Designated original

Roy Blickwedel
Remedial Project Manager
Corporate Environmental Programs

GE
640 Freedom Business center
King of Prussia, PA 19406

T 610 992 7935
F 610 992 7898
roy.blickwedel@corporate.ge.com

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U. S. Nuclear Regulatory Commission
Gary Janosko, Chief
Fuel Cycle Licensing Branch, FCSS
c/o Document Control Desk
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

Subject: License Amendment Request for Changing the Ground Water Protection Standard for Radium in Source Materials License SUA-1475 (TAC LU0092) Groundwater Corrective Action Program – Docket 40-8907

Dear Mr. Janosko:

UNC proposes to change the method by which compliance with the groundwater protection standard for combined radium-226 and 228 is evaluated. Please note that the Proposed Amendment Text does not include language from the pending proposed change that substitutes trihalomethane analysis and reporting for chloroform (UNC's revised License Amendment Request dated July 14, 2005). We bring this to your attention so that any and all revisions to Condition 30.B. will incorporate NRC's determination for both amendment requests.

Existing Conditions

30.B. Comply with the following groundwater protection standards at point of compliance Wells GW-1, GW-2, GW-3, 632, EPA-23, EPA-28, and 509-D I the Southwest Alluvium; 614, 604, EPA-4, EPA-5, and EPA-7 in Zone 1; and 517, 613, 708, and 711 in Zone 3:

Arsenic = 0.05 mg/l, beryllium = 0.05 mg/l, cadmium = 0.01 mg/l, chloroform = 0.001 mg/l, gross alpha = 15.0 pCi/l, lead = 0.05 mg/l, lead-210 = 1.0 pCi/l, nickel = 0.05 mg/l, radium-226 and 228 = 5.0 pCi/l, selenium = 0.01 mg/l, thorium-230 = 5.0 pCi/l, uranium = 0.3 mg/l and vanadium = 01 mg/l.

Justification

UNC's proposed revision is based upon the attached report, "*Technical Analysis Report in Support of License Amendment Request for Changing the Method of Determining Exceedances of the Combined Radium Groundwater Protection Standard in Source Material License SUA-1475 (TAC LU0092) Groundwater Corrective Action Program*" (Veolia Water (N.A. Water Systems), August 2005). The proposed revision accounts for the fact that the current site standard lies well within the background concentration ranges for radium-226 and 228 in the Southwest Alluvium and Zone 1. The proposed revision incorporates a statistical testing procedure to objectively determine if the combined radium concentration is attributable to the occurrence and migration of seepage-impacted water or if it is within the normal and expected background distribution.

Proposed Amendment Text

30.B. Comply with the following groundwater protection standards at point of compliance Wells GW-1, GW-2, GW-3, 632, EPA-23, EPA-28, and 509-D I the Southwest Alluvium; 614, 604, EPA-4, EPA-5, and EPA-7 in Zone 1; and 517, 613, 708, and 711 in Zone 3:

Arsenic = 0.05 mg/l, beryllium = 0.05 mg/l, cadmium = 0.01 mg/l, chloroform = 0.001 mg/l, gross alpha = 15.0 pCi/l, lead = 0.05 mg/l, lead-210 = 1.0 pCi/l, nickel = 0.05 mg/l, radium-226 and 228 = 5.0 pCi/l, selenium = 0.01 mg/l, thorium-230 = 5.0 pCi/l, uranium = 0.3 mg/l and vanadium = 01 mg/l.

Should the groundwater protection standard for radium-226 and 228 in the Southwest Alluvium or in Zone 1 be exceeded in any compliance well, then the Two Sample Test of Proportions and the Kruskal-Wallis test will be applied to determine if the concentration is a valid exceedance of the site standard. The Two Sample Test of Proportions will be applied to quarterly compliance data, while the Kruskal-Wallis test will be applied to compliance data lumped from the most recent four quarters in the Southwest Alluvium and the most recent six quarters in Zone 1.

Please contact me if you have any questions.

Sincerely,

Roy S. Blickwedel

Roy S. Blickwedel, P.G.
Remedial Project Manager
Corporate Environmental Programs

enc.
cc: William von Till, NRC ✓
Larry Bush, UNC
Mark Jancin, NA Water Systems (w/out encl.)

