control requests.	VOC off-gas discharge will be kept within acceptable regulatory limits.

ARAR = Applicable or Relevant and Appropriate Requirement
CFR = Code of Federal Regulations
GCA = Guam Code Annotated
MCL = Maximum Contaminant Level
TBC = To Be Considered
(1) = Note: Only applicable to air stripping wellhead treatment option.

TABLE 5-3. ACTION-SPECIFIC APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS AND TO-BE-CONSIDERED GUIDANCE FOR THE PROPOSED REMEDY

Source or Authority	Requirement, Standard, or Criterion	Type	Description	Remarks
Federal				
Safe Drinking Water Act, Underground Injection Control Program	40 CFR 144	Relevant and Appropriate	The underground injection of fluids must meet the established standards and procedures. The control program restricts the underground injection of wastes and treated wastewater.	Meets discharge requirements by using appropriate treatment technologies if necessary.
Clean Air Act (CAA)	CAA Section 109 and 40 CFR 50	Applicable	Permits and regulates air emissions if considered a major source.	If air stripping is used for wellhead treatment, VOC off-gas discharge would not be considered a major source; therefore, off-gas treatment would not be required.
Guam				
Guam Wellhead Protection Program Adopted March 4, 1993 and Guam's Water Resource and Development Operating Regulations	10 GCA, Chapter 46	Applicable	Protects groundwater in wells/wellfields that supply drinking water. Regulates permitting of production and monitoring wells, and contractor licensing.	Meets requirements by imposing institutional controls on permits.
Water Resources Conservation Act	10 GCA, Chapter 48	Applicable	Restricts development of groundwater through licensing and permit issuance for well drilling and operation, and sets construction standards.	Meets requirements by imposing institutional controls on permits.
Underground Injection Control Regulations	10 GCA, Chapter 53	Applicable	Restricts subsurface injection to prevent contamination and/or deterioration of groundwater resource.	Meets discharge requirements by using appropriate treatment technologies if necessary.

ARAR = Applicable or Relevant and Appropriate Requirement
CFR = Code of Federal Regulations
GAR = Guam Administrative Rules
GCA = Guam Code Annotated
TBC = To Be Considered

TABLE 5-4. LOCATION-SPECIFIC APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS AND TO-BE-CONSIDERED GUIDANCE FOR THE PROPOSED REMEDY

Source or Authority	Requirement, Standard, or Criterion	Type	Description	Remarks
Federal				
National Historic Preservation Act	16 USC Section 469; 36 CFR 65; 40 CFR 6.301(b)	Applicable	Action to recover and preserve artifacts if in an area where action may cause irreparable harm, loss, or destruction of significant artifacts.	Will consult with Guam and National Register of Historic Places if necessary.
Guam				
No location-specific ARARs or TBCs identified for groundwater.				

ARAR = Applicable or Relevant and Appropriate Requirement
CFR = Code of Federal Regulations
TBC = To Be Considered
USC = United States Code

6.0 Summary of Technology Screening

A summary of the potentially applicable groundwater technologies evaluated in this FFS is presented in Table 5-1. The remedies evaluated in this FFS are presumptive remedies or those considered most appropriate for the observed contaminants and geologic setting. Each remedy alternative, except ICs and Contingency for Wellhead Treatment, was considered not implementable and low in restoration potential. In addition, the costs to implement these remedies, as shown in Table 5-1, are exorbitantly high except for ICs and Contingency for Wellhead Treatment.

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7.0 Conclusions and Recommendations

The hydrogeologic conditions and contaminant distribution at the MARBO Annex present a formidable challenge that existing remedial technologies are not capable of adequately addressing. Due to the complexities of the underlying vadose zone and limestone aquifer, technologies that might be retained for further consideration under more conventional subsurface conditions (i.e., thinner and more homogeneous vadose zone, no secondary solution channels, lower aquifer transmissivities, more adequately defined contaminant distribution and migration pathways) were eliminated in this FFS screening.

Based on the technical impracticability of utilizing existing remedial technologies, the proposed remedy at MARBO Annex involves a TI Waiver for groundwater, with the continuation of ICs, including the contingency for wellhead treatment at any on-MARBO water production wells or any existing or future off-MARBO Annex production wells within the extent of the TCE and PCE plumes. This alternative would achieve the RAO and would ensure that efforts addressing the TCE and PCE contamination are fully implementable and practicable, thereby preventing unnecessary expenditures on potentially unsuccessful treatment technologies.

A Justification for a TI Waiver is included as Appendix A of this document. Following regulatory concurrence of this FFS and Justification for a TI Waiver, a ROD Amendment supporting the TI Waiver for MARBO Annex groundwater will be prepared and submitted during the second five-year review of MARBO Annex OU ROD due in 02 March 2009.

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APPENDIX A: JUSTIFICATION FOR A TECHNICAL IMPRACTICABILITY WAIVER AT MARBO ANNEX OPERABLE UNIT FOR THE GROUNDWATER RECORD OF DECISION AMENDMENT

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LIST OF ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
AOC	Area of concern
ARARs	Applicable or Relevant and Appropriate Requirements
bgs	below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
COCs	contaminant of concern
DNAPL	Dense non-aqueous phase liquid
DO	Dissolved oxygen
EA	EA Engineering, Science, and Technology, Inc.
ENSO	El Nino\Southern Oscillation
ft	feet
FFA	Federal Facility Agreement
FFS	Focused Feasibility Study
FS	Feasibility Study
GPA	Guam Power Authority
GovGuam	Government of Guam
Guam EPA	Guam Environmental Protection Agency
GWA	Guam Waterworks Authority
IC	Institutional Control
ICF	ICF Technology, Inc.
IRP	Installation Restoration Program
LTGM	Long-Term Groundwater Monitoring
MARBO	Marianas Bonins
MCL	Maximum Contaminant Level
MNA	monitored natural attenuation
mgd	million gallons per day
µg/L	micrograms per liter
mg/L	milligrams per liter
mV	millivolts
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NGL	Northern Guam Lens

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

NPL	National Priorities List
ORP	Oxidation-reduction Potential
OSWER	Office of Solid Waste and Emergency Response (USEPA)
OU	Operable Unit
PCE	tetrachloroethene
RA	Remedial Action
RI	Remedial Investigation
ROD	Record of Decision
SARA	Superfund Amendments and Reauthorization Act
TCE	trichloroethene
TI	Technical Impracticability
USAF	United States Air Force
USEPA	United States Environmental Protection Agency

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Justification for a Technical Impracticability Waiver at MARBO Annex Operable Unit for the Groundwater Record of Decision Amendment

1.0 Overview

Elevated levels of trichloroethene (TCE) and tetrachloroethene (PCE) in groundwater have been identified at the base of the freshwater lens at the Marianas Bonins Command (MARBO) Annex Operable Unit (OU), which is located adjacent to Andersen Air Force Base (AFB) on the north central karst limestone plateau of Guam (Figures 1-1 and 1-2). The United States Air Force (USAF), as the lead agency, is waiving the applicable or relevant and appropriate requirements under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), the Superfund Amendments and Reauthorization Act of 1986 (SARA), the Safe Drinking Water Act, and to the extent practical, the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) for groundwater restoration to Maximum Contaminant Levels (MCLs) because of Technical Impracticability (TI).

Remediating groundwater within the basal freshwater lens at the MARBO Annex is not feasible because of the depth of contamination (approximately 400 feet [ft] below ground surface [bgs]), the transient, rapid groundwater-flow conditions, and the limitations of existing technologies (particularly limited spatial delivery/influence and negative effects on nearby production wells). In addition, residual shallow subsurface sources of TCE and PCE contamination in the shallow freshwater lens have not been identified after extensive Remedial Investigations (RI) and a Long-term Groundwater Monitoring (LTGM) Program. Although believed to be separate occurrences (with TCE of unknown origin and PCE presumably originating from the MARBO Laundry), there is no indication of shallow contaminant sources for the observed TCE and PCE dissolved-phase plumes.

The TCE and PCE dissolved-phase plumes are not amenable to remediation and appear to be contained in a laterally static system at the base of the freshwater lens. The Record of Decision (ROD)-selected operating Remedial Action (RA) of Monitored Natural Attenuation (MNA) with Institutional Controls (ICs) (EA Engineering, Science, and Technology, Inc. [EA], 1998a), including the contingency for wellhead treatment at any water supply wells impacted by the plumes, has been operating since 1998. However, residual levels of dissolved-phase TCE and PCE persist at concentrations that do not allow for unrestricted use of the property within an acceptable timeframe. The RA was planned to achieve cleanup in an estimated 10 to 40 years. Since this does not appear to be possible and other alternatives do not appear to be feasible, this document is being submitted with a Focused Feasibility Study (FFS) to support a ROD amendment invoking a TI Waiver for MARBO Annex groundwater.

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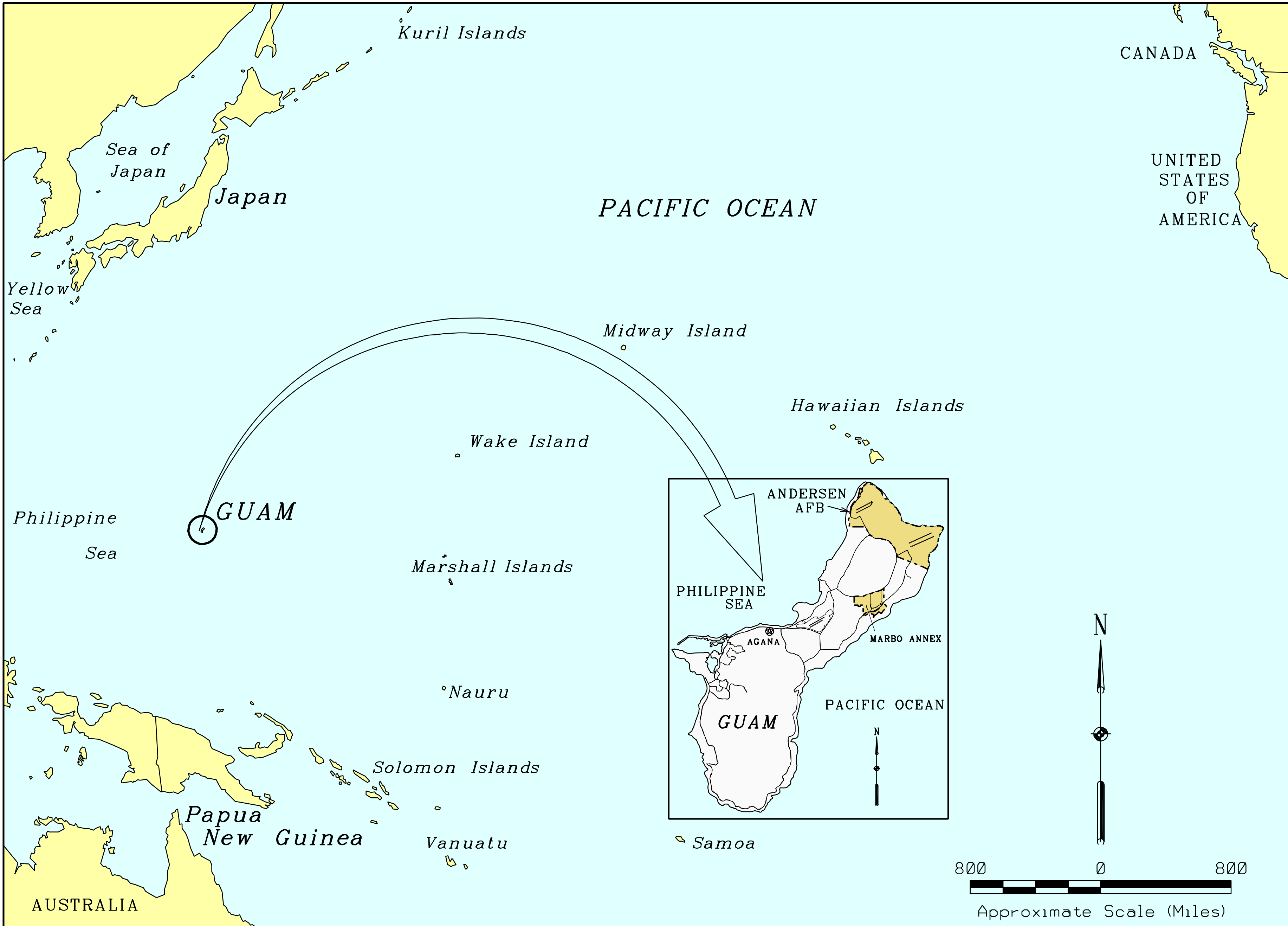

Figure 1-1. Location Map of Guam.

Figure 1–2. Location Map of Andersen Air Force Base on Guam.

2.0 Site Location

Guam is the largest of the Mariana Islands and is located in the western Pacific Ocean between 13º15’ and 13°39’ north latitude and 144º37’ and 144º57’ east longitude, approximately half way between Japan and New Guinea (Figure 1-1). The island has an area of nearly 209 square miles and is approximately 30 miles long and 4 to 8 miles wide.

Andersen AFB is located in the northern half of the island and consists of several parcels of land (Figure 1-2). The largest contiguous portion of Andersen AFB property consists of the Main Base and the Northwest Field, which together are approximately 8 miles wide, 2 to 4 miles long, and 24.5 square miles in area. Currently the majority of base operations are located at the Main Base. Northwest Field has generally been inactive since the mid-1950’s (EA, 1997). The Main Base and Northwest Field are bounded by the Rota Channel to the north, the Philippine Sea to the west, and the Pacific Ocean to the east (Figure 1-2).

MARBO Annex, like Harmon Annex, is AFB property that is not contiguous with the Main Base and the Northwest Field of Andersen AFB (Figure 1-2). The MARBO Annex, comprising 2,432 acres, lies approximately 4 miles south of the Main Base.

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3.0 Background

Andersen AFB began conducting RIs at the MARBO Annex as early as 1985. In 1992, USEPA Region 9 formally listed Andersen AFB on the National Priorities List (NPL) with a Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) identification number of GU6571999519. By 1993, the USAF entered into a Federal Facility Agreement (FFA) with the USEPA and Guam EPA and began its Superfund cleanup program in accordance with CERCLA.

According to the FFA and in response to groundwater impacts in the MARBO Annex, Andersen AFB designed an OU approach to manage the remedial investigation of potential contaminant sources under the Installation Restoration Program (IRP). Prior to 1996, the original OUs were designated numerically (ICF Technology, Inc. [ICF], 1994). MARBO Annex groundwater, along with groundwater from Harmon Annex, Main Base, and Northwest Field, were given a base wide designation as OU-2. Subsequent to 1996, Andersen AFB re-designated their OUs into geographically distinct areas that combined soil, potential contaminant sources, and groundwater (Andersen AFB, 2003). The OU for MARBO Annex groundwater became the MARBO Annex OU.

The MARBO Annex OU includes the following six IRP Sites, along with the groundwater beneath them (Figure 3-1):

- IRP Site 20/Waste Pile 7
- IRP Site 22/Waste Pile 6
- IRP Site 23/Waste Pile 5
- IRP Site 24/Landfill 29
- IRP Site 37/War Dog Borrow Pit
- IRP Site 38/MARBO Laundry

Although, physically located in the MARBO Annex, the following three IRP Sites are included in the Site Wide OU (Figure 3-1):

- IRP Sites 41, 42, and 43

There were no constituents of concern (COCs) identified at IRP Site 23/Waste Pile 5 or IRP Site 37/War Dog Borrow Pit that posed unacceptable risks to human health or the environment (EA, 1998a). Subsequently, a No Further Action was recommended for these IRP sites. The remaining sites (except for IRP Sites 41, 42, and 43) are grouped and presented together according to a common RA. The RA for IRP Site 22/Waste Pile 6, IRP Site 24/Landfill 29, and IRP Site 38/MARBO Laundry are Completed RAs. The RAs for IRP Site 20/Waste Pile 7 and the groundwater beneath the MARBO Annex are considered operating RAs, where the RA has been initiated, but the cleanup levels have not been achieved. Monitoring of the RA has been conducted through semi-annual groundwater monitoring as part of the LTGM Program at Andersen AFB (EA, 1995; EA 1998a; EA, 1998b).

In the case of IRP Site 20/Waste Pile 7, cleanup levels are not applicable because protectiveness depends on the implementation of engineering controls (cover) and land use controls. IRP Sites 41, 42, and 43 were recently investigated. Results of this investigation are currently being evaluated in an RI/Feasibility Study (FS). Upon completion of the RI/FS, the data will be incorporated into a ROD document.

Certain monitoring wells installed within the basal freshwater lens beneath the MARBO Annex have indicated historic contamination (pre-dating monitoring initiation) with TCE and PCE concentrations above MCLs. Well IRP-29, screened within the lower portion of the basal freshwater lens, has indicated cyclic variation of PCE over time with a maximum of 7 micrograms per liter (µg/L). The proximity of the MARBO Laundry to IRP-29 has raised the question of a possible connection, though no direct link has been observed. Well IRP-31, also screened within the lower portion of the freshwater lens, has exhibited cyclic trends of TCE contamination with sustained maxima of approximately 605 µg/L. Guam Power Authority GPA-1 and GPA-2, fully screened through the freshwater lens but sampled at the base of the lens, are located down gradient to IRP-31 and have exhibited cyclic trends of TCE contamination that have, at times, slightly exceeded the MCL (Figure 3-2).

The cyclic increases and decreases in COC concentrations observed deep in the freshwater lens temporally coincide with changes in the elevation of the water table and the thickness of the freshwater lens. These variations in the configuration of the freshwater lens appear to be influenced mainly by long-term variations in the amount of precipitation and fluctuations in sea level. As discussed in Section 7.0, the vertical movement of parcels of groundwater past a fixed sampling point appears to have created a well sampling artifact that fluctuates in response to these long-term stimuli.

Because the dissolved-phase TCE and PCE are geographically distinct plumes, a common source to these occurrences is not plausible. Within the context of this TI Waiver, the TCE and PCE plumes are, however, being addressed together as a regional groundwater problem. Though a significant amount of potential sources have been investigated as IRP sites, surface and/or subsurface sources for the TCE and PCE within MARBO Annex groundwater have not been identified.

Subsequent Sections of this Justification for a TI waiver address the TI evaluation components as follows:

1. **Specific ARARs for TI determination**: Section 12.0 elaborates on specific ARARs or media cleanup standards for which this TI determination is being sought.
2. **Spatial Area over which TI Decision Will Apply**: Section 12.0 describes the spatial extents of the TI waiver.
3. **Conceptual Site Model**: Sections 4.0-9.0 provide general information on the site physical characteristics, land and resource use, geology, hydrogeology, the occurrence of TCE and PCE, and investigation of potential source areas for observed groundwater contamination at the MARBO Annex.
4. **Restoration Potential**: Sections 10.0-10.4 describe the restoration potential of the site and include justifications for the TI classification.

5. **Cost Estimate of Remedies Evaluated**: Section 10.5 qualitatively describes estimated costs involved in restoration alternatives. A quantitative cost analysis is provided in Table 4-1 of the FFS.