United Nuclear Corporation
Gallup, New Mexico

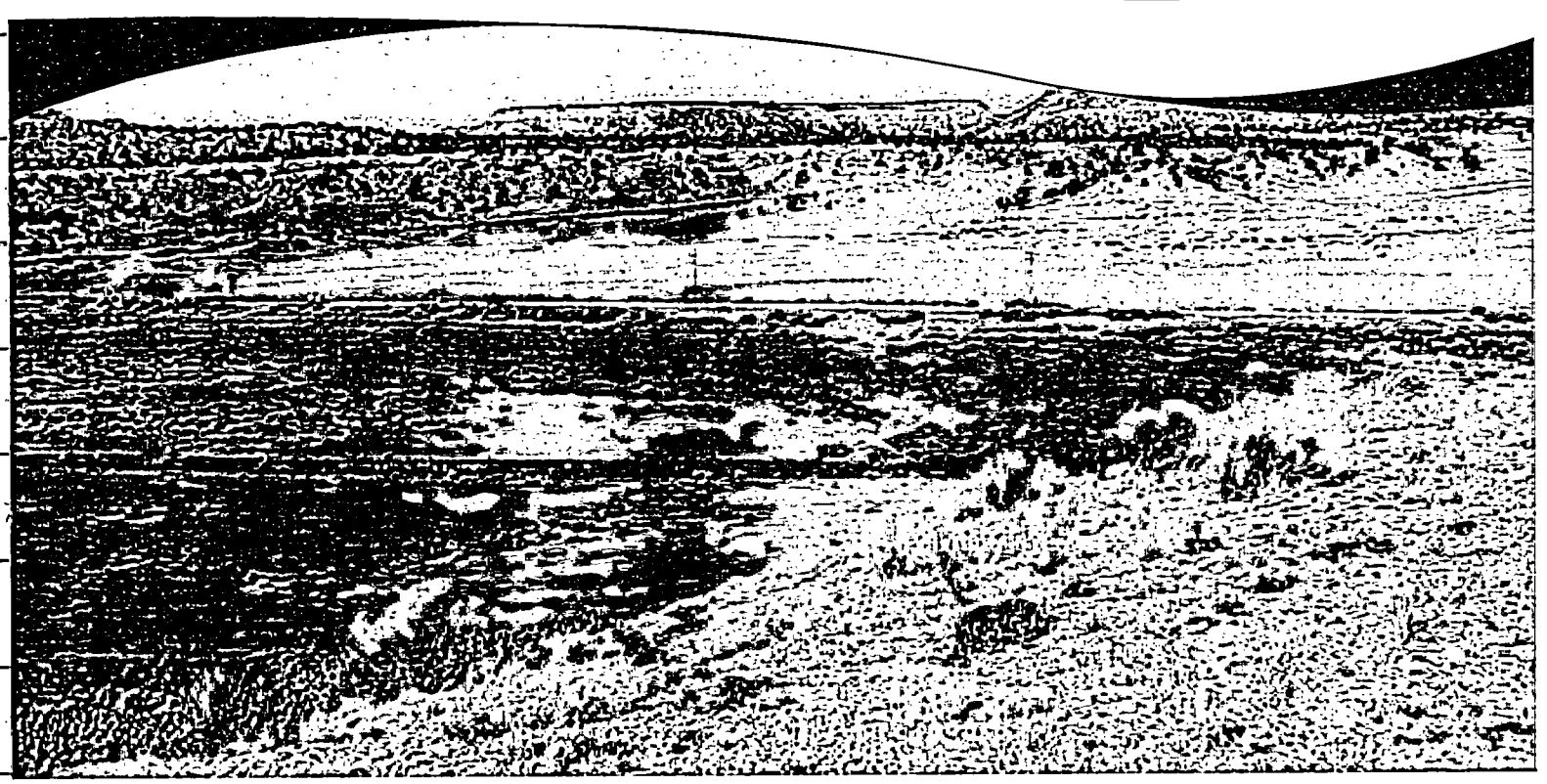
Technical Analysis Report in Support of License Amendment Request for Changing the Method of Determining Exceedances of the Combined Radium Groundwater Protection Standard in Source Materials License SUA-1475 (TAC LU0092)

Groundwater Corrective Action Program

Church Rock Site, Church Rock, New Mexico

September 2005

NA WATERSYSTEMS



UNITED NUCLEAR CORPORATION
GALLUP, NEW MEXICO

TECHNICAL ANALYSIS REPORT IN SUPPORT OF LICENSE AMENDMENT REQUEST FOR CHANGING THE METHOD OF DETERMINING EXCEEDANCES OF THE COMBINED RADIUM GROUNDWATER PROTECTION STANDARD IN SOURCE MATERIALS LICENSE SUA-1475 (TAC LU0092) GROUNDWATER CORRECTIVE ACTION PROGRAM CHURCH ROCK SITE, CHURCH ROCK, NEW MEXICO

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PREPARED BY:
JAMES A. EWART, P.G., PH.D.

APPROVED BY:
MARK D. JANCIN, P.G.

56003960

120 Radnor Road
State College, PA 16801
814.231.2170 phone
814.231.2174 fax

United Nuclear Corporation
Radium Technical Analysis Report
Table of Contents

Page No.

Section 1 Introduction and Background 1

Section 2 Statistical Analyses 3
Classification of the Well Sample Data 3
Summary Statistics and Sample Distributions 6
Tests of Normality 9
Comparisons of Compliance Sample Sets to Background 9
Comparison of Combined Radium in Compliance Wells to the Site Standard ... 10
Southwest Alluvium 10
Zone 1 11

Section 3 Discussion 12
Southwest Alluvium 12
Zone 1 13

Section 4 Recommended Change to Method of Determining Exceedances of the Site Standard for Combined Radium in the Southwest Alluvium and Zone 1 15

List of Tables (located within report text)

Table 1 Compliance Wells in the Southwest Alluvium and Zone 1

Table 2 Key Indicators of Tailings Seepage Impact

Table 3 Wells Having Samples Representative of Background Water Quality

Table 4 Summary Statistics for Combined Radium

Table 5 Percentages of Zone 1 Compliance Well Samples Exceeding the Site Standard for Combined Radium

List of Figures

Figure 1 Box and Whisker Plot of Combined Radium in Samples from Zone 1 Wells

Figure 2 Box and Whisker Plot of Combined Radium in Samples from Southwest Alluvium Wells

Appendices

Appendix A Time Series of Bicarbonate, Chloride, and Combined Radium for Wells in the Southwest Alluvium (Part 1) and Zone 1 (Part 2) (July 1989 – October 2004)

Appendix B Basic Statistics Output from Chemstat

Appendix C Normal Probability Plots and Tests of Normality

Appendix D Nonparametric Comparisons of Radium Data from Compliance Wells to Background Wells

Appendix E Comparison of Radium Data from Compliance Wells to the Site Standard Two-Sample Test of Proportions

Appendix F Example Applications of the Krusakal-Wallis and Two-Sample Test of Proportions with 2004 Quarterly and Multiple Quarter Compliance Sample Data Sets from the Southwest Alluvium and Zone 1

United Nuclear Corporation
Radium Technical Analysis Report
Section 1
Introduction and Background

This technical analysis report provides a rationale and recommendation for revising the method of determining exceedances of combined radium concentrations in groundwater at the Church Rock site. The analysis addresses the Southwest Alluvium and Zone 1, and is based on statistical and logical arguments for changing from the current, deterministic method of determining exceedances to a statistical method that is more accurate and appropriate. The current site standard for combined radium is the federal Maximum Contaminant Level (MCL) for drinking water, 5 pCi/L. This analysis demonstrates that the method for determining exceedances should statistically incorporate the fact that historic background water quality shows exceedances that are unrelated to tailings seepage impact.

The recognized site background water quality is derived from the former discharge of mine water in the arroyo. Most, though not all, of the groundwater present in the alluvium and bedrock at the Church Rock site was derived from infiltrated mine discharge. Subsequent seepage of fluids from the tailings disposal area created impacted groundwater having chemical signatures that are distinct from the background quality water. Therefore, maps of seepage-impacted water migration (and related chemical signatures) have been used to distinguish groundwater impacted by tailings fluids from background quality groundwater (Zone 1 Groundwater Geochemistry Report, Church Rock Site, Gallup, New Mexico, Earth Tech, May 2000; Final Report and Technical Impracticability Evaluation – Southwest Alluvium Natural Attenuation Test, Church Rock Site, Earth Tech, November 2002; and Annual Review Report -- 2004, Groundwater Corrective Action, Church Rock Site, Church Rock, New Mexico, N.A. Water Systems, December 2004). This work has demonstrated that the chemical signatures of tailings-fluid impacted groundwater are different in the Southwest Alluvium and the two bedrock hydrostratigraphic units.