In addition, specific discussions on the TI Waiver may be found in Sections 10.0 through 12.0. The conclusions of this document are contained within Section 13.0.

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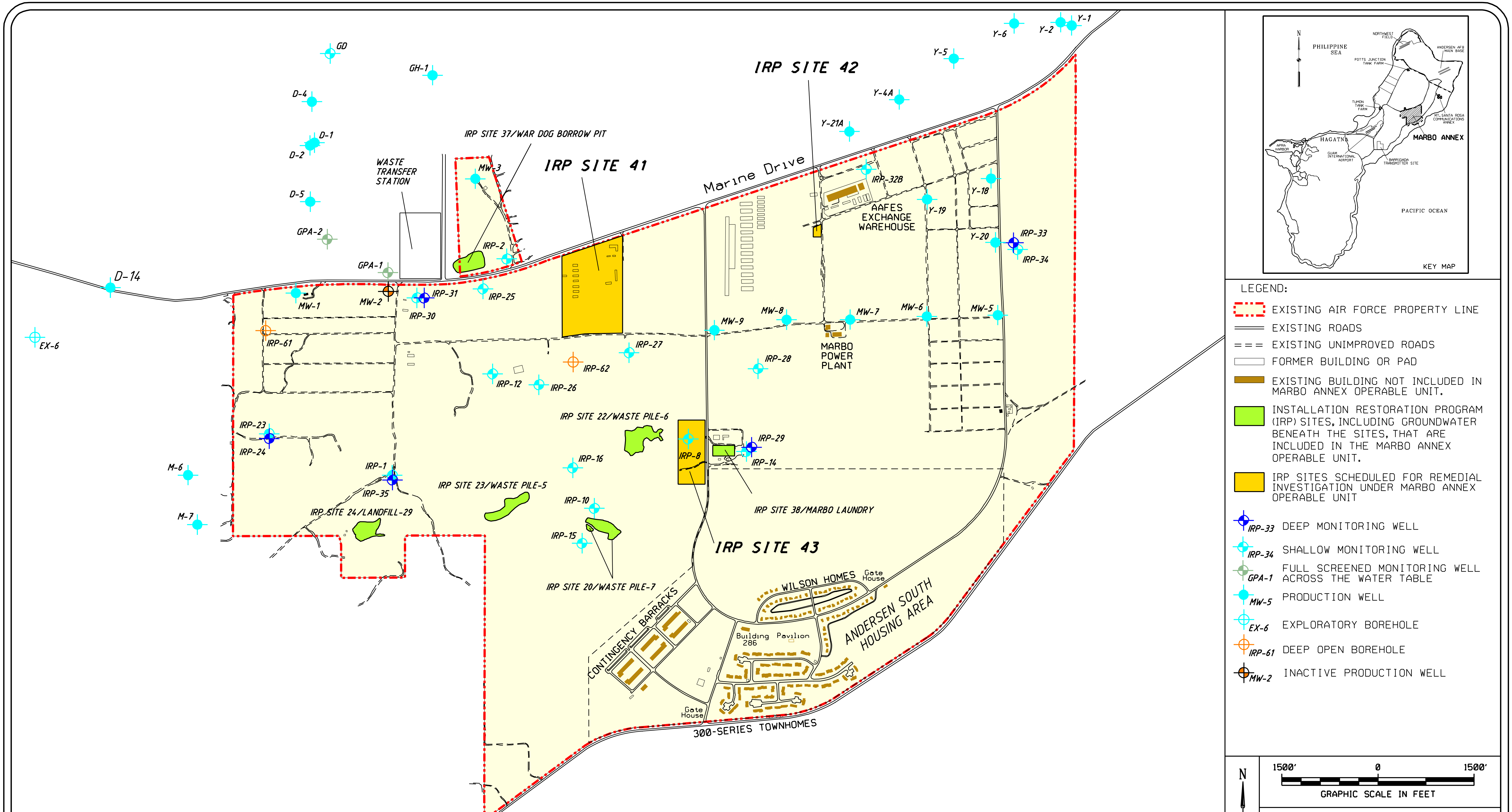

Figure 3-1. Installation Restoration Program Sites and Production Wells in MARBO Annex Operable Unit.

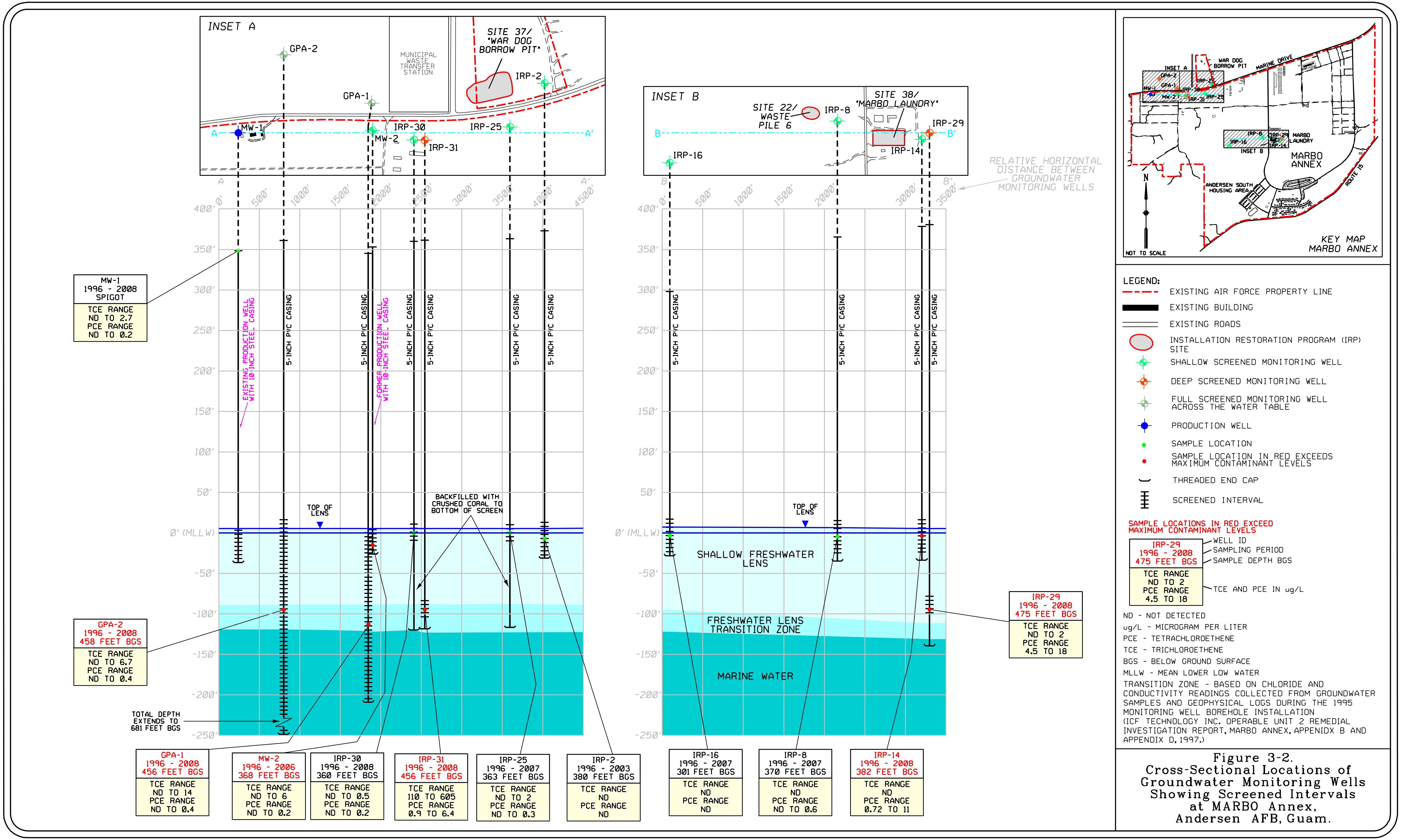

Figure 3-2. Cross-Sectional Locations of Groundwater Monitoring Wells Showing Screened Intervals at MARBO Annex, Andersen AFB, Guam.

4.0 Physical Characteristics of MARBO Annex

MARBO Annex is located on a broad uplifted limestone plateau that is underlain by volcanic rocks. The limestone plateau is characterized with karstic features such as caverns and fissures and ranges in elevation from 300 to over 500 ft above mean sea level. The karst terrain is very porous and provides rapid infiltration of surface water to the underlying freshwater aquifer, rendering no permanent surface water bodies at MARBO Annex.

The surface of the limestone plateau on Guam is interrupted by two volcanic peaks, Mount Santa Rosa and Mataguac Hill, which are located northeast and north of the MARBO Annex, respectively (Figure 4-1). These low permeability volcanic outcrops extend into the subsurface to form a lateral barrier that directs the groundwater flow from the MARBO Annex towards the Tumon Bay (Figures 4-1 and 4-2). According to the groundwater monitoring data (Foster Wheeler Environmental Company/EA, 2003; EA 2008), the groundwater at MARBO Annex is encountered at approximately 281 ft to 400 ft bgs. Based on the 2001 Guam Water Quality Standards, the groundwater at MARBO, whether fresh or saline, is categorized as a G-1 Resource Zone for potable water (Guam EPA, 2001). Consequently, any wastewater discharges within the G-1 Resource Zone is regarded as a tributary to the potential potable groundwater supply and must be free of pollutants.

Water extracted from the production wells located in the MARBO Annex is distributed to Andersen AFB. Currently, seven of the eight Andersen AFB production wells (MW-1, MW-3, and MW-5 through MW-9 series wells), located on the MARBO Annex (Figure 3-1) are used for water production, and can yield approximately 2.1 million gallons per day (mgd) to meet the average Base consumption of 1.6 mgd (Andersen AFB, 2003). The closest Andersen AFB production well (MW-2) to the TCE and PCE groundwater contamination was taken offline and is currently inactive. The Guam Waterworks Authority (GWA) has also installed production wells on the northern and eastern side of MARBO. However, these wells are located upgradient or cross gradient of the vicinity of the TCE and PCE contamination. The current implementation of Land Use Restrictions and Existing Wellhead treatment by the USAF and the Guam EPA is operating effectively because these controls eliminate the risk of a direct exposure path to COCs.

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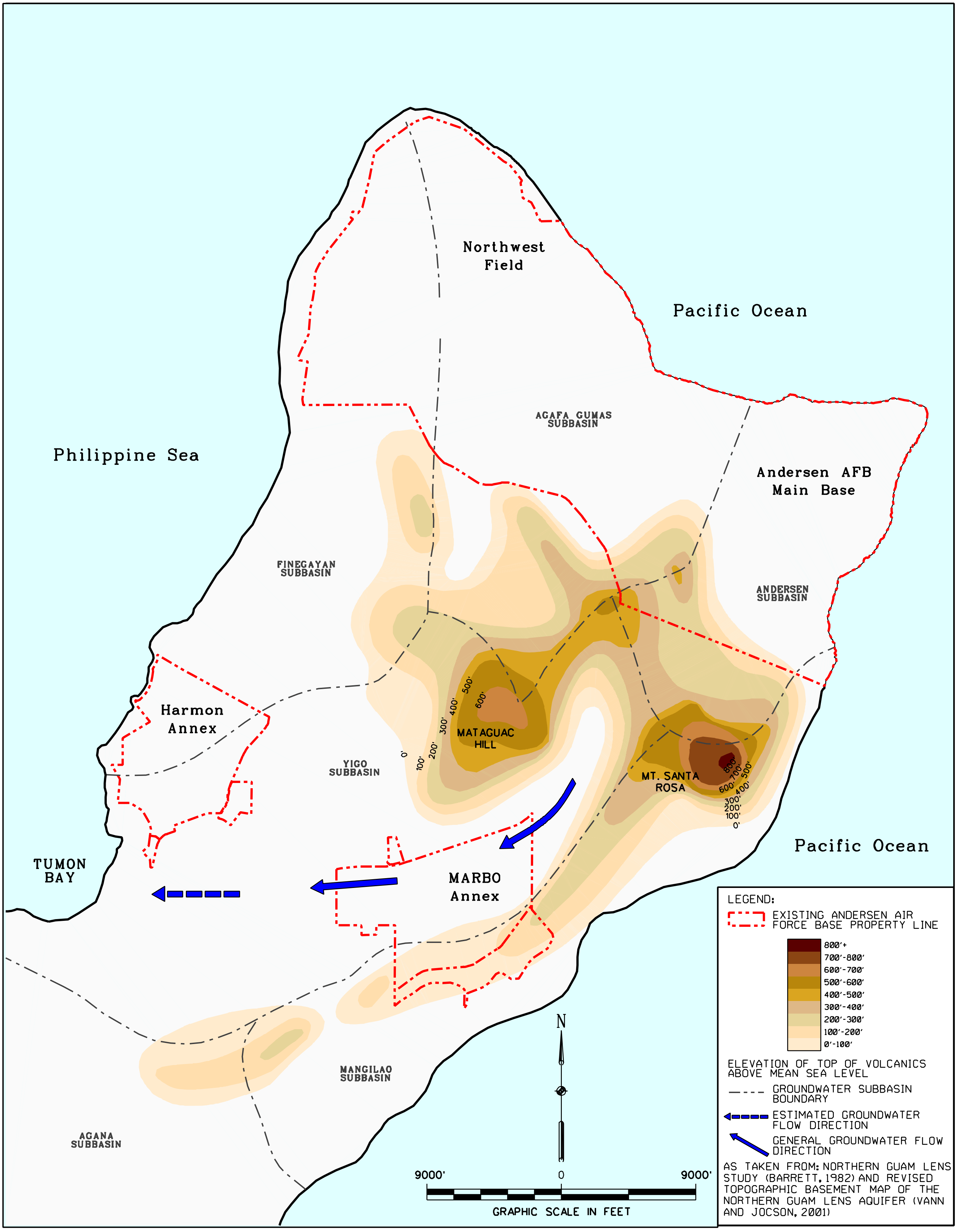

Figure 4-1. Volcanic Structure Contours.

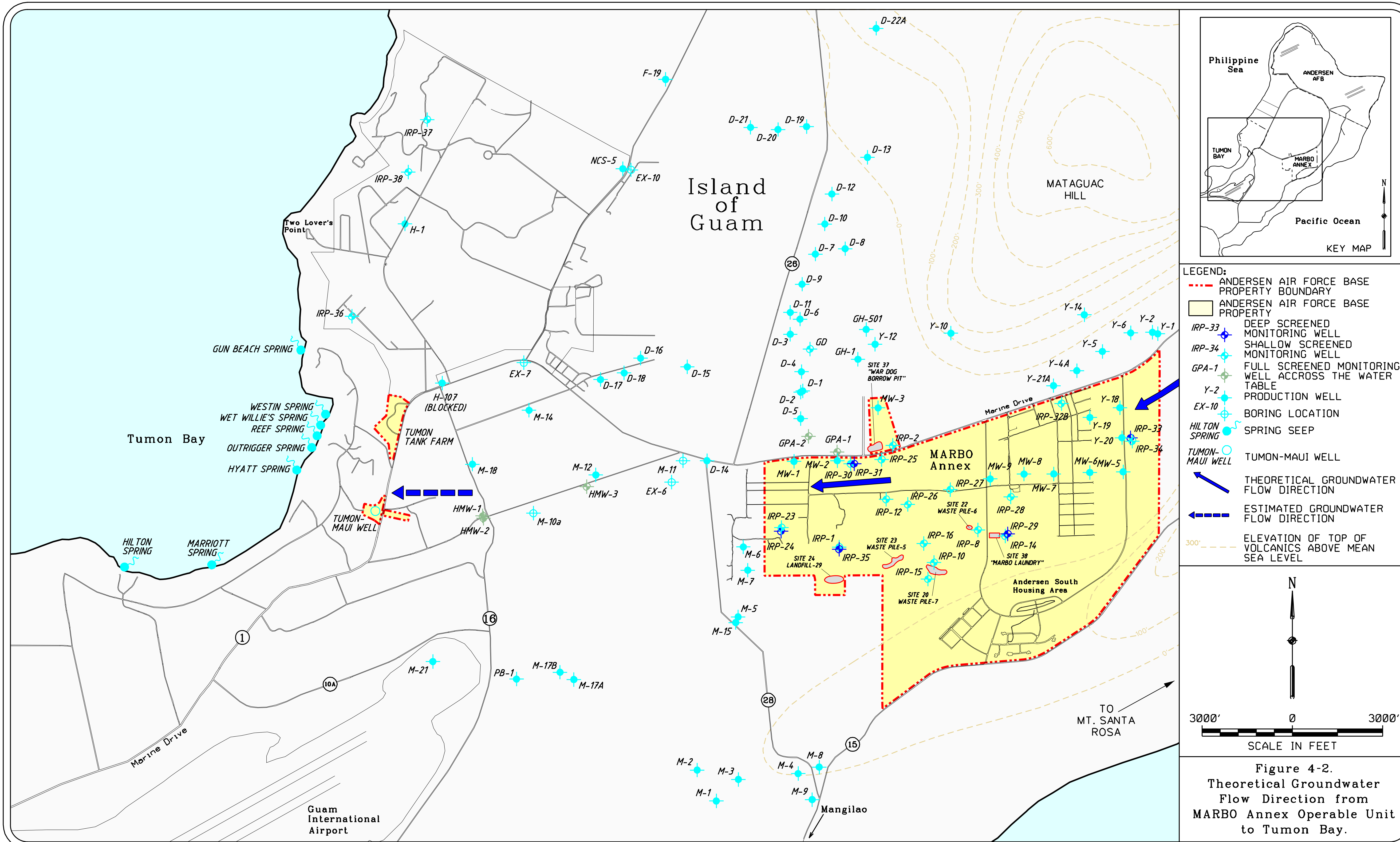

Figure 4-2. Theoretical Groundwater Flow Direction from MARBO Annex Operable Unit to Tumon Bay.

5.0 Land Use of MARBO

Subsequent to finalizing the MARBO ROD in 1998, various land parcels have been transferred or have been proposed for transfer to other federal agencies or the Government of Guam (GovGuam). Two parcels, covering 81 acres and 395 acres (Figure 5-1), have been transferred to GovGuam. The 81-acre parcel contains active GWA production wells (Y-18, Y-19, and Y-20) and included the planned construction of a High School. The 231-acre parcel contains a fire station and future land use plans include the construction of a police station.

A 1,569-acre parcel was offered to the United States Marines, for training facilities, however, in the fall of 2003, the Marines indicated that they were not interested in acquiring the property. The USAF is considering alternate plans for the future disposition of this parcel. Another 224-acre parcel is being retained by the USAF for a variety of purposes. Institutional controls near IRP Site 20 will be maintained although IRP Site 20 may be eventually transferred out of the IRP Program. Several linked areas are being retained to support the USAF groundwater production and distribution system at MARBO. One area (the Army and Air Force Exchange Services Warehouse) is being retained for USAF warehousing activities and the second area (the location of the former MARBO Laundry building) is vacant and considered open space.

Three Areas of Concern (AOC 54, AOC 55, and AOC 56) located in MARBO Annex, were recommended for further investigation under the Phase II Environmental Baseline Survey (EA, 1998b). These AOCs were redesignated under the Site Wide OU as IRP Sites 41, 42, and 43, respectively. These IRP Sites were recently investigated. Results of this investigation are currently being evaluated in an RI/ FS. Upon completion of the RI/FS, the data will be incorporated into a ROD document.

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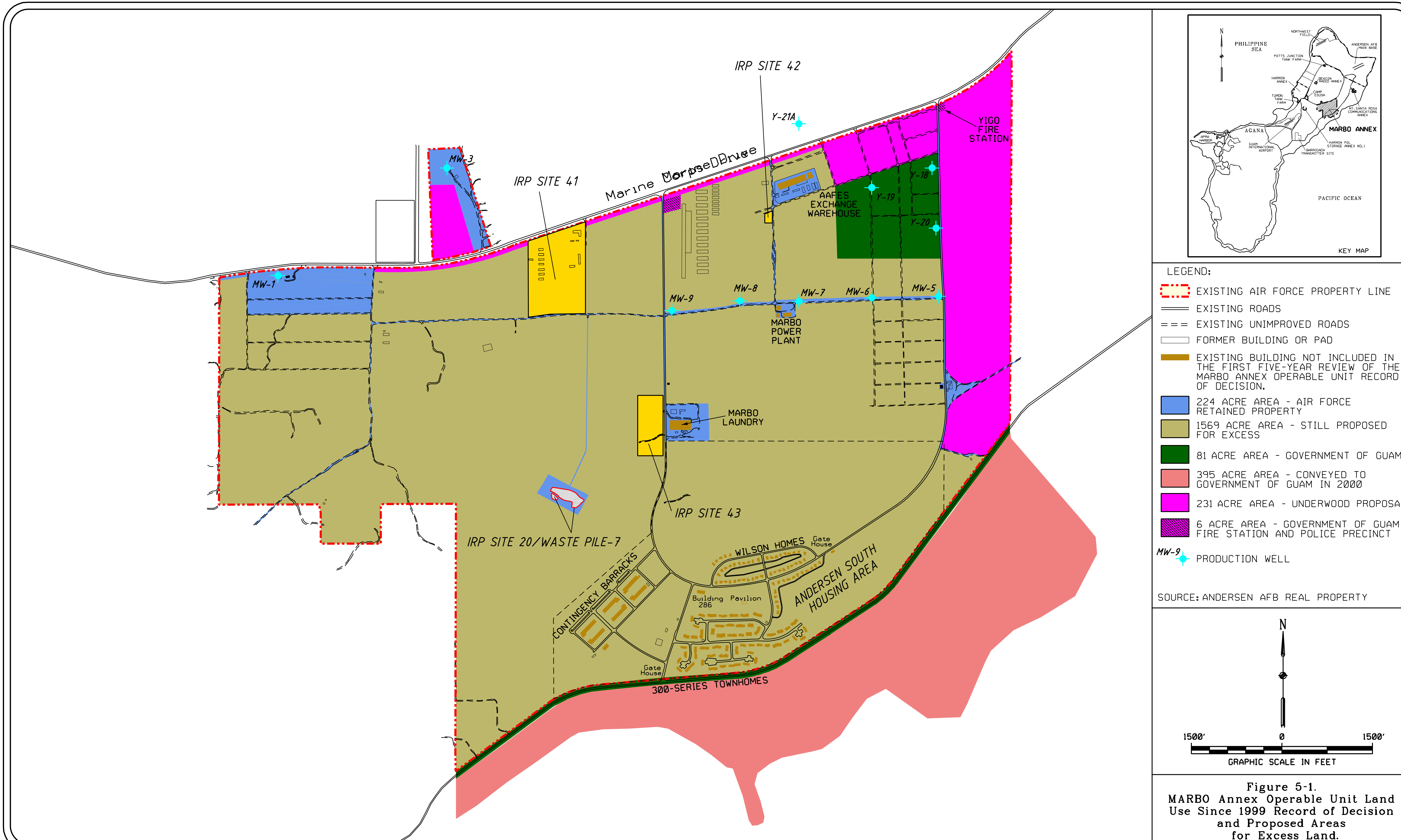

Figure 5-1.
MARBO Annex Operable Unit Land Use Since 1999 Record of Decision and Proposed Areas for Excess Land.

6.0 General Geology of MARBO Annex

A detailed description of MARBO Annex geology is included in the OU2 RI (ICF, 1997) and is summarized below.

The MARBO Annex is underlain by the Barrigada and Mariana limestone formations. The Barrigada formation is generally a deep water depositional deposit of fine grained texture, composed of foraminifera tests. The Barrigada limestone was deposited on the volcanically derived Alutom formation and forms an outcropped semicircle around the edges of the MARBO Annex. Maximum thickness of this formation exceeds 540 ft (Tracey et al., 1964). The younger Mariana limestone, which composes the surface geology, includes approximately 80% of the exposed reef-associated limestones of Guam. This formation laps on the Barrigada limestone as a vertical and transgressional facies change from a deep to a shallow water depositional environment. The Mariana limestone consists of two members; the main body of the limestone, and the Agana Argillaceous member. The main body of the limestone bedrock contains four reef-associated facies that are: the reef facies, the fore-reef facies, the detrital facies, and the molluscan facies. The reef facies is a massive, generally compact, porous and cavernous, white limestone of reef origin, and is made up of mostly corals in growth position, encrusted with calcareous algae. This facies has been subdivided into constructional coral, construction algal, and constructional coral-algal subfacies (Tracey et al., 1964). The constructional coral subfacies is predominantly composed of coral colonies that appear to be patch reefs within a lagoonal environment.

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7.0 Hydrogeology of the MARBO Annex

The northern half of Guam exhibits characteristics of a Simple Carbonate Island, a Carbonate-Cover Island, and a Composite Island according to the type of Carbonate Island Karst Model (Mylroie et al., 2001). Although a freshwater lens (overlying marine water) exists in the subsurface for all model types observed on Guam, the types differ by location of the limestone-volcanics contact relative to the elevation of the water table and relative to the elevation of the ground surface. The volcanics act as an aquaclude to groundwater flow. As discussed in Section 4.0, the two volcanic peaks (Mount Santa Rosa and Mataguac Hill) control this relationship and, therefore, effect the distribution and migration of groundwater in the vicinity of these features, resulting in channeling flow of groundwater toward Tumon Bay in the limestone (Figures 4-1 and 4-2).

Groundwater is the principal source of drinking water for the population of Guam and the source of freshwater for other uses. The karst limestone of the Northern Guam Lens (NGL) produces approximately 40 mgd of freshwater for these uses. Even though Guam receives roughly 100 inches per year of rainfall, surface water does not exist on the northern half of Guam due to the highly permeable, eogenetic, karst limestone. The general hydrogeology of the NGL is summarily highlighted below:

- The Barrigada and Mariana limestone formations are the primary groundwater aquifers underlying the MARBO Annex.
- Groundwater flow (and contaminant migration) at MARBO Annex is very complex due to karstic geologic features, secondary solution channelizing, and production well pumping.
- The vadose zone consists of approximately 400 feet (ft) of coralline-reef limestone, which has a heterogeneous porosity distribution with diffuse groundwater flow within primary porosity and discrete, channelized groundwater flow in secondary, dissolution-enhanced porosity.
- Though some infiltrating precipitation is captured as storage in vadose zone primary porosity, the vast majority of infiltration percolates through the vadose secondary porosity and – due to density effects - creates a freshwater lens that floats atop a transition zone underlain by a marine water.
- This freshwater lens in the area of MARBO is approximately 100 ft thick and is highly conducive to groundwater flow. Hydraulic conductivities as high as 20,000 ft per day were observed during the MARBO OU Remedial Investigation (RI) (ICF Technology, Inc., 1997) and during dye trace studies conducted on the Main Base during the MARBO OU RI field work.
- A brackish transition zone (mixing zone), approximately 20 ft in thickness, exists between the freshwater lens and the underlying marine water.
- The rapid infiltrating recharge to the upper portion of the freshwater lens propagates quickly (weeks to months) to coastal discharge areas (seeps and/or large-scale dissolution features).
- The rapidly infiltrating recharge has created strongly oxidized groundwater conditions throughout the fresh water lens, as evidenced by shallow and deep dissolved oxygen

(DO) concentrations generally ranging from 5 to 8 milligrams per Liter (mg/L) and oxidation-reduction potential (ORP) ranging from 100 to 500 millivolts (mV).

- The strong lateral flow component that is observed in the upper portion of the freshwater lens is not evident (based on contaminant trends) in the basal portion of the lens.
- The elevation of the water table and thickness of the freshwater lens vary in response to rapid stimuli (large short-term rain events), moderate-term stimuli (seasonal rainfall and monsoonal wind effects on sea level), and long-term stimuli (precipitation fluctuations due to El Nino/Southern Oscillation events and eustatic sea level rise).
- The effect of short- and long-term stimuli on the thickness of the freshwater lens has lead to cyclic variation on the observed chloride levels in deep groundwater when observed at a vertically fixed sampling point. For example, chloride levels in groundwater at IRP-29 and IRP-31 have cyclically varied between approximately 20 and 200 mg/L.

Figures 7-1 and 7-2 illustrate the conceptual relationship between water level, lens thickness, chloride concentration, and contaminant concentration as a function of time.

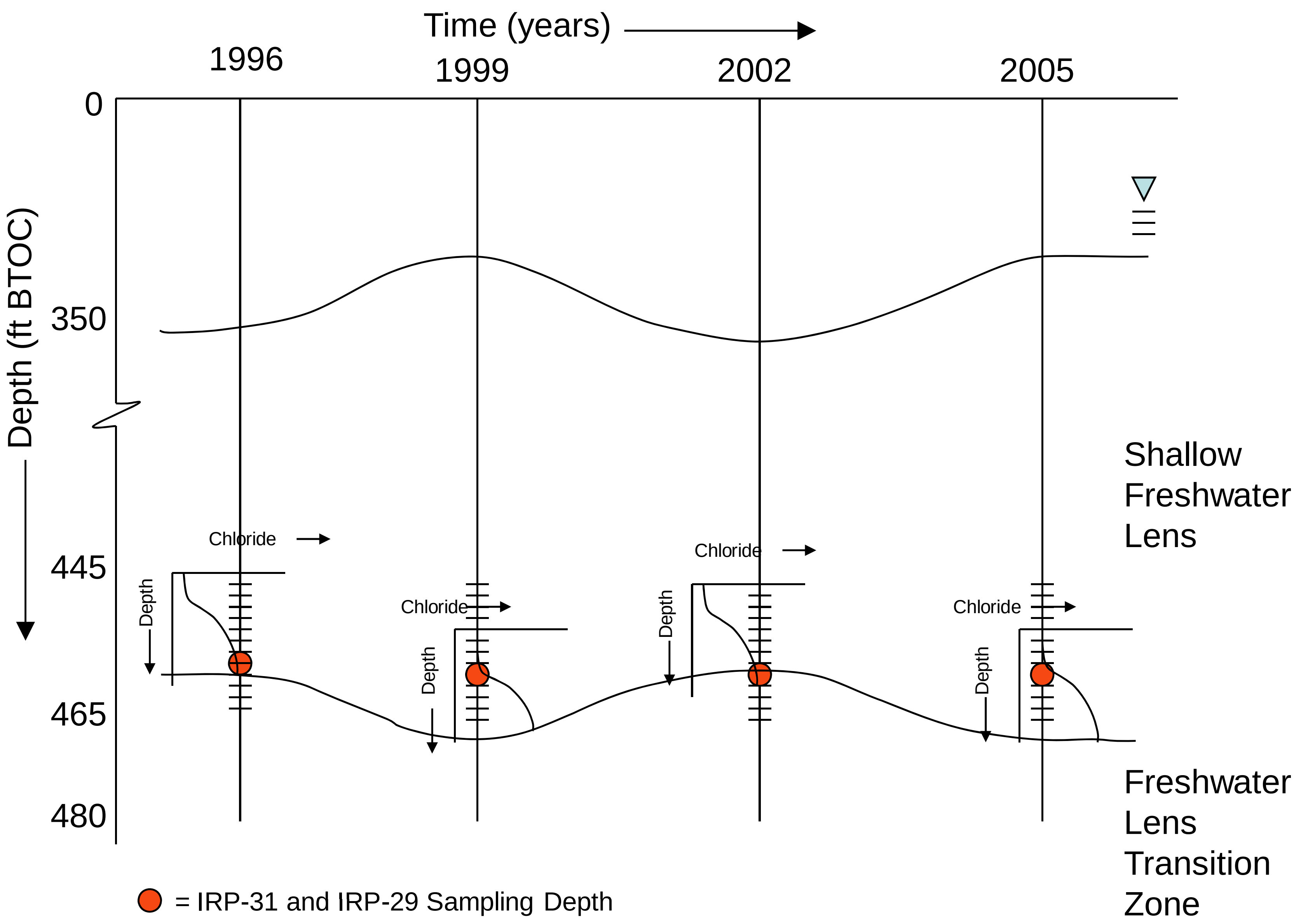

Figure 7-1. Conceptual Model of Chloride Concentration Cyclicity Versus Time at IRP-31 and IRP-29.

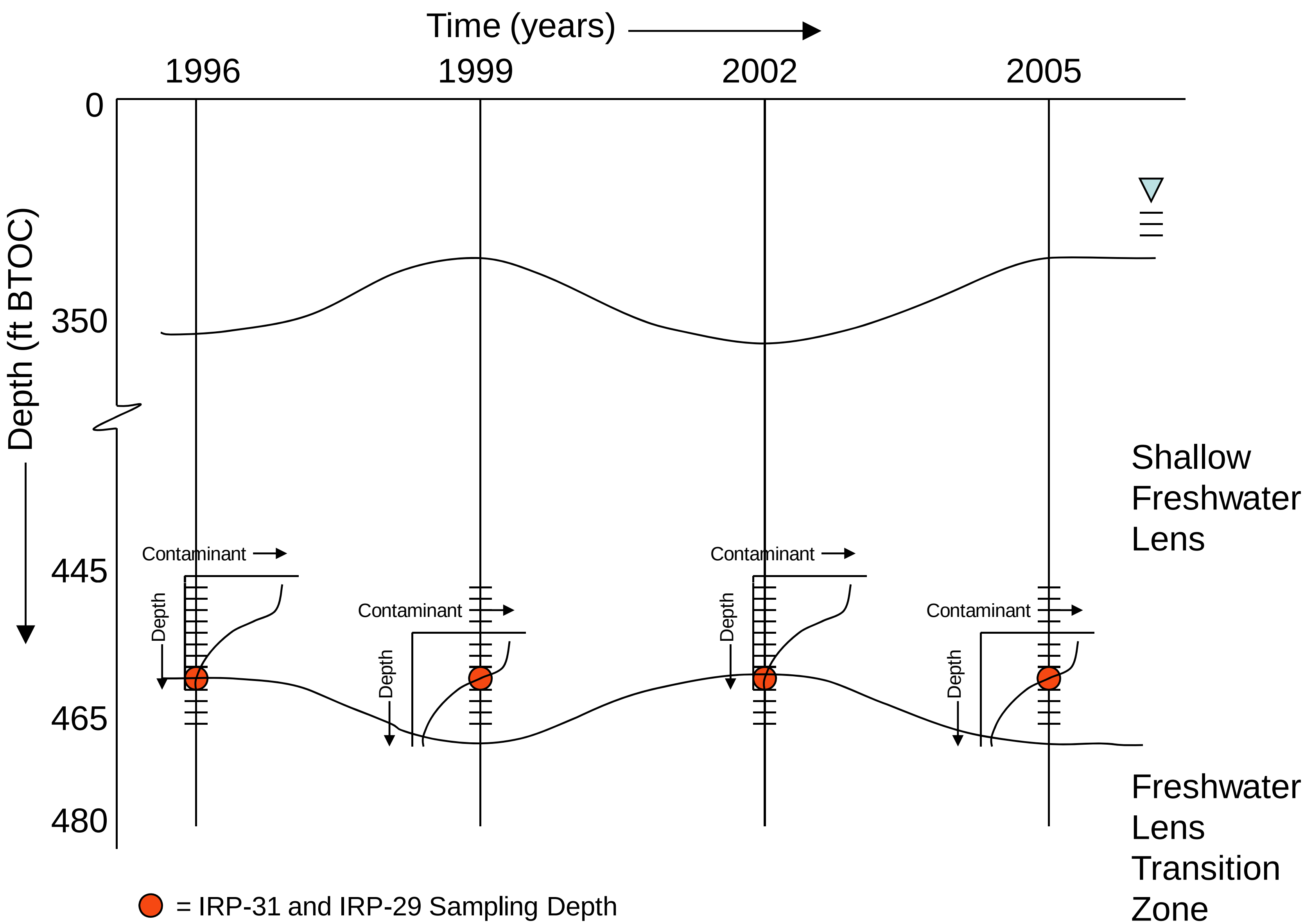

Figure 7-2. Conceptual Model of TCE (IRP-31) and PCE (IRP-29) Concentration Cyclicity Versus Time.

8.0 Occurrence of TCE and PCE in MARBO Annex Groundwater

Two areas within the deep groundwater freshwater lens have been identified as having dissolved TCE and PCE exceeding the MCLs (5 µg/l). Of the most likely contaminant source areas within the MARBO Annex, based on soil sampling and analysis conducted at MARBO, none were found to contain surface or near-surface materials that could be acting as continuing sources of TCE or PCE. The following findings regarding the nature and extent of TCE and PCE occurrence provide the basis for the conceptual site model of groundwater contamination at the MARBO Annex.

8.1 Fate and Transport of TCE and PCE in MARBO Annex Groundwater

Based on historical results (RI and the LTGM program), two potential constituents of concern have been identified (PCE and TCE). These constituents historically have exceeded their respective MCLs at the locations of IRP-29 and IRP-31, respectively, and surrounding wells on occasion. The historic distribution of MCL exceedence for PCE and TCE within MARBO OU 2 groundwater is depicted in Figure 8-1.

TCE and PCE have either been non-detect or detected at low concentrations (below the MCL of 5µg/L) in all shallow monitoring wells, except IRP-14 (see graphs of shallow and deep well TCE or PCE concentration versus time in Attachment 1). PCE has decreased over time in groundwater samples collected from IRP-14. The linear decline in PCE within shallow groundwater at IRP-14 over the past 11 years suggests that PCE in the shallow aquifer is being attenuated through the physical process of hydrodynamic dispersion. This is likely due to strong horizontal flow components in the shallow portion of the freshwater lens that result in rapid turnover rates. TCE and PCE concentrations are one to two magnitudes higher in groundwater samples collected from deep wells IRP-31 and IRP-29, respectively. This is likely due to past density driven flow of dense non-aqueous phase liquid (DNAPL) and indicates that the deep groundwater of the freshwater lens is significantly more static and less mobile than shallow groundwater.