The chemical characteristics of background groundwater quality also differ among the three hydrostratigraphic units. As will be shown here, combined radium is one of the chemical constituents whose concentrations in background groundwater differs significantly among the hydrostratigraphic units. These differences have been identified and explained as a consequence of, among other causes, the origin of the water and the different chemical characteristics of the geologic materials comprising the hydrostratigraphic units.

The present method of exceedance determination compares each compliance sample analysis for combined radium with a uniform site standard concentration of 5 pCi/L. This method makes no allowances for differences of background water quality

in the various hydrostratigraphic units or, more significantly, the relationship of the site standard to the populations of combined radium concentrations in the background groundwater. Therefore, it would be a fallacy of logic to interpret a determination of an "exceedance" by the current method as having anything to do with the relationship of compliance sample results to background water quality. For example, this report will show that in the Southwest Alluvium, the frequency of site-standard exceedance for combined radium is greater in the population of background groundwater samples than it is in the population of the compliance groundwater samples. Furthermore, a very different (and greater) frequency of site-standard exceedance is found in the population of background groundwater samples from Zone 1. Therefore, the present method of comparison to the site standard is neither an appropriate nor a consistent measure of exceedances from background.

Recognized statistical methods can provide an appropriate and consistent measure of exceedances from background. Two such methods, the Two-Sample Test of Proportions and the Kruskal-Wallis method, are proposed to be used concurrently as an alternative to the current method. As with the current method, the proposed alternative methods would be used quarterly to compare combined radium results from compliance wells to the site standard and to background water quality. The basis for this proposal is provided in the following section, and a detailed explanation of its implementation is provided in the last section of this report.

United Nuclear Corporation
Radium Technical Analysis Report
Section 2
Statistical Analyses

The analyses described in this report include basic statistical parameters, distributional plots and tests, comparisons of compliance samples to background samples, and comparisons of both sample sets to the site standard for combined radium.

The radium data used in these analyses are those listed in Appendix A of the 2004 site annual review report (Annual Review Report -- 2004, Groundwater Corrective Action, Church Rock Site, Church Rock, New Mexico, N.A. Water Systems, December 2004). They include results for combined radium (radium 226 and radium 228) in samples collected since July 1989. The tabulation includes most existing and historically sampled wells.

The statistical analyses presented here were prepared with Chemstat (Starpoint Software, version 5.2). This program is designed to support statistical analyses for RCRA and CERCLA projects. The statistical algorithms used are for the most part taken from federal EPA guidance documents. Some algorithms are derived from guidance published by other federal agencies, including the U.S. Navy.

Classification of the Well Sample Data

Well samples were divided into three categories for the purpose of statistical analysis: pre-mining water quality, post-mining/pre-tailings water quality (the recognized background water quality for regulatory purposes), and compliance samples. Compliance wells are listed for the Southwest Alluvium and Zone 1 in Table 1:

Table 1
Compliance Wells in the Southwest Alluvium and Zone 1

Southwest Alluvium	Zone 1
509 D	614
EPA 23	604
GW 1	EPA 7
GW 2	EPA 5
GW 3	EPA 4
EPA 28	
632	

Well data were classified as background primarily by the lack of evidence of the chemical effects of tailings-derived fluids. Previous work has shown that bicarbonate, chloride, and pH are the key indicators of seepage impact (most recently discussed in the 2004 site annual review report, N.A. Water Systems, December 2004). The relative usefulness of these indicator parameters and their threshold concentrations varies among the three hydrostratigraphic units, because of the different intrinsic chemical properties of those units. For example, pH is a useful indicator primarily in Zone 3, which is not addressed by this proposal. Established key indicators of tailings seepage impact for the Southwest Alluvium (Southwest Alluvium Groundwater Geochemistry Report, Church Rock Site, Church Rock, New Mexico, Earth Tech, June 2000) and Zone 1 (Earth Tech, May 2000) are listed in Table 2:

Table 2
Key Indicators of Tailings Seepage Impact

	Southwest Alluvium	Zone 1
bicarbonate	> 1000 mg/L	
chloride		> 50 mg/L

In addition to the indicators listed in Table 2, the determination of possible impact at each well also included judgments based on the location of that well relative to the mapped distribution of the seepage impact through time and the chemical history of the well (see Figures 2 and 8 for the Southwest Alluvium and Figure 48 for Zone 1 in the 2004 site annual review report). Therefore, time series graphs and maps of the indicator parameter concentrations were used to identify well data that could be considered to have background quality by an apparent absence of tailings fluid effects. Concentration-time series charts for bicarbonate, chloride, and combined radium for each of the wells in Tables 1 and 2 are provided in Appendix A. Note that non-detect results are not plotted in the time-series charts.