TCE and PCE concentrations observed in the deep groundwater over time show cyclical increases and decreases that appear to coincide with changes in the elevation of the water table and thickness of the freshwater lens (Figure7-2). These variations in the configuration of the freshwater lens appear to be influenced by short term and long term variations in precipitation and sea level. The historical data indicate that the overall freshwater lens has gotten thicker and thinner in response to long term variations in precipitation while the vertical horizons of the groundwater sampling locations in MARBO Annex wells have remained static. More specifically, with the increase in precipitation there is a corresponding rise in the top of the lens that is coupled with a lowering in the base of the lens. The data from the shallow freshwater lens (and other findings) indicate that:

- There is no indication of a continued shallow contaminant source of PCE or TCE in the MARBO area.
- The PCE concentrations observed in the shallow freshwater lens in the vicinity of the MARBO Laundry has been decreasing linearly over time.

- The physical processes (strong horizontal flow) operating in the shallow freshwater lens have attenuated the dissolved PCE to levels below the MCL.

Conversely, historical data also suggest that the processes operating deep in the freshwater lens are not as dynamic as in shallow groundwater. The cyclical PCE and TCE trends indicate that in the deep freshwater lens:

- The highest concentrations of PCE and TCE (detected at IRP-29 and IRP-31, respectively) have been observed in groundwater samples collected near the base of the freshwater lens, where these contaminants appear to be trapped within the karst limestone matrix.
- There is a much weaker lateral flushing (and thus hydrodynamic dispersion) in the deep portion of the freshwater lens than shallower in the lens.
- The TCE and PCE contamination may be from relatively "old" sources.
- The TCE and PCE observed in IRP-31 and IRP-29, respectively, appear to have resulted from separate sources (Figure 8-1)
- PCE and TCE concentrations have cyclically fluctuated over time in relation to changes in the lens thickness in response to intense rain events, seasonal rainfall, and long term El Nino/Southern Oscillation (ENSO) effects, but have stayed within an established concentration range and show no appreciable increase or decrease, on average, over the past 11 years.
- Neither physical (e.g., dilution) nor biological processes (e.g., reductive dehalogenation) are operating to significantly attenuate TCE or PCE in the deep freshwater lens. Groundwater geochemical conditions are far too toxic to allow for biological reductive dehalogenation.

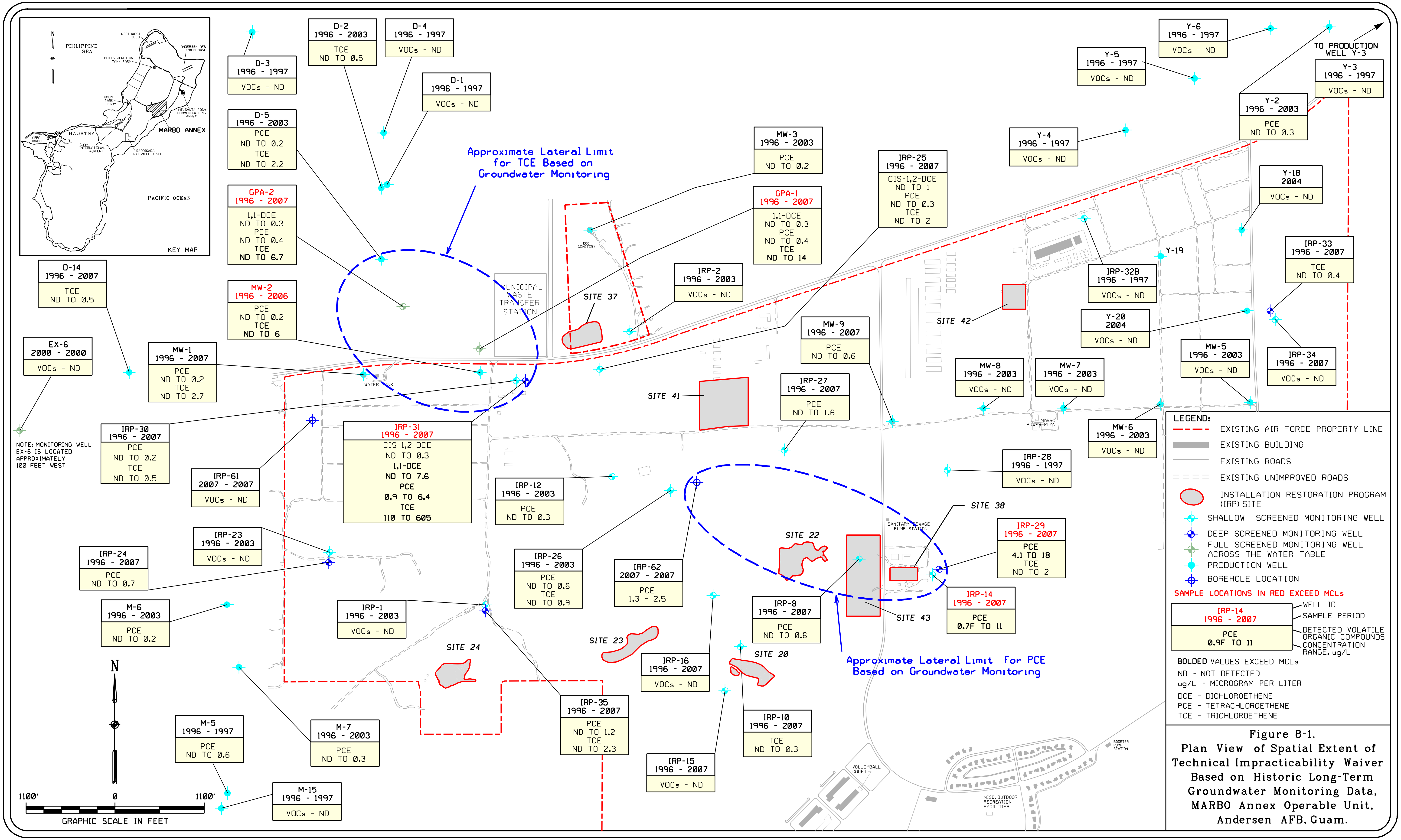

Figure 8-1.
Plan View of Spatial Extent of Technical Impracticability Waiver Based on Historic Long-Term Groundwater Monitoring Data, MARBO Annex Operable Unit, Andersen AFB, Guam.

9.0 Investigation of Potential Sources for MARBO Annex Groundwater Contamination

A review of the MARBO Annex OU IRP Sites was included in Section 3.0 (Background). A total of 12 sites within the MARBO Annex were identified. No sources of PCE or TCE (identified within groundwater) have been identified to date at any of these IRP sites. In addition, no source is likely to be found in the future because of physical limitations to accessibility at the MARBO Annex. In addition, water quality data collected in the shallow freshwater lens over the past 15 years indicates that there does not appear to be a residual contaminant source.

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10.0 Justification for a TI Waiver

USEPA's *Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration* (OSWER Directive 92342-25) (TI Guidance) requires that all reasonable efforts be made to identify the location of source areas, but it recognizes that locating and remediating sources can be difficult and that in certain complex geologic environments it may be impracticable (TI Guidance. pg. 13). Without new information coming to bear, the dense flora and complex karst geology at MARBO Annex make any additional source identification efforts impracticable. The USAF is committed to the MARBO Annex ROD, however, to investigate any information that might become available in the future on potential contaminant source areas that may be the cause of sustained groundwater impacts to the deep portion of the freshwater lens.

USEPA prefers that TI decisions be made only after interim or full-scale aquifer remediation has been implemented. This is the case because of the difficulty in predicting the effectiveness of remedies based on limited site characterization data alone. The ROD selected operating RA of MNA with ICs (EA, 1998a), including the contingency for wellhead treatment at any water supply wells impacted by the plumes. The ROD-selected operating RA has been operating since 1998, but residual levels of dissolved phase TCE and PCE (in deep freshwater lens) persist at concentrations that do not allow for unrestricted use of the property within an acceptable timeframe. The RA was planned to achieve cleanup in an estimated 10 to 40 years. Since this does not appear to be possible and other alternatives do not appear to be feasible (or achieve cleanup in an acceptable timeframe), this Justification for a TI Waiver is being prepared and submitted with a FFS to support a ROD amendment to invoke a TI Waiver for MARBO Annex groundwater.

Several physical and chemical remediation limitations are described in the TI guidance as being suitable, though not automatically sufficient, to justify a TI determination. These limitations include geologic constraints such as complex fracturing of bedrock aquifers, extremely high or low permeability and large depth to groundwater. Chemical limitations include the presence of non-aqueous phase liquids, whether free phase or residual, and significant potential for adsorption or entrapment of the contaminant within the rock or soil comprising the aquifer.

The critical limitations to groundwater restoration at the MARBO Annex include all of the foregoing geologic and chemical constraints.

10.1 Depth to Groundwater

As stated previously, depth to groundwater is approximately 400 ft at the MARBO Annex. Drilling into the aquifer is difficult on the MARBO Annex because the carbonate rock is heavily karstic, which cause lost circulation problems and stuck tools. The average cost of drilling an extraction or injection well is $100,000, while the cost of a monitoring well is approximately $50,000. The high cost per well caused by the depth to groundwater and the drilling difficulties has placed severe limits on the ability to investigate and remediate the TCE and PCE occurrences observed in the deep freshwater lens.

Concentrations of dissolved-phase TCE above the MCL have been observed in the deep freshwater in the vicinity of IRP-31 at downgradient locations GPA-1 and GPA-2 (Figure 10-1). Similarly, dissolved-phase PCE has been observed in the deep freshwater at the downgradient location of IRP-62. These locations serve to delineate the downgradient areas of the respective TCE and PCE plumes (Figure 8-1) and, therefore, limit the extent of the TI Waiver to areas defined within, or along the boundaries of, the MARBO Annex.

10.2 Limitations on Remediating the Source

The strong lateral flow component in the shallow aquifer has served to remove the source of dissolved phase PCE (and presumably TCE) from the shallow zone; thus, relegating continued sources to within the deep portion of freshwater lens. Long-term monitoring of shallow (IRP-14) versus deep (IRP-29) PCE concentrations in groundwater surrounding the MARBO Laundry substantiates this deduction. No source and no traces of VOCs have been found in the vadose zone. TCE has not been identified in shallow groundwater in the vicinity of IRP-31 and, presumably has attenuated prior to the LTGM program or simply cannot be found.

Source remediation at the MARBO Annex presents several problems. First, the sources of the TCE and PCE have not been identified after significant effort and there is no guarantee that additional investigations could locate the sources. If the sources were located, the USAF could still do no better than provide containment through pump and treat because the depth to groundwater and the complex karst setting preclude any type of physical barriers, the source area would then still require a TI Waiver. Even if the sources still exist (and could be identified), treatment at the sources may not be possible because of the complex geology, the extreme difficulty of remediating the target depths, and the nature of dense non-aqueous phase liquids (DNAPLs) (if present, which is unlikely). There is no known technology, whether it be vapor extraction, bioremediation or innovative technologies such as steam, surfactants, cosolvents, resistance heating, conductive heating, or electro-osmosis that can address the complex and diverse set of constraints found at the MARBO Annex.

One possible explanation for the lack of TCE and PCE attenuation within the deep portion of the freshwater lens over time is that the impacted zone of the deep freshwater lens is not flushed adequately, and thus static, relative to shallower portions of the aquifer. This complication is compounded by the finding that some dissolved (and potentially sorbed) phase TCE and PCE mass is likely trapped within the diffuse primary porosity, with only slow, mass-limited diffusion to conduit flow zones. The release of dissolved phase TCE and PCE from the diffuse porosity is not likely to occur within an acceptable timeframe for any potentially viable technology.

The TI Guidance (pg. 8) states that:

“The long-term remediation objectives for a DNAPL source zone should be to remove the free phase, residual, and vapor-phase DNAPL to the extent practicable and contain DNAPLs sources that cannot be removed. The USEPA recognizes that it may be difficult to locate and remove all of the subsurface DNAPL within a DNAPL zone. Removal of DNAPL mass should be pursued wherever practicable and, in general, where significant reduction of current or future risk will result.” Based on groundwater sample results at MARBO, there is no indication that DNAPLs are present. If DNAPLs were present, concentrations of TCE and PCE would likely be several orders of magnitude higher than observed values and shallow aquifer concentrations would be sustained over time, rather than declining (as at IRP-14). Although there is no indication of DNAPL, a persistent TCE and PCE source (in the form of dissolved and sorbed phase) exists within the deep fresh water lens at the location of IRP-31 and IRP-29, respectively.

As stated previously, locating and remediating the TCE and PCE sources is not practicable at MARBO. Additionally, the PCE plume is contained on the MARBO Annex. Though the dissolved-phase TCE plume lies close to the northwest boundary (hydraulically downgradient) of MARBO Annex, TCE concentrations leaving MARBO Annex are less than 15 µg/L (highest recorded concentration over time observed at GPA-1 was 14 µg/L), which poses a human health risk in the range of 10^{-5} to 10^{-6}. The downgradient 5 µg/L edge of the TCE plume has been identified in the vicinity of GPA-2, which has shown cyclic variation in TCE concentration over time with the peak concentration at or below 7 µg/L. Because the TCE and PCE plumes are contained (and no pumping wells are currently operating in these areas), pursuing delineation and removal of potential residual sources would not provide a significant reduction in current or future risk.

10.3 Complex Geology

The aquifer exists within a complex karst limestone, with large, solution channels created by secondary porosity and low-permeability, diffuse flow within primary porosity. This environment is extremely heterogeneous on a local scale. No correlations between infiltrating flow and solution features (or orientation) is discernible between wells. The majority of groundwater infiltration and transmission toward island shorelines is, in general, controlled by the interconnected solution channels, but the complexity of the features has lead to a lack of understanding of flow phenomena on a local scale. In addition to the lack of understanding of discrete flow within solution channels, the contribution of diffuse flow within the primary porosity and the diffusion of contaminants out of the diffuse zones are poorly understood.

The design and proper implementation of a pump and treat system is made difficult by the negative effects potentially created by the vertical upwelling of TCE and PCE as well as the upwelling of salt water that would damage the aquifer. The highly transmissive, channelized aquifer would provide a vehicle for the transmission of either the contaminants or the salt water from the deep portion to shallower portions of the aquifer, where nearby production wells actively produce from. The design of a pump and treat system is also made difficult by the long-term tailing effects on cleanup timeframe due to mass transfer limitations on TCE and PCE diffusing out of the diffuse porosity into the primary flow zones.

10.4 Large Groundwater Volume

The high aquifer transmissivity (up to 200,000 square ft per day) and the associated high volume of water flowing through the system would require tremendous extraction and treatment capacities to address the TCE and PCE plumes. The MARBO Annex production wells in the vicinity of the dissolved-phase TCE and PCE contamination (e.g., MW-1 through MW-3), pumping at an average historic rate of 6 to 8 million gallons per month (EA, 1997) have done nothing to reduce the concentrations of TCE and PCE in the deep aquifer, though these wells exist within the shallow portion of the aquifer only.

Extraction and treatment of the large volume of water required to reach plume containment also would not address remediating the sources. (The estimated volume of contaminated groundwater within the spatial limits of the TI waiver for TCE and PCE is 3.4E08 gal and 2.8E08 gal, respectively.) In addition to the technical and practical difficulties associated with installing and operating such a vast network of extraction and injection wells in the largely undeveloped confines of MARBO Annex, the power required to run such a system is not currently available (or dependable enough) with the existing Guam power grid.

Even if a method did exist that could remediate the source, it would still be cost prohibitive to remediate the groundwater plumes. In addition, we have no way to estimate a timeframe for remediating the plumes because we do not know the mass loading originating from the source or the kinetics of the mass transfer limitations from the contamination locked in the diffuse porosity.

In addition to the engineering difficulties associated with pump and treat at MARBO Annex, the GWA has strict limitations on the installation of new extraction wells because of the delicate water balance on Guam. An extraction/injection system on the required scale would do more harm than good to the overall nature of the groundwater system and would probably not be approved by the GWA or the GovGuam considering the likely potential for upwelling of groundwater contaminants and saltwater from the underlying transition zone and marine water, respectively, as a result of the upward hydraulic gradient generated from such a system.

10.5 Cost Considerations

According to the TI guidance, TI Waivers should be considered where remedial action is technically impracticable because of engineering feasibility or reliability. Use of the term “engineering perspective” implies that a TI determination should primarily focus on the technical capability of achieving the cleanup level, with cost playing a subordinate role. The-Preamble to NCP states that TI determinations should be based on:

“...engineering feasibility and reliability, with cost generally not a major factor unless compliance would be inordinately costly.” (55 FR 8748, March 8, 1990)

Remediating the groundwater at the MARBO Annex would be inordinately costly given the physical constraints posed by the hydrogeology of the system (as shown in Table 4-1 of the FFS). Further, the proposed remedy that will be put forth in an amendment to the ROD calls for wellhead treatment, as necessary, ensuring that there will be no complete exposure pathway to human health risk.

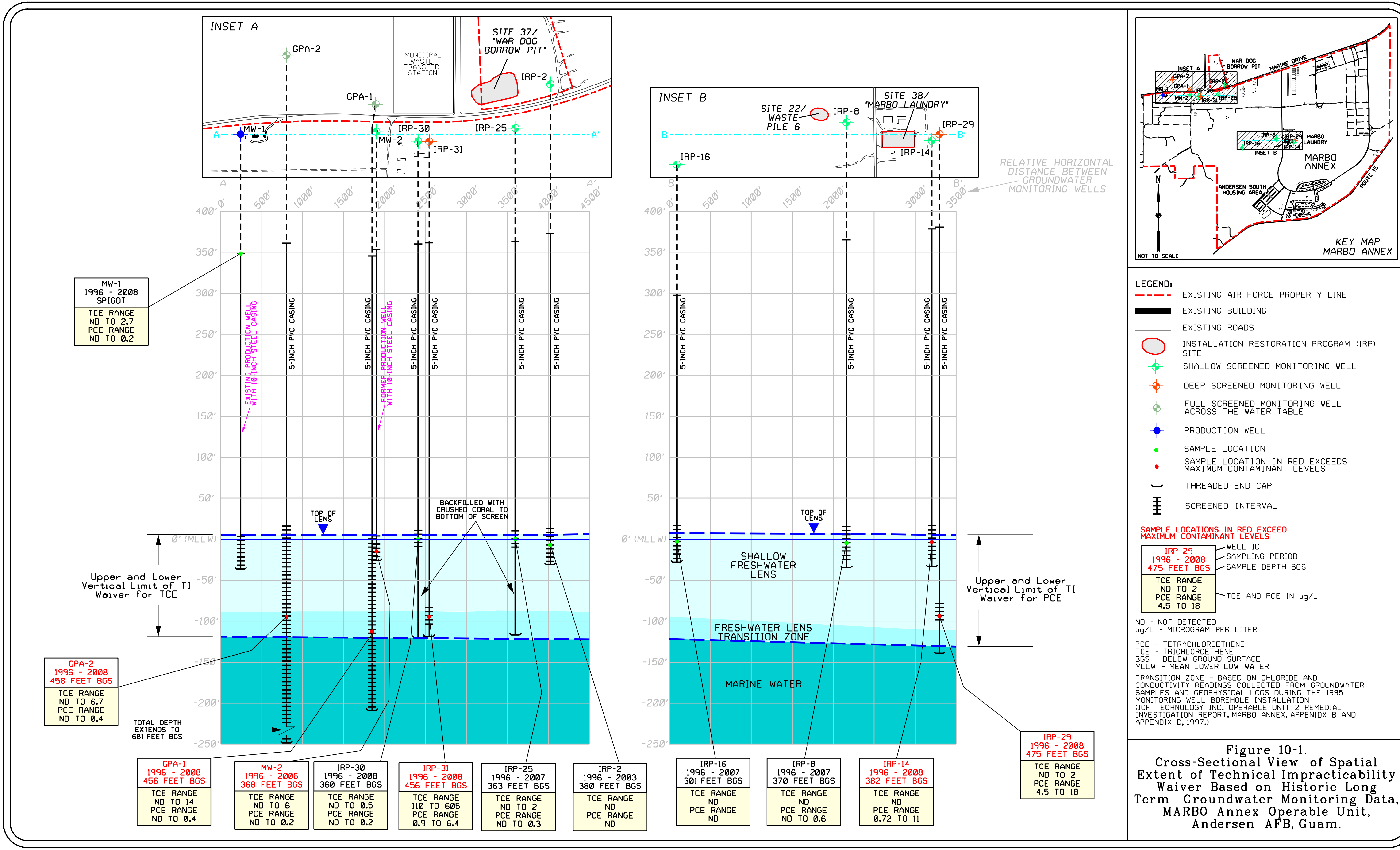

Figure 10-1. Cross-Sectional View of Spatial Extent of Technical Impracticability Waiver Based on Historic Long Term Groundwater Monitoring Data, MARBO Annex Operable Unit, Andersen AFB, Guam.

11.0 Proposed Remedy

The proposed remedy at MARBO Annex involves a TI Waiver for groundwater, with the continuation of ICs, including the contingency for wellhead treatment at any on-MARBO Annex water production wells or existing or future off-MARBO Annex production wells within the extent of the TCE and PCE plumes. Wellhead treatment units will be installed by the USAF on any water supply wells that are impacted at concentrations above one-half the MCL for TCE or PCE. All of the LTGM data imply that the TCE and PCE plumes are relatively stable and that there has been no increase in TCE or PCE concentrations, other than cyclical variations in response to meteorological stimuli.

Though the LTGM performed for MARBO Annex will be decreased in response to the proposed remedy, the remedy requires the USAF to monitor select monitoring wells in the area semi-annually and to provide wellhead treatment at any well that contains TCE and/or PCE concentrations above one-half the MCL (where that contamination is determined to be from MARBO) if no treatment system exists on that well or to pay the incremental cost caused by the presence of TCE and/or PCE if a well already has a treatment system. This covers any existing production wells and also any production wells that might be drilled in the future.

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12.0 Nature of the TI Waiver

It is USEPA policy that any remedy, including MNA and ICs (including wellhead treatment), requires a reasonable timeframe for remediation of in-situ groundwater to MCLs. Because this goal cannot be achieved with MNA within a reasonable timeframe, MNA constitutes a failed remedy.

A TI Waiver is necessary for this ROD because the aquifer will not be actively remediated to MCLs with MNA and because the restoration goals and cleanup timeframe are considered unachievable. The size, location, and nature of the source are completely undetermined, and thus, we have no way to estimate a remediation timeframe. The specific ARAR for which this TI determination is being sought pertains to restoring the groundwater underlying the MARBO Annex to concentrations below the Federal MCL for TCE and PCE (5 µg/l). The proposed TI Waiver for the area covered by the MARBO Annex and the region of the TCE plume (5 µg/L limit) extending off of MARBO in a northwest direction toward wells GPA-1 and GPA-2 is shown in plan view (Figure 8-1). The estimated volume of contaminated groundwater within the spatial limits of the TI waiver for TCE and PCE is 3.4E08 gal and 2.8E08 gal, respectively. After the ROD Amendment, a long term monitoring plan will be submitted. Monitoring and 5-year reviews are required until the original ARARs are met. The USAF will continue to monitor and to provide the contingency of wellhead treatment as long as the contaminant plumes exist.

12.1 Effects of the TI Waiver

The NCP states that:

"EPA expects to return usable groundwaters to their beneficial uses wherever practicable, within a timeframe that is reasonable given the particular circumstances of the site".
(§300.430(a)(1)(iii)(F))

The groundwater at the MARBO Annex is currently available for beneficial uses and will continue to be available for full beneficial use through application of the proposed remedy (i.e., contingency inclusion of wellhead treatment). If the contaminant plumes migrate or grow (through natural transport or by an inducement into a flow field of a new production well), the contingency of wellhead treatment at off-site wells will provide complete protection of human health and the environment.

12.2 Spatial Limit of the TI Waiver

Figure 10-1 is presented to show the upper and lower vertical limits of TI waiver for TCE and PCE. Even though, the present extent of TCE and PCE above MCLs is limited to the deeper portion of groundwater lens, the spatial limit of TI waiver has been extended to include the entire aquifer column from the marine water to the top of the groundwater table in case of future water production from the shallow fresh water lens causing upwelling of TCE and PCE contamination from the deeper portion of the aquifer.

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13.0 Conclusions

A TI Waiver for the MARBO Annex is appropriate because it is not feasible or practicable from an engineering and technological viewpoint to remediate the dissolve-phase TCE or PCE or to remediate the sources. The need for a TI Waiver is supported by the presence of sustained TCE and PCE deep sources, a 400 foot depth to groundwater, the complex hydrogeology of the karst limestone, and the large volume of water that moves through the subsurface system.

Finally, the water balance on a Pacific island such as Guam is extremely important and delicate because of the island population's dependence on groundwater for drinking (and other potable uses) and for maintaining a salt water intrusion barrier. Water quality may be treated, but quantity cannot be replaced and a large-scale pump and treat system may have detrimental side effects on the island's water balance.

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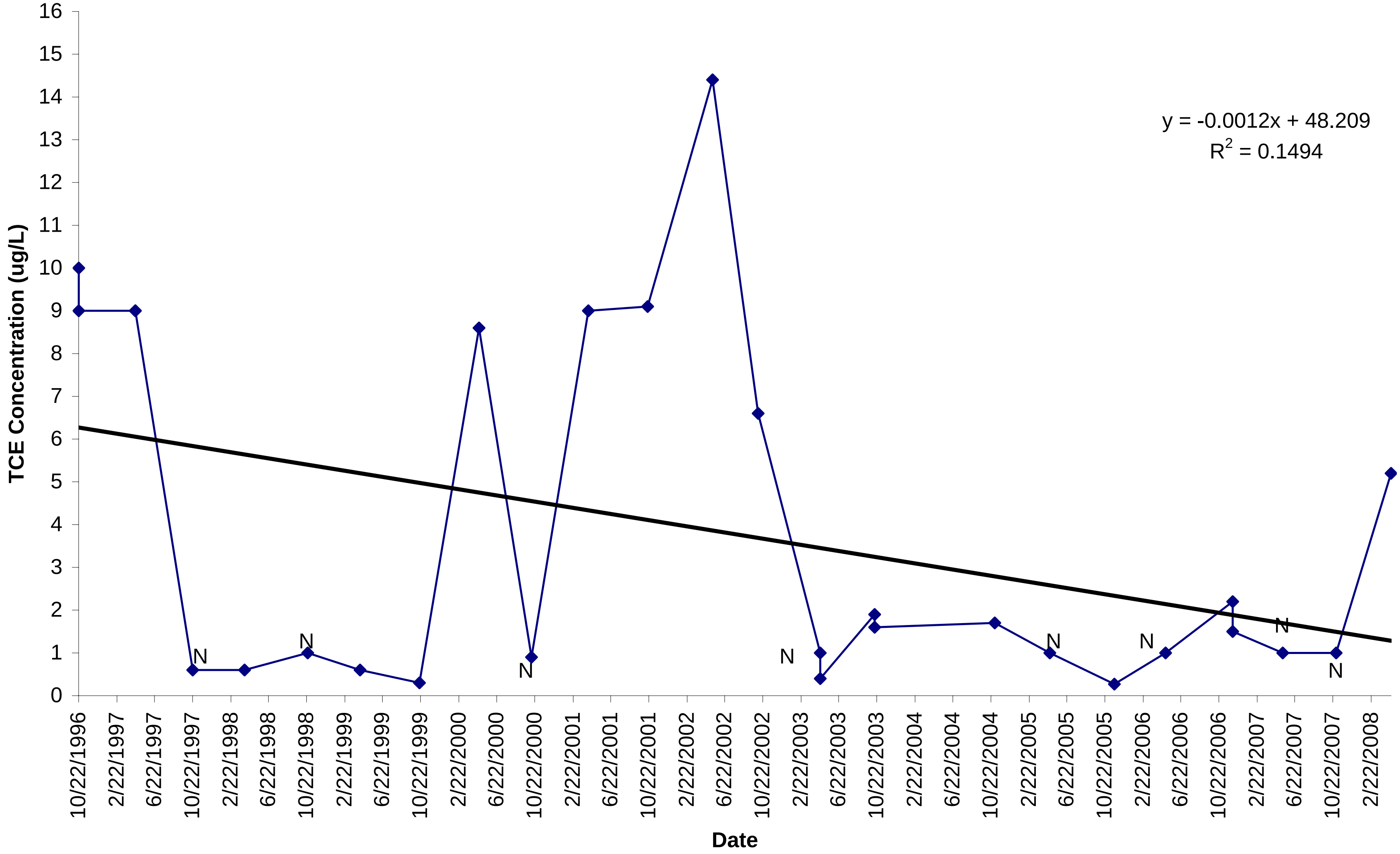
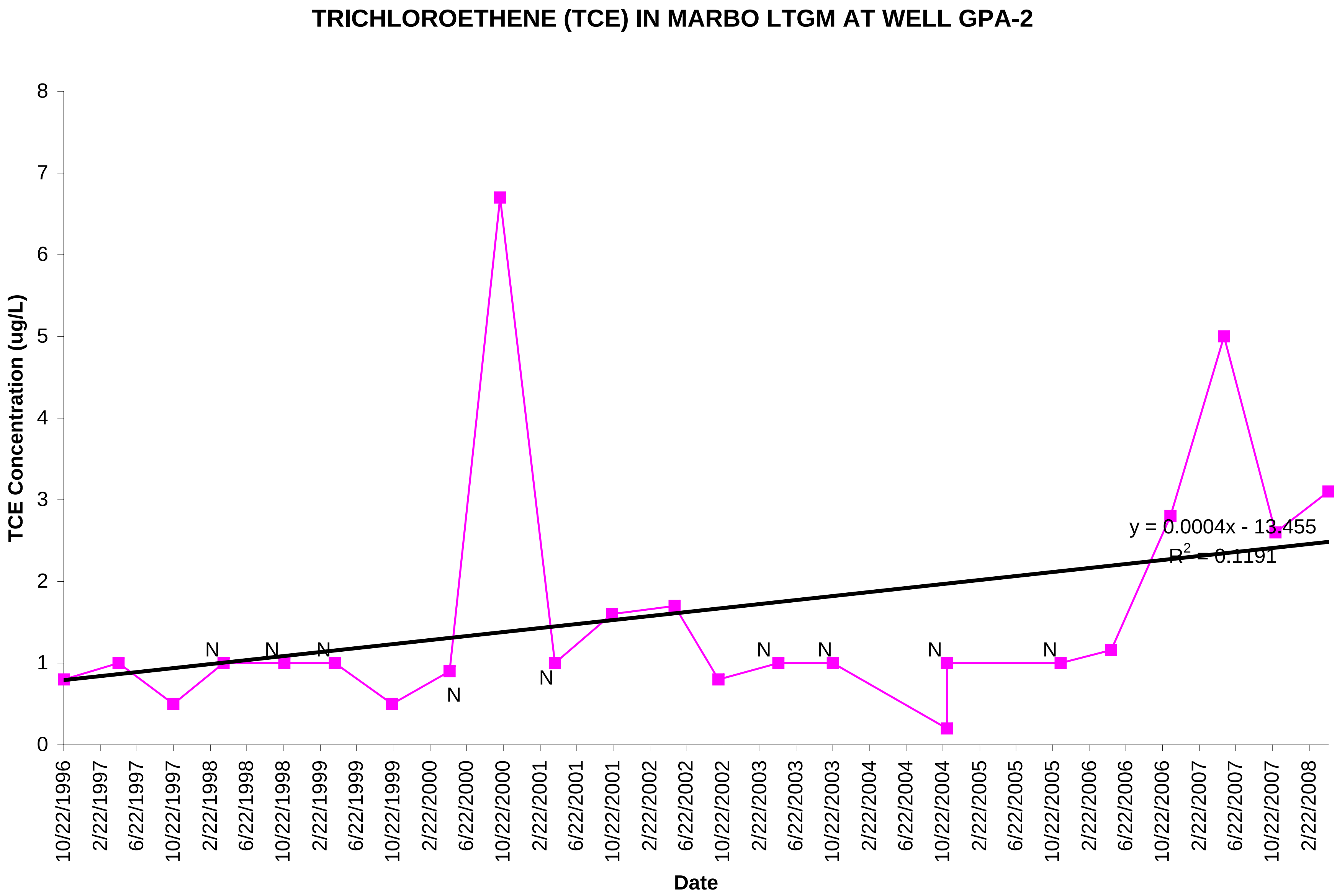
ATTACHMENT 1: WELL GRAPHS OF CONTAMINANT CONCENTRATION VERSUS TIME FOR SHALLOW AND DEEP WELLS IN THE VICINITY OF TCE AND PCE OCCURRENCES

TRICHLOROETHENE (TCE) IN MARBO LTGM AT WELL GPA-1





TRICHLOROETHENE (TCE) IN MARBO LTGM AT WELL GPA-2
TCE Concentration (ug/L)
0
1
2
3
4
5
6
7
8
N
N
N
N
N
N
N
N
N
y = 0.0004x - 13.455
R^2 = 0.1191
10/22/1996
2/22/1997
6/22/1997
10/22/1997
2/22/1998
6/22/1998
10/22/1998
2/22/1999
6/22/1999
10/22/1999
2/22/2000
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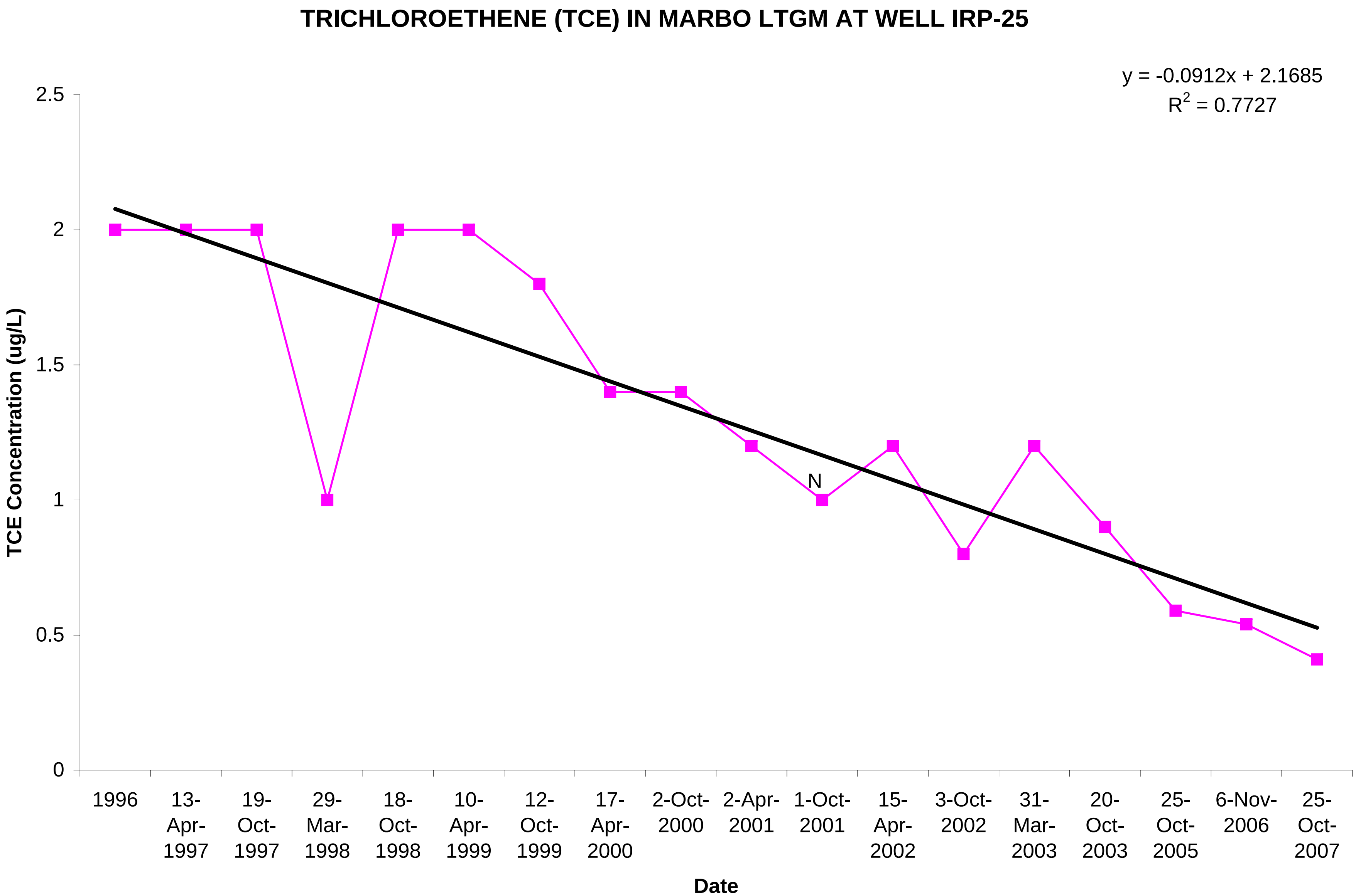
2/22/2008
Date