Wells having samples representative of background water quality are listed in Table 3:

Table 3
Wells Having Samples Representative of Background Water Quality

Southwest Alluvium	Zone 1
029A	619
624 (7/89-10/95)	EPA 2
627	EPA 4 (POC*)
639	EPA 8
642	
644	
645	
EPA 22A	
EPA 25 (7/89 - 10/95)	
EPA 27	
EPA 28 (POC*)	
SBL-01	

Point-of-compliance wells are also included as background data in statistical comparisons.

The determinations of background quality were made according to the criteria described above. Parenthetic date ranges are listed for periods of background quality water at wells later affected by tailings fluid. The list in Table 3 is not exhaustive, and the absence of a well data set does not necessarily indicate that the well has been affected by tailings fluids. Rather, the list is limited to unambiguous background data. Note that Table 3 excludes well GW 4 (now dry), which meets the criteria for background water quality but also has had the highest combined radium concentration ever recorded in the Southwest Alluvium (15.3 pCi/L). Data from GW 4 were omitted to avoid the possibility of skewing the background data distribution with this outlier value.

It should be noted that background and point-of-compliance are not mutually exclusive sample categories. For example, Wells EPA 28 and EPA 4 are compliance wells (Table 1) that have also been identified as having background water quality (Table 3). For the purposes of statistical comparisons made in this report, samples from these two wells were included in both the compliance and background sample populations.

The third category of well samples includes those representative of pre-mining water quality. These samples are limited to Zone 1 Wells 141, 142, and 143. Data from these wells were not included in the statistical analyses for the following reasons:

- The 1997 site annual review report (Ground Water Corrective Action, Annual Review -- 1997, Church Rock Site, Gallup, New Mexico, Rust Environment and Infrastructure, December 1997; p. 418) demonstrated that tailings-impacted water from the Central Cell has not had sufficient time to migrate to the north-northeast to the locations of monitoring Wells 141, 142, and 143. These wells are located along the northern property boundary of Section 36. As explained next, the water quality in these wells is interpreted as pre-mining in age, which is older than the recognized background water (which is post-mining/pre-tailings in age).
- Long-term sulfate concentrations have almost entirely been below 600 mg/L; chloride concentrations have almost entirely been below 25 mg/L; and field pH has almost entirely been above 7.0 standard units. The first two parameter values are significantly lower than those associated with background water quality, and the pH is higher. Combined radium concentrations in Wells 141, 142, and 143 have significantly lower ranges, medians, and $75^{th}/25^{th}$ percentiles compared to background waters (see Figure 1). The historic groundwater quality in these three wells is summarized in the 2004 site annual review report (N.A. Water Systems, December 2004; Appendix C, Table C.1).
- By comparison, Well EPA 2 (background quality, see Table 3) has shown long-term sulfate concentrations that have almost entirely exceeded 1,500 mg/L; chloride concentrations have almost entirely been between 20 and 30 mg/L; field pH has almost entirely been below 7.0; and combined radium has shown sporadic exceedances of 5 pCi/L that we now recognize as being characteristic of background water quality. To the south-southwest, Well EPA 4 (background quality, see Table 3) has shown long-term sulfate exceedances of the site standard (2,125 mg/L); chloride concentrations have almost entirely been between 30 and 50 mg/L; field pH has almost entirely been below 7.0; and combined radium has shown sporadic exceedances of 5 pCi/L. The absence of elevated metals and radionuclides in EPA 2 and EPA 4 indicate that both of these wells represent background water quality (Zone 1 Groundwater Geochemistry Report, Earth Tech, May 2000). Figure 1 shows the similarity in their historic combined radium distributions, which are distinctly different from the long-term distributions in the pre-mining age waters found in Wells 141, 142, and 143.