TRICHLOROETHENE (TCE) IN MARBO LTGM AT WELL IRP-25
y = -0.0912x + 2.1685
R2 = 0.7727
TCE Concentration (ug/L)
2.5
2
1.5
1
0.5
0
N
1996
13-Apr-1997
19-Oct-1997
29-Mar-1998
18-Oct-1998
10-Apr-1999
12-Oct-1999
17-Apr-2000
2-Oct-2000
2-Apr-2001
1-Oct-2001
15-Apr-2002
3-Oct-2002
31-Mar-2003
20-Oct-2003
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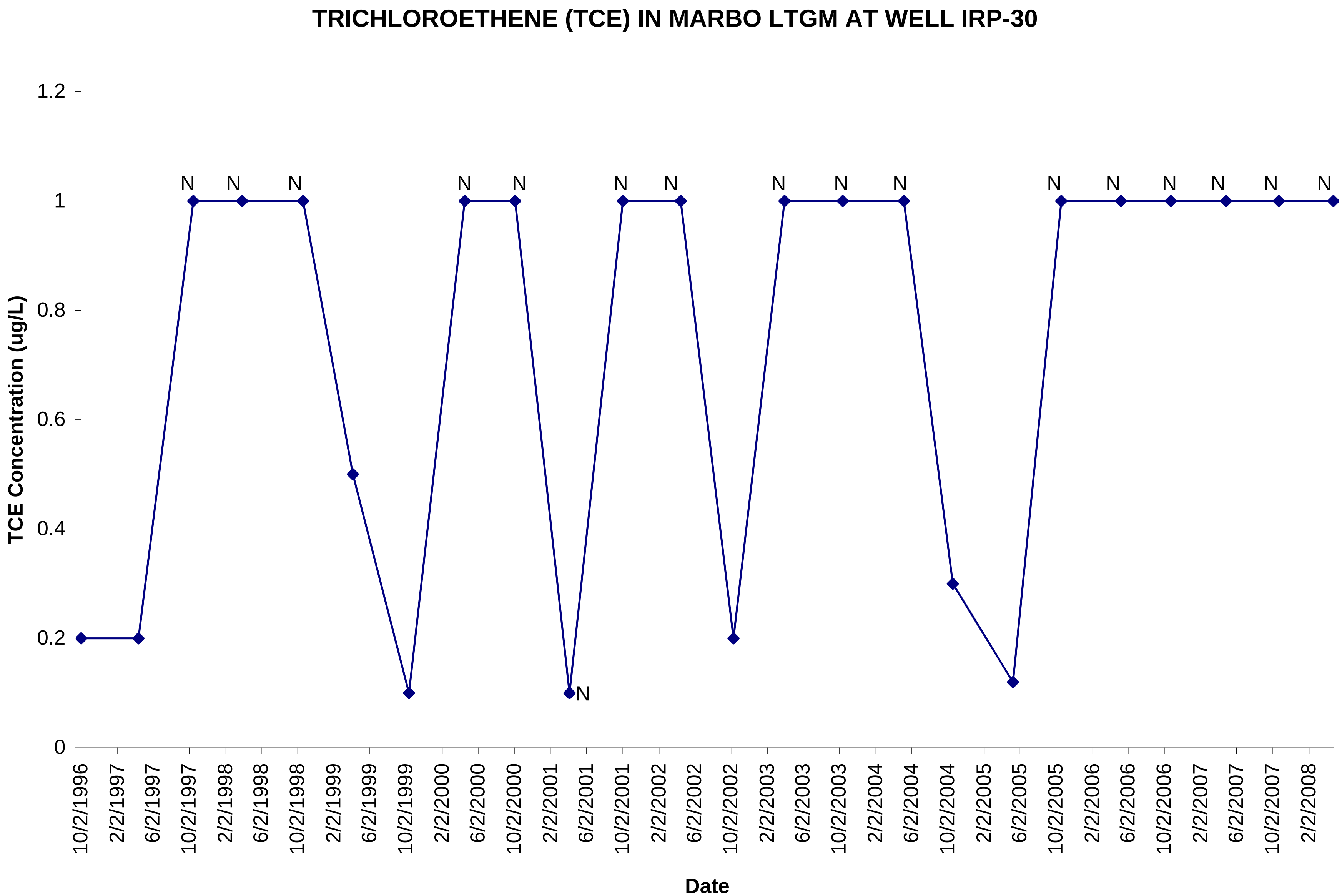
6-Nov-2006
25-Oct-2007
Date


TRICHLOROETHENE (TCE) IN MARBO LTGM AT WELL IRP-30
TCE Concentration (ug/L)
1.2
1
0.8
0.6
0.4
0.2
0
N
10/2/1996
2/2/1997
6/2/1997
10/2/1997
2/2/1998
6/2/1998
10/2/1998
2/2/1999
6/2/1999
10/2/1999
2/2/2000
6/2/2000
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6/2/2005
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10/2/2006
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6/2/2007
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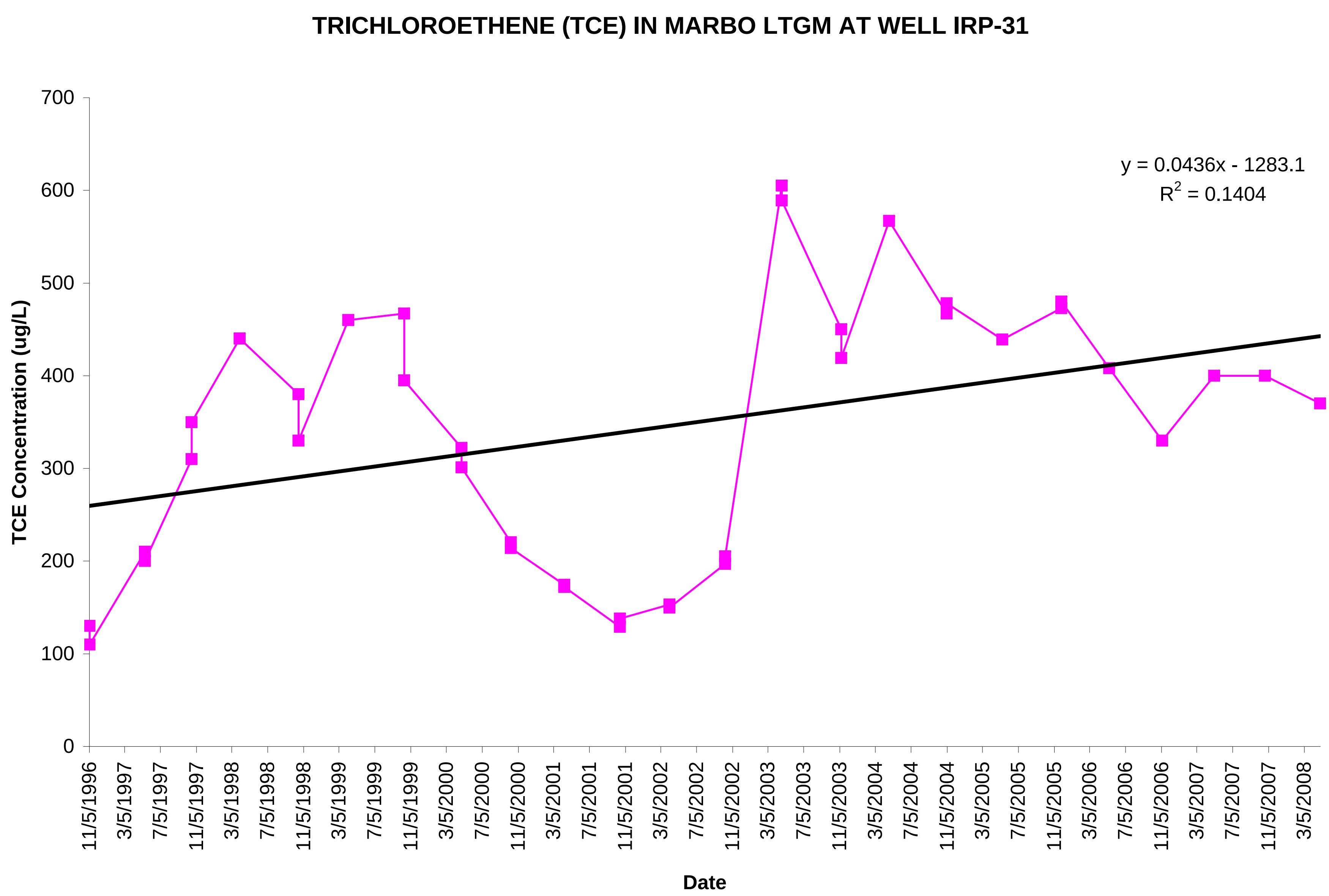
2/2/2008
Date


TRICHLOROETHENE (TCE) IN MARBO LTGM AT WELL IRP-31
y = 0.0436x - 1283.1
R2 = 0.1404
TCE Concentration (ug/L)
0
100
200
300
400
500
600
700
11/5/1996
3/5/1997
7/5/1997
11/5/1997
3/5/1998
7/5/1998
11/5/1998
3/5/1999
7/5/1999
11/5/1999
3/5/2000
7/5/2000
11/5/2000
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7/5/2004
11/5/2004
3/5/2005
7/5/2005
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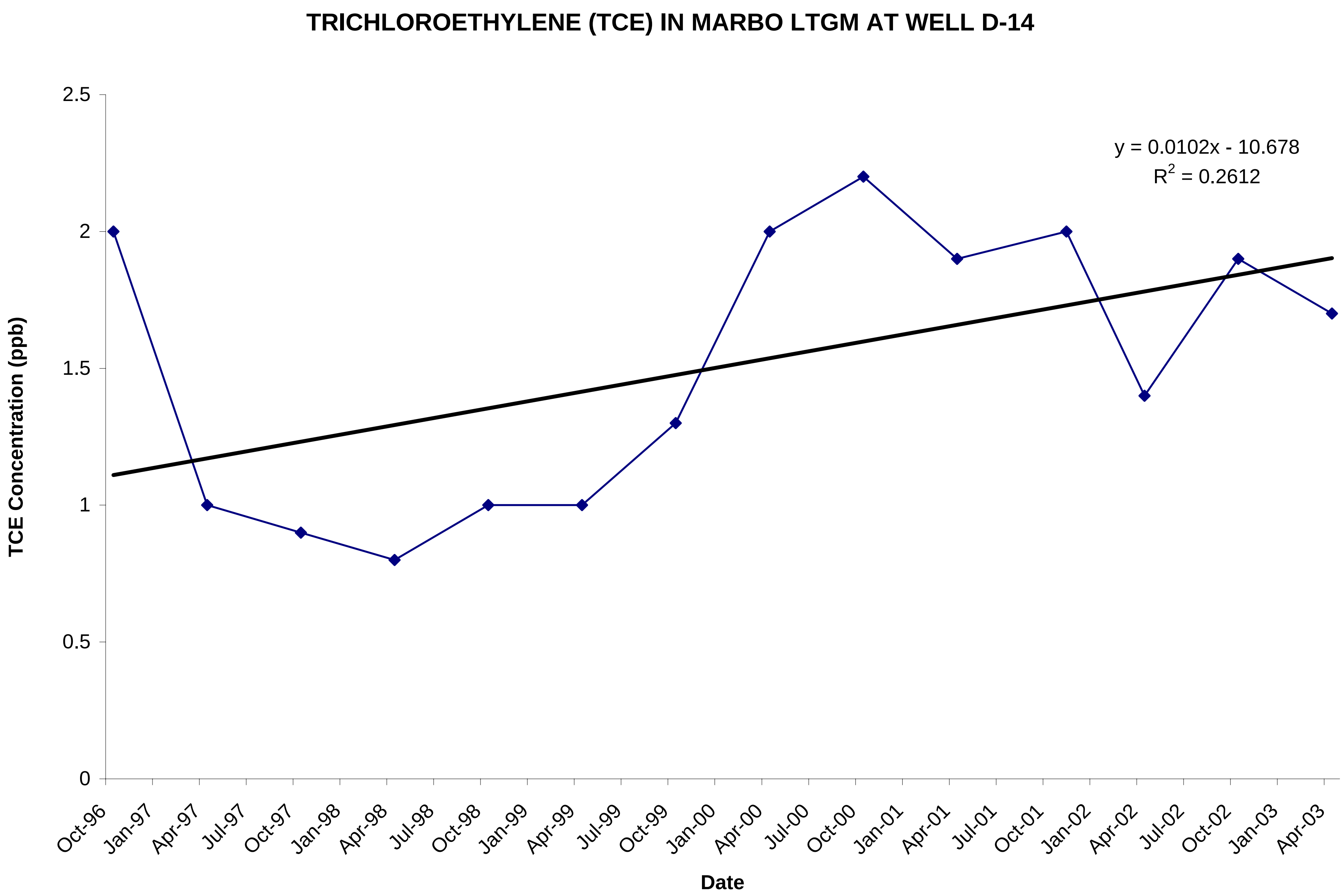
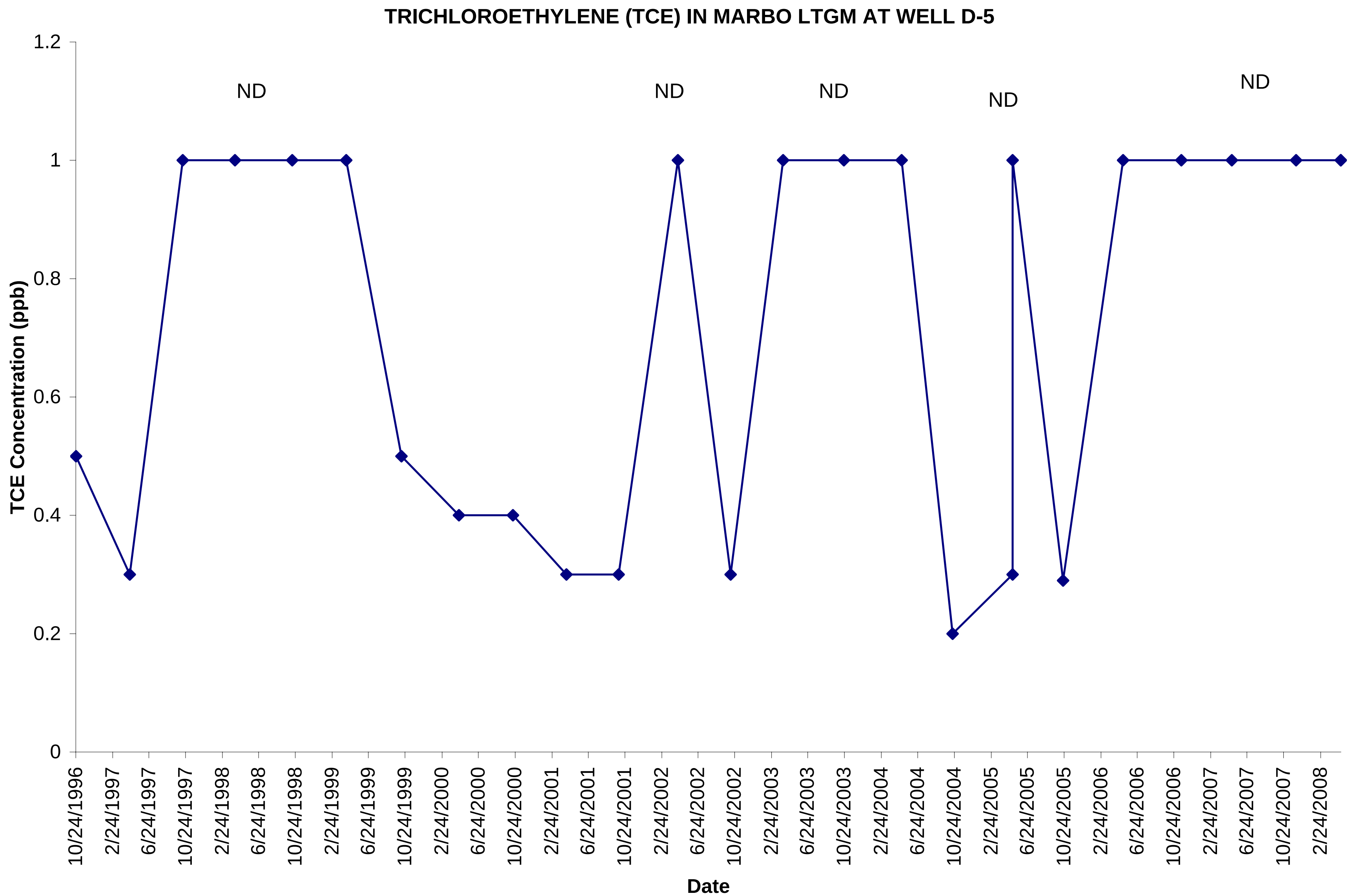
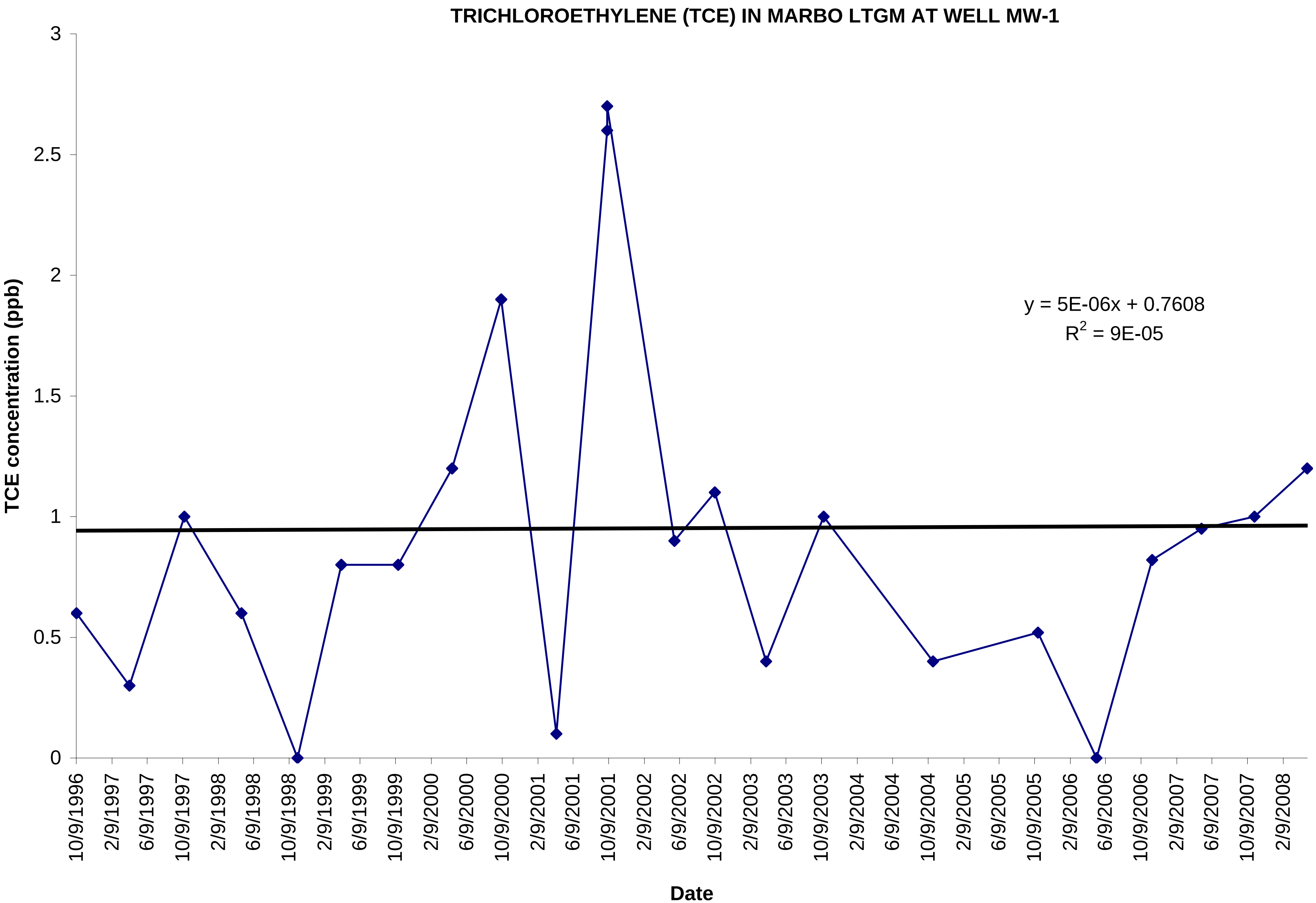
7/5/2007
11/5/2007
3/5/2008
Date

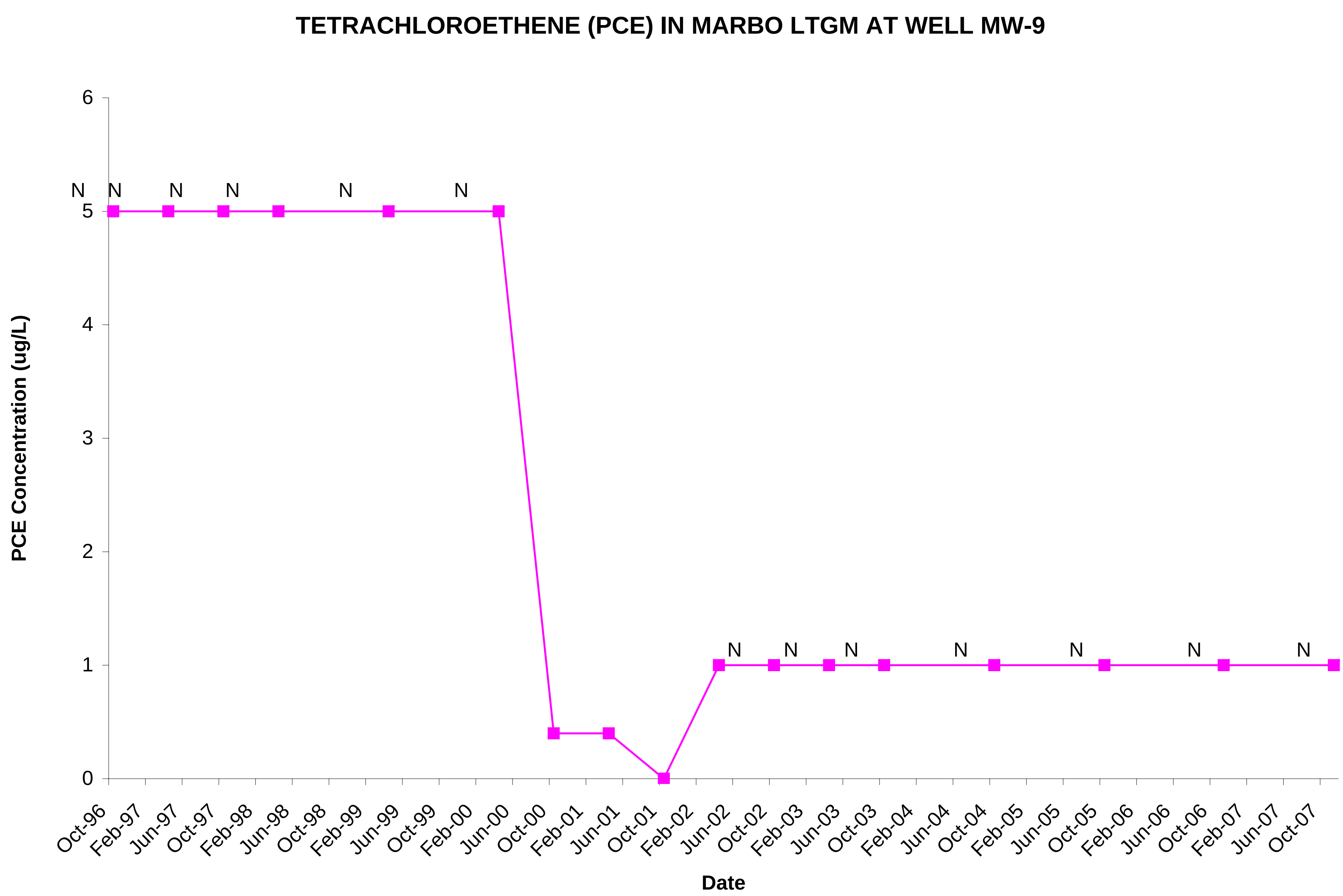


TRICHLOROETHYLENE (TCE) IN MARBO LTGM AT WELL D-14
y = 0.0102x - 10.678
R2 = 0.2612
TCE Concentration (ppb)
2.5
2
1.5
1
0.5
0
Oct-96
Jan-97
Apr-97
Jul-97
Oct-97
Jan-98
Apr-98
Jul-98
Oct-98
Jan-99
Apr-99
Jul-99
Oct-99
Jan-00
Apr-00
Jul-00
Oct-00
Jan-01
Apr-01
Jul-01
Oct-01
Jan-02
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Date

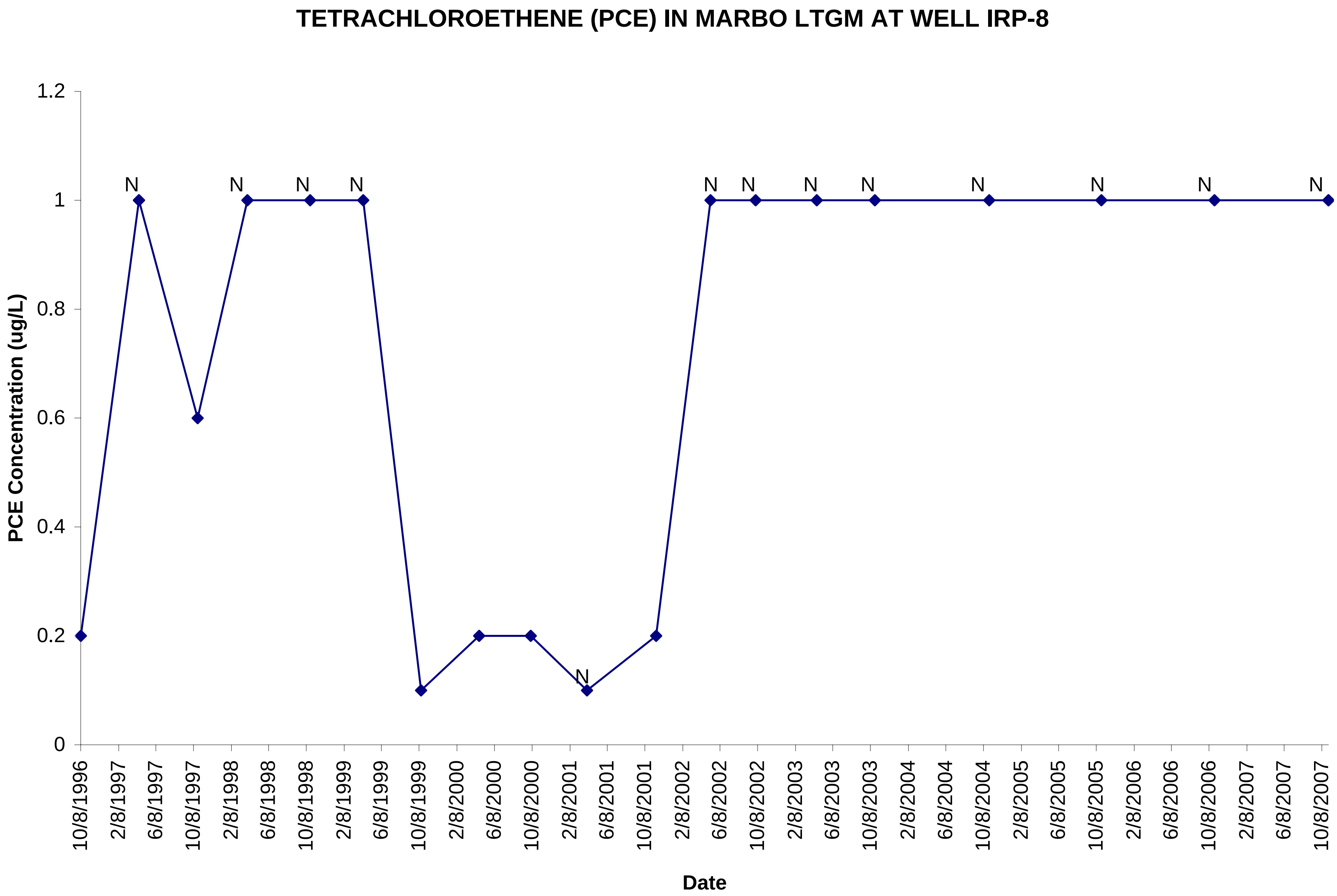

TRICHLOROETHYLENE (TCE) IN MARBO LTGM AT WELL D-5
TCE Concentration (ppb)
1.2
1
0.8
0.6
0.4
0.2
0
ND
ND
ND
ND
ND
10/24/1996
2/24/1997
6/24/1997
10/24/1997
2/24/1998
6/24/1998
10/24/1998
2/24/1999
6/24/1999
10/24/1999
2/24/2000
6/24/2000
10/24/2000
2/24/2001
6/24/2001
10/24/2001
2/24/2002
6/24/2002
10/24/2002
2/24/2003
6/24/2003
10/24/2003
2/24/2004
6/24/2004
10/24/2004
2/24/2005
6/24/2005
10/24/2005
2/24/2006
6/24/2006
10/24/2006
2/24/2007
6/24/2007
10/24/2007
2/24/2008
Date

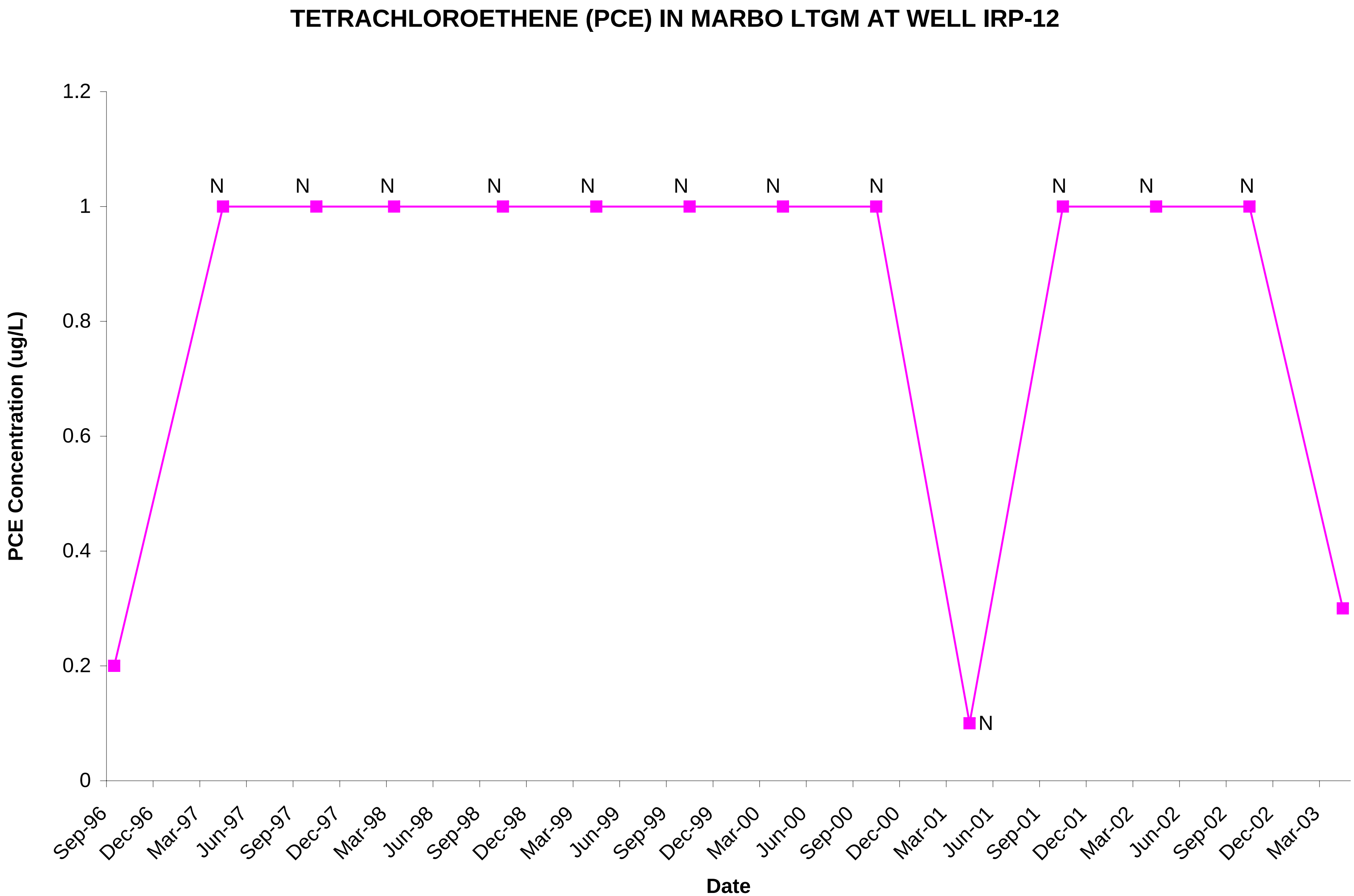


TRICHLOROETHYLENE (TCE) IN MARBO LTGM AT WELL MW-1
TCE concentration (ppb)
Date
y = 5E-06x + 0.7608
R^2 = 9E-05
0
0.5
1
1.5
2
2.5
3
10/9/1996
2/9/1997
6/9/1997
10/9/1997
2/9/1998
6/9/1998
10/9/1998
2/9/1999
6/9/1999
10/9/1999
2/9/2000
6/9/2000
10/9/2000
2/9/2001
6/9/2001
10/9/2001
2/9/2002
6/9/2002
10/9/2002
2/9/2003
6/9/2003
10/9/2003
2/9/2004
6/9/2004
10/9/2004
2/9/2005
6/9/2005
10/9/2005
2/9/2006
6/9/2006
10/9/2006
2/9/2007
6/9/2007
10/9/2007
2/9/2008



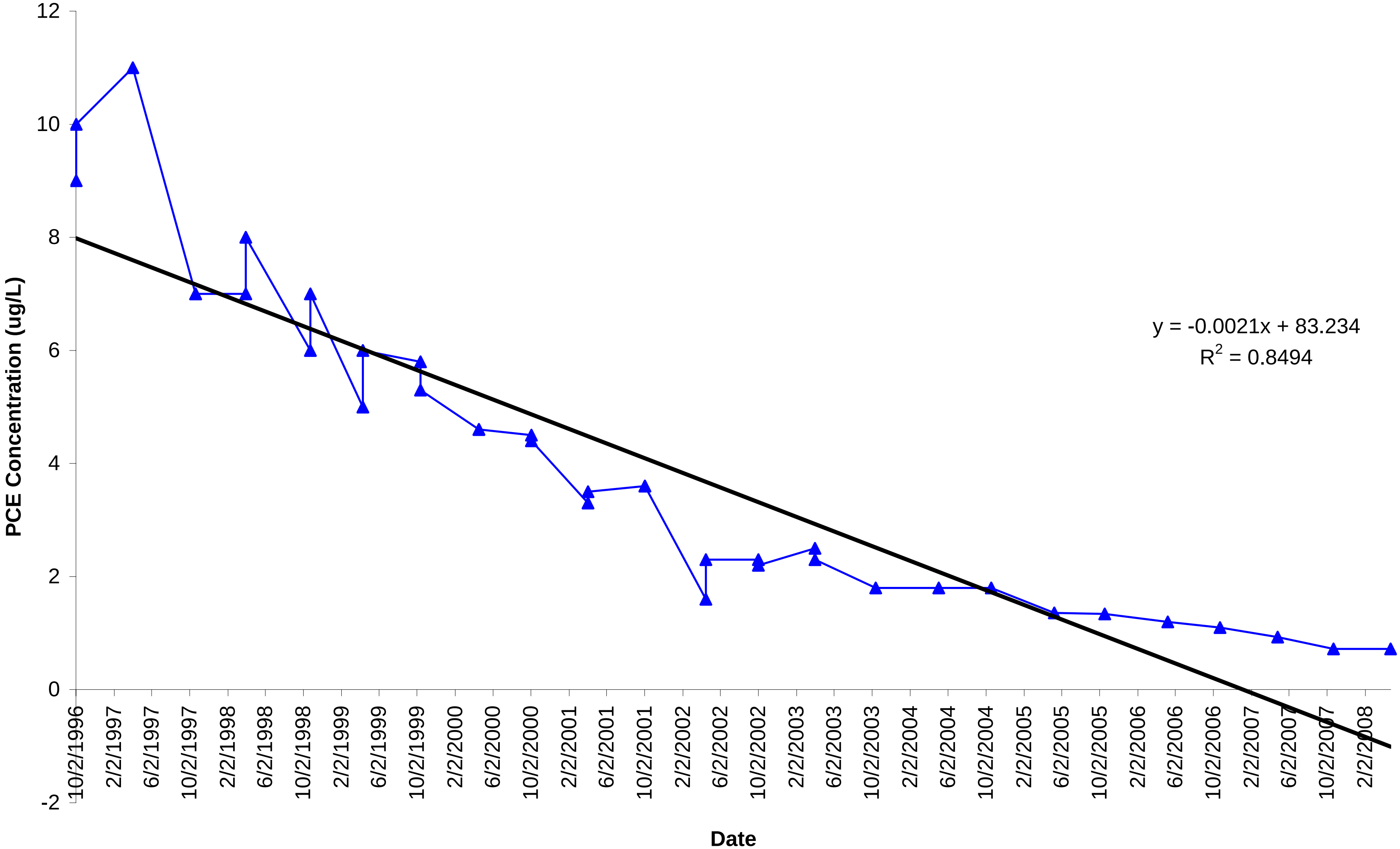
TETRACHLOROETHENE (PCE) IN MARBO LTGM AT WELL MW-9
PCE Concentration (ug/L)
Date
0
1
2
3
4
5
6
N
Oct-96
Feb-97
Jun-97
Oct-97
Feb-98
Jun-98
Oct-98
Feb-99
Jun-99
Oct-99
Feb-00
Jun-00
Oct-00
Feb-01
Jun-01
Oct-01
Feb-02
Jun-02
Oct-02
Feb-03
Jun-03
Oct-03
Feb-04
Jun-04
Oct-04
Feb-05
Jun-05
Oct-05
Feb-06
Jun-06
Oct-06
Feb-07
Jun-07
Oct-07