Summary Statistics and Sample Distributions

Summary statistics for the background and compliance data sets are presented in Table 4. Additional summary statistics for the individual well data sets are in Appendix B. Box and whisker plots of the sample distributions are shown in Figures 1 and 2.

Of particular note from the summary statistics are comparative differences of the compliance data sets and background data sets in the two hydrostratigraphic units. For example, the listed percentiles of sample distributions (see Table 4) indicate that

the compliance data set from the Southwest Alluvium is shifted toward lower concentrations than the background data set. This is particularly evident in the portions of the sample distributions above the 50th percentile (median). Furthermore, a greater percentage of background sample results exceeded the site standard of 5 pCi/L (5.5 percent) than did compliance sample results (3.5 percent).

Exceedances of the site standard were more common in Zone 1 than in the Southwest Alluvium. This was true of the Zone 1 background data set, and even more so of the compliance data set. Twenty seven percent of background samples and 41 percent of compliance samples exceeded the site standard in Zone 1.

In Zone 1, the compliance data set is shifted toward higher concentrations than the respective background data set. The degrees of difference between the compliance and background data sets are evident over at least the upper 75 percent of the distributions. For example, 17 percent of the compliance radium results exceeded the upper 5 percent of background results (95th percentile) in Zone 1. Seven percent of compliance results exceeded the maximum background result in Zone 1.

Sample distributions of combined radium in Zone 1 and the Southwest Alluvium are illustrated by box and whisker plots in Figures 1 and 2. The plots indicate that sample distributions of radium results are skewed, having much longer tails at the higher concentration ranges. The distributions are also censored at the low range, because of the numerous non-detect results. These observations apply to both background and compliance well sample sets. Note that non-detect results are plotted at one-half of the detection limit in Figures 1 and 2 and in all of the statistical analyses presented in this report (see following section).

Table 4
Summary Statistics for Combined Radium

	Southwest Alluvium	Zone 1
Pooled		
Total Measurements	900	546
Total Non-Detects	283 (31.4%)	5 (0.9%)
Pooled Mean	1.66	5.01
Pooled Std Dev	1.55	4.56
Compliance		
Measurements	543	319
Non-Detects	194 (36.2%)	3 (0.94%)
Mean	1.59	5.8
Std Dev	1.4	5.4
Minimum	0.2	0.3
25%tile	0.3	2.2
Median	0.5	4.5
75%tile	1.7	7.2
Maximum	8.7	33.4
90%tile	3.7	12.3
95%tile	4.5	16.6
percent >5 pCi/L	3.5	41.4
percent>background 95th	2.4	17
percent>background max	0.0	7
Background		
Measurements	357	227
Non-Detects	73 (26.1%)	2 (0.09%)
Mean	1.78	3.9
Std Dev	1.74	2.7
Minimum	0.2	0.2
25%tile	0.3	1.7
Median	0.7	3.5
75%tile	2.1	5.1
Maximum	12	14.8
90%tile	4.1	6.9
95%tile	5.2	9.4
percent >5 pCi/L	5.5	26

Original Data (Not Transformed)
Non-Detect Results Replaced with 1/2 Detection Limit
Concentration units pCi/L

Tests of Normality

Two tests of normality were made for radium results from the background and compliance wells. The methods are probability plots and the Shapiro-Francia analysis of variance test for normality. Both tests employ algorithms described by EPA guidance for RCRA (Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Addendum to Interim Final Guidance, EPA, 1992). The Shapiro-Francia analysis is the preferred method for sample sets exceeding 50 samples. The test results are presented in Appendix C.

The normality tests indicate a failure of the assumption of normal probability at a 95 percent confidence level for combined radium in both the background and the compliance well data sets for both hydrostratigraphic units. An examination of the probability plots (Appendix C) shows that deviations from a normal distribution are evident at lower concentrations, particularly near the detection limit. Plotting non-detect results at one half the detection limit extended the linear portions of the probability curves somewhat into the lower concentration ranges. Log transformations (base 2 and base 10) tended to reduce the linearity of the probability curves at higher concentrations. Therefore, no transformations of the data, except for converting non-detect results to one-half the detection limit, were used in the statistical analyses presented in this report. The conversion of non-detect results to one-half of the detection limit is also consistent with EPA guidance for RCRA (EPA, 1992).

In the case of combined radium, detection limits were based on the results for the two constituent isotopes, radium 226 and radium 228. In those cases when only one of the two isotopes was detected, the reported concentration of combined radium was taken to equal the concentration of the detected isotope and was not modified. When neither isotope was detected, the concentration value for combined radium was taken to be one-half of the sum of the detection limits for the two isotopes.

Nonparametric methods were selected for the remainder of the analyses presented here, because of the failure of the sample distributions to meet tests of normality and because of the high percentages of non-detect results in the Southwest Alluvium background and compliance well sample sets.

Comparisons of Compliance Sample Sets to Background

The Kruskal-Wallis test, a non-parametric analysis of variance, was selected to compare the compliance well data set as a group, and individually by well, to the background data set for combined radium. The Kruskal-Wallis test is recommended for such comparisons by EPA guidance in cases where either the number of non-detect results is between 15 and 90 percent or the sample distributions do not follow a normal distribution (EPA, 1992).

The results of the Kruskal-Wallis tests for the Southwest Alluvium and Zone 1 are provided in Appendix D. The test compares the rank mean of the compliance well sample set to that of the background sample set. The test results indicate that as a group, the compliance wells have statistically significant differences from the background data set in each of the hydrostratigraphic units. The compliance well data sets are significantly lower than background in the Southwest Alluvium and significantly higher than background in Zone 1.

The tests also compare rank means of the compliance well sample sets, individually by well, to that of the background sample set. Differences are compared first to critical values for the 1 percent error level recommended by the EPA and then at a group-wise 5 percent error level that is less likely to produce false positives and is more statistically accurate. Both tests gave similar results.

For the Southwest Alluvium, one compliance well (632) was found to have a statistically higher rank mean than the background data set. One other compliance well (EPA 28) had a higher rank mean than the background data set, but this difference was determined not to be statistically significant. It should also be noted that EPA 28 has been determined to have background water quality (see Table 3).

The group-wise comparison for Zone 1 indicates a statistically significant elevation of the compliance well results over the background data. The individual well comparisons indicate only one Zone 1 compliance well sample data set, 604, was significantly elevated relative to the background data.

Comparison of Combined Radium in Compliance Wells to the Site Standard

The Two-Sample Test of Proportions was selected to compare compliance well results for combined radium to the site standard (5 pCi/L). This test is a non-parametric test provided in the U.S. Navy 1999 Guidance Document (U.S. Navy, Handbook for Statistical Analysis of Environmental Background Data, prepared by SWDIV and EFA West of Naval Facilities Engineering Command, July 1999) as a test to determine whether compliance-location observations are statistically elevated when compared to background and to a compliance limit such as a site-specific standard. The test is suitable for non-normally distributed data and for populations with a significant number of non-detects. Results of the Two-Sample Test of Proportions are provided in Appendix E.

Southwest Alluvium

In the Southwest Alluvium, the proportion of the compliance well data set that exceeded the site standard is not statistically greater than the proportion of background sample results that exceeded the site standard. Even in lieu of a statistical test, this result is evident from the fact that the percentage of background

results that have exceeded the site standard is 5.5 percent, while that of the compliance well samples is only 3.5 percent. The Two-Sample Test of Proportions is one-sided. Therefore, the question of whether the proportion of background samples exceeding the standard is significantly higher is not addressed. If the Two-Sample Test of Proportions is posed to answer the question of whether the proportion of background samples exceeding the site standard in the Southwest Alluvium is significantly greater than the proportion of compliance samples, the answer is yes at a 95 percent confidence level. This follows from the fact that the site standard falls at a lower percentile in the distribution of background sample results than it does in the distribution of compliance well sample results.

Zone 1

As might be expected from the summary statistics presented above, the results of the Two-Sample Test of Proportions differ in Zone 1 from those in the Southwest Alluvium. In Zone 1, the proportion of compliance well data that exceeded the site standard was found to be significantly greater than the proportion of background data that exceeded the site standard.

United Nuclear Corporation
Radium Technical Analysis Report
Section 3
Discussion

In the final section of this report, the recommendation is made that the current method of determining combined radium exceedances should be replaced by more valid statistical methods: the Two-Sample Test of Proportions and the Kruskal-Wallis test. Therefore, it is worthwhile to examine the application of these tests to the usual compliance sample data sets collected quarterly from the Southwest Alluvium and Zone 1. Example applications of these tests to recent quarterly compliance data from the Southwest Alluvium and Zone 1 are presented below.