TETRACHLOROETHENE (PCE) IN MARBO LTGM AT WELL IRP-8
PCE Concentration (ug/L)
Date
0
0.2
0.4
0.6
0.8
1
1.2
N
10/8/1996
2/8/1997
6/8/1997
10/8/1997
2/8/1998
6/8/1998
10/8/1998
2/8/1999
6/8/1999
10/8/1999
2/8/2000
6/8/2000
10/8/2000
2/8/2001
6/8/2001
10/8/2001
2/8/2002
6/8/2002
10/8/2002
2/8/2003
6/8/2003
10/8/2003
2/8/2004
6/8/2004
10/8/2004
2/8/2005
6/8/2005
10/8/2005
2/8/2006
6/8/2006
10/8/2006
2/8/2007
6/8/2007
10/8/2007

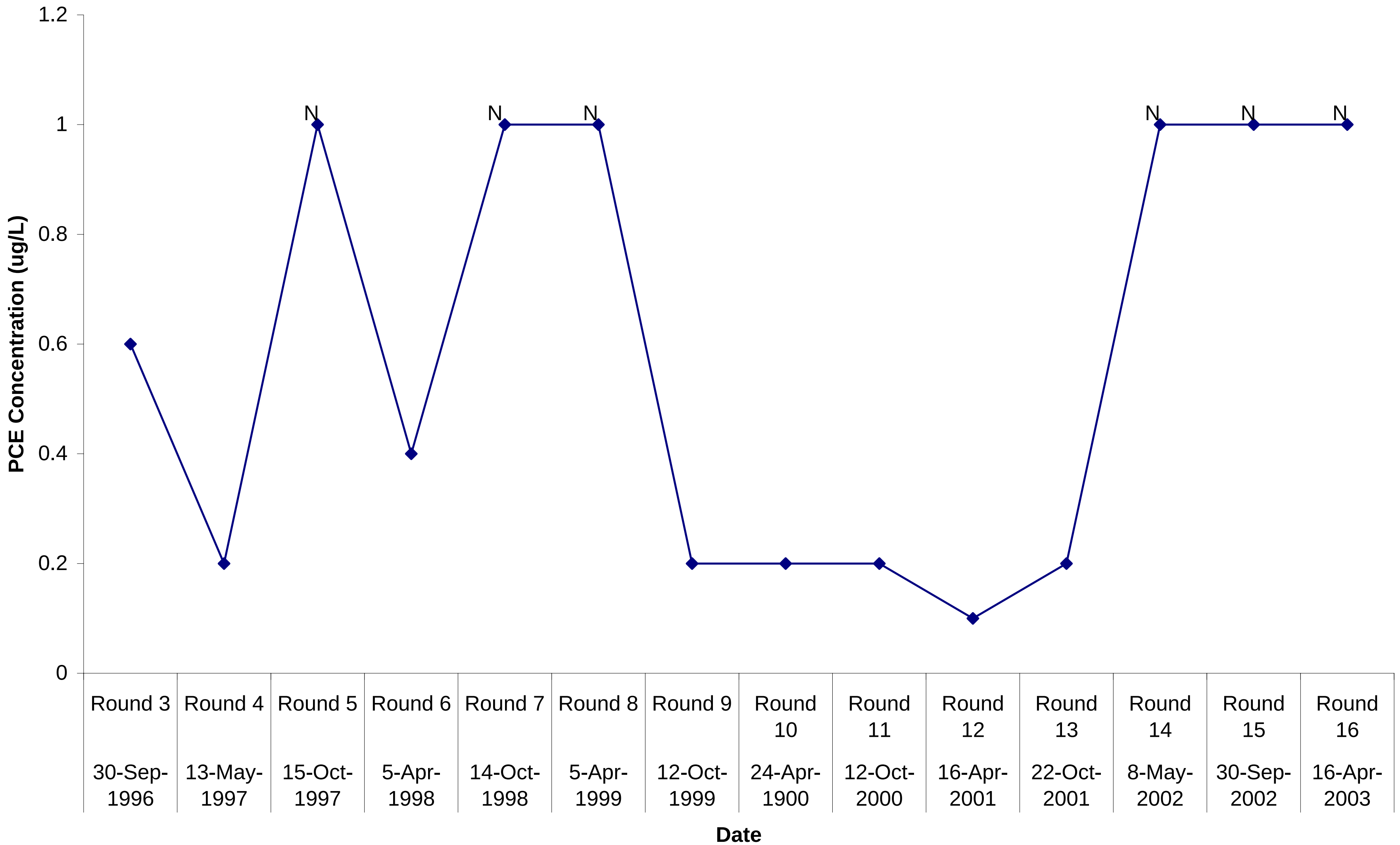


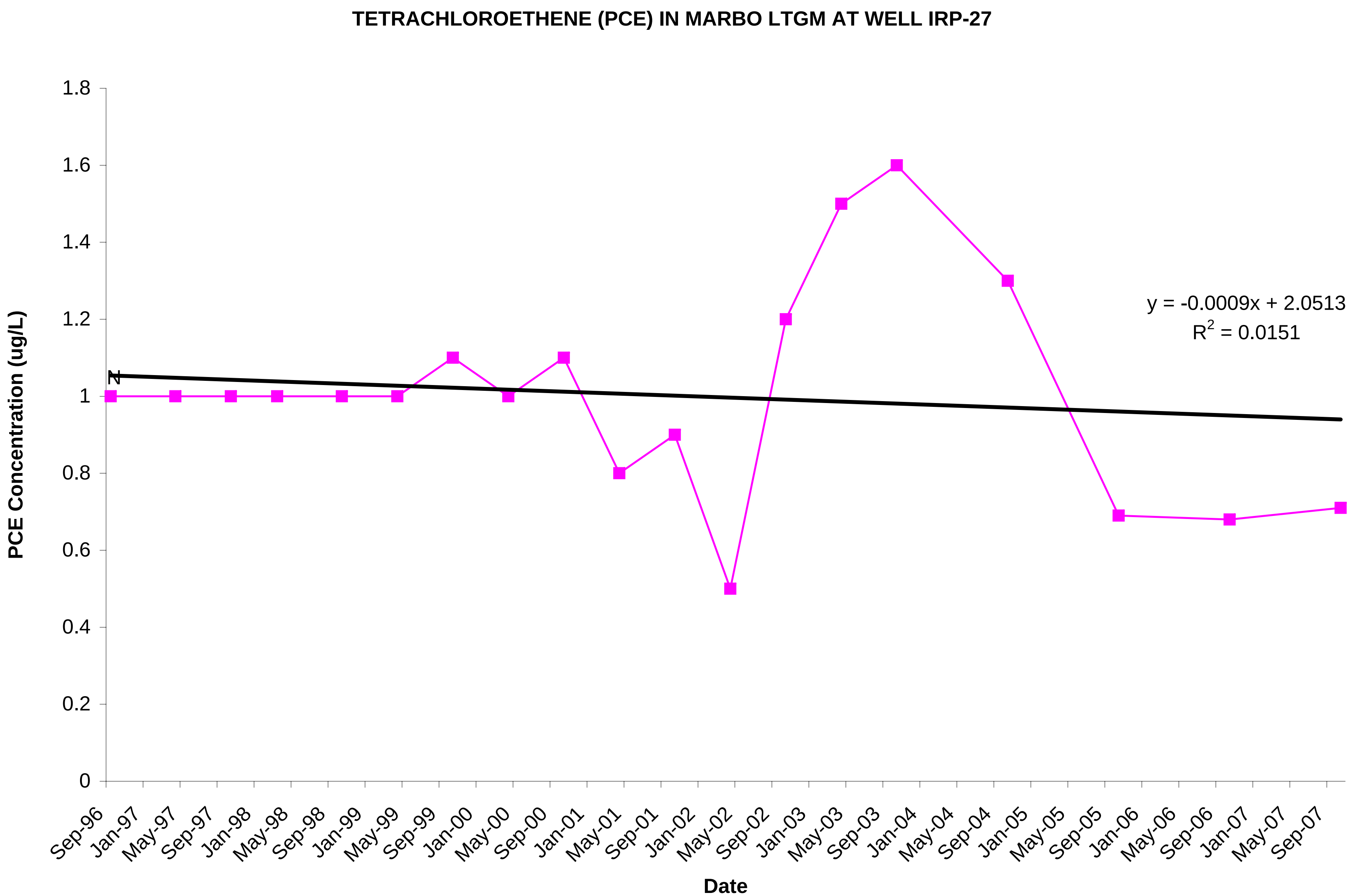
TETRACHLOROETHENE (PCE) IN MARBO LTGM AT WELL IRP-12
PCE Concentration (ug/L)
1.2
1
0.8
0.6
0.4
0.2
0
N
N
N
N
N
N
N
N
N
N
N
N
N
Sep-96
Dec-96
Mar-97
Jun-97
Sep-97
Dec-97
Mar-98
Jun-98
Sep-98
Dec-98
Mar-99
Jun-99
Sep-99
Dec-99
Mar-00
Jun-00
Sep-00
Dec-00
Mar-01
Jun-01
Sep-01
Dec-01
Mar-02
Jun-02
Sep-02
Dec-02
Mar-03
Date

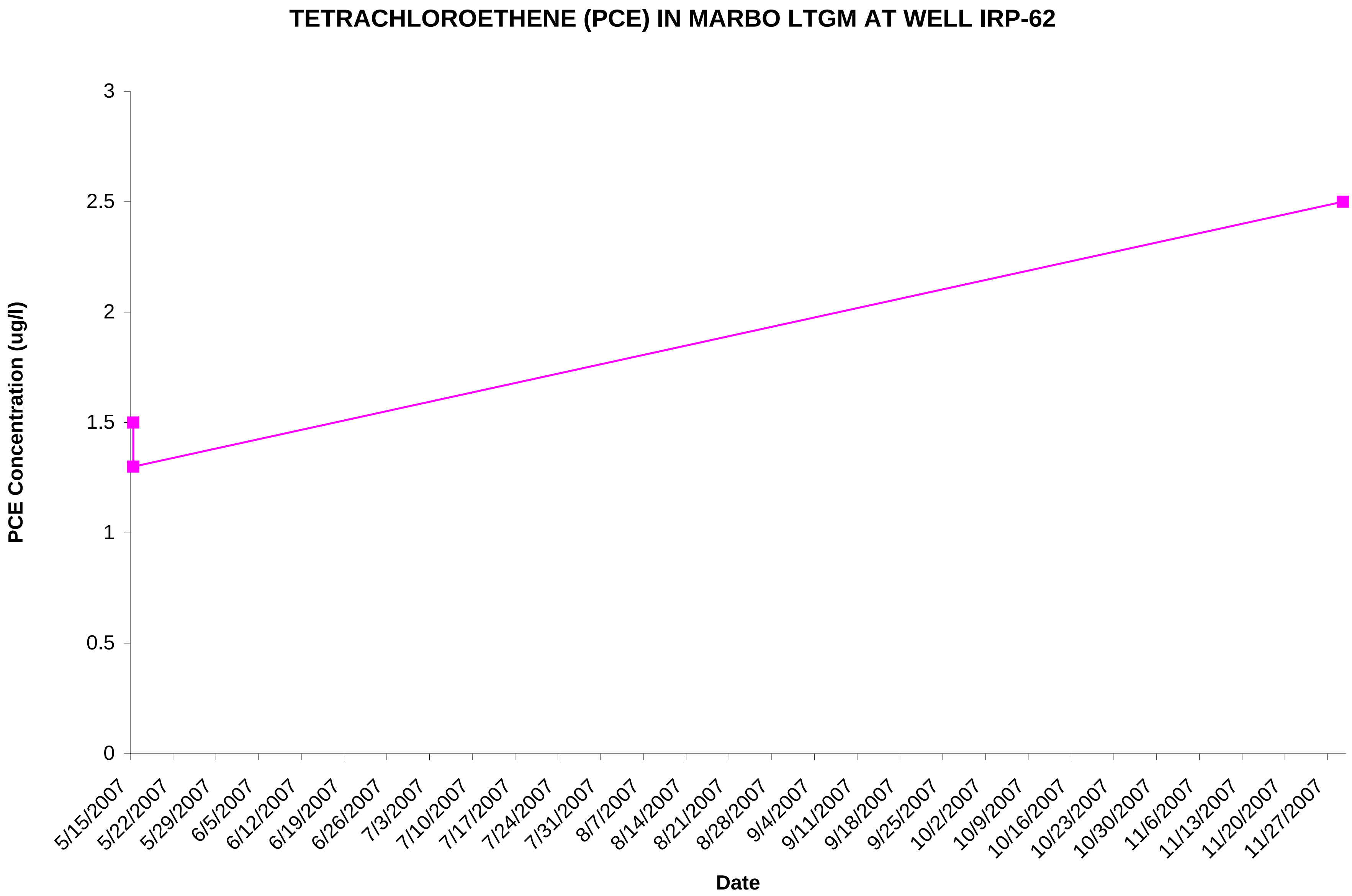
TETRACHLOROETHENE (PCE) IN MARBO LTGM AT WELL IRP-14



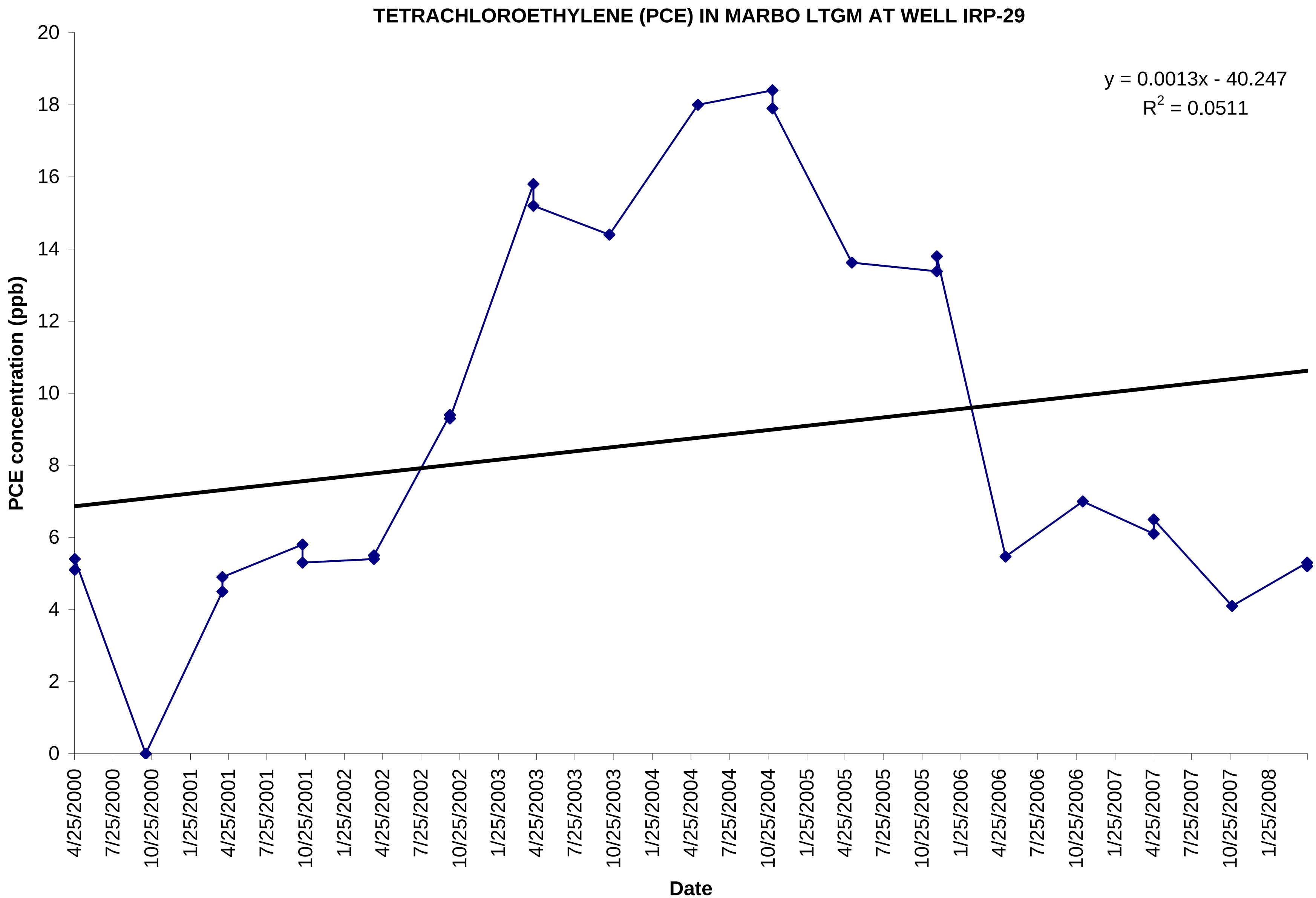
TETRACHLOROETHENE (PCE) IN MARBO LTGM AT WELL IRP-26




TETRACHLOROETHENE (PCE) IN MARBO LTGM AT WELL IRP-27
PCE Concentration (ug/L)
Date
y = -0.0009x + 2.0513
R^2 = 0.0151
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Sep-96
Jan-97
May-97
Sep-97
Jan-98
May-98
Sep-98
Jan-99
May-99
Sep-99
Jan-00
May-00
Sep-00
Jan-01
May-01
Sep-01
Jan-02
May-02
Sep-02
Jan-03
May-03
Sep-03
Jan-04
May-04
Sep-04
Jan-05
May-05
Sep-05
Jan-06
May-06
Sep-06
Jan-07
May-07
Sep-07



TETRACHLOROETHENE (PCE) IN MARBO LTGM AT WELL IRP-62
PCE Concentration (ug/l)
3
2.5
2
1.5
1
0.5
0
5/15/2007
5/22/2007
5/29/2007
6/5/2007
6/12/2007
6/19/2007
6/26/2007
7/3/2007
7/10/2007
7/17/2007
7/24/2007
7/31/2007
8/7/2007
8/14/2007
8/21/2007
8/28/2007
9/4/2007
9/11/2007
9/18/2007
9/25/2007
10/2/2007
10/9/2007
10/16/2007
10/23/2007
10/30/2007
11/6/2007
11/13/2007
11/20/2007
11/27/2007
Date



TETRACHLOROETHYLENE (PCE) IN MARBO LTGM AT WELL IRP-29
y = 0.0013x - 40.247
R^2 = 0.0511
PCE concentration (ppb)
0
2
4
6
8
10
12
14
16
18
20
4/25/2000
7/25/2000
10/25/2000
1/25/2001
4/25/2001
7/25/2001
10/25/2001
1/25/2002
4/25/2002
7/25/2002
10/25/2002
1/25/2003
4/25/2003
7/25/2003
10/25/2003
1/25/2004
4/25/2004
7/25/2004
10/25/2004
1/25/2005
4/25/2005
7/25/2005
10/25/2005
1/25/2006
4/25/2006
7/25/2006
10/25/2006
1/25/2007
4/25/2007
7/25/2007
10/25/2007
1/25/2008
Date