Southwest Alluvium

Example applications of the Kruskal-Wallis test and the Two-Sample Test of Proportions to the four quarterly compliance sample sets from 2004 are provided in Appendix F. The results are generally consistent with those obtained from the pooled historical compliance data sets. In each case, the Two-Sample Test of Proportions indicated that the proportion of site standard exceedances in the compliance data sets was not significantly greater than in the background data set. Only two of the 2004 compliance sample sets had a combined radium result higher than the site standard (Well 632 in the third and fourth quarters).

A trial of the Two-Sample Test of Proportions was made using several historic sample sets having differing numbers of individual compliance sample results for combined radium in excess of the site standard. (These results are not shown in Appendix F.) Most sample sets have no compliance sample results in excess of the standard. Next most numerous are those having one sample exceedance, such as those of October 2004 and July 2004. Curiously, no sample sets since July 1989 have had two compliance well sample exceedances, while three sets (January 1993, January 1994, and July 1994) had three exceedances. A fictitious set with two exceedances was fabricated and tested. Note that the test depends on relative proportions of sample results greater than the standard and in no other respect is dependent on the actual sample values. Therefore, the results of the trials are applicable to future quarterly sample sets as long as the compliance sample size remains seven and the background data set is not changed.

The trial tests indicate that if three of the seven compliance sample results exceed the site standard, then the exceedances are to be deemed statistically significant at a 95 percent confidence level. As indicated, this occurred in three of the 61 quarterly events between July 1989 and October 2004.

The example applications of the Kruskal-Wallis test to 2004 quarterly data differed from the test of the pooled historical compliance data by not discerning a significant difference between compliance and background data sets. This difference is interpreted to be a consequence of sensitivity loss due to the relatively small compliance data sets (seven samples). Four samples is the recommended minimum number of compliance samples for the Kruskal-Wallis test. This is also the reason why individual well comparisons to background do not appear in the quarterly comparisons provided in Appendix F. To overcome this limitation, a fifth application of the Kruskal-Wallis test was made using pooled compliance data from all four quarters. This test discerned a significant difference between the pooled 2004 compliance data and the background data set (because of significantly greater concentrations of combined radium in the background data set). With the exception of Well 632, all of the compliance well data sets were found to have rank means lower than the background data set (see Appendix F). While the mean of the compliance data from Well 632 was higher than that of the background, this difference was not found to be statistically significant.

Zone 1

Unlike the case in the Southwest Alluvium, it is evident that combined radium in Zone 1 is significantly elevated (at a 95 percent confidence level) in the compliance well data sets relative to background water quality. This is the case whether the comparison is made relative to an indicator of central tendency, such as the rank mean (Kruskal-Wallis test), or to the site standard. As discussed earlier in this report, the relative elevation of the compliance well data sets also applies at the upper ends of the sample distributions. For example, the maximum background sample value was exceeded by 7 percent of compliance sample results in Zone 1 (see Table 4).

While the compliance well combined-radium data are elevated relative to background in Zone 1, it is also the case that 27 percent of the background sample values exceeded the site standard (see Table 4). Therefore, the site standard falls at even lower percentiles in the background sample distribution in Zone 1 than it does in the Southwest Alluvium. Consequently, it is important to recognize that comparison of individual compliance well sample results to the site standard is a poor means of testing elevation relative to background water quality.

Example applications of the Kruskal-Wallis test and the Two-Sample Test of Proportions to the four quarterly compliance sample sets from 2004 are provided in Appendix F. The example tests were made in the same manner as explained above for the Southwest Alluvium compliance data. One difference is that six, rather than four, pooled quarters of compliance data were needed to run individual well comparisons to background using the Kruskal-Wallis test. This requirement arises from the smaller compliance sample size in Zone 1 (five rather than seven samples).

However, the quarterly compliance samples are of sufficient number to run group-wise comparisons with both statistical tests.

Tests made with the Two-Sample Test of Proportions indicated a less than significant proportion of site standard exceedances by compliance samples in each quarter. This differs from the result of the same test run with the pooled historical compliance data, which did discern a significant difference. The primary reason for this difference is that the numbers of site standard exceedances in the compliance data sets have significantly reduced over time since July 1989. Only 6 of 30 (20 percent) sample results in the pooled six quarters of compliance data exceeded the site standard (Two-Sample Test of Proportions using Third Quarter 2003 through Fourth Quarter 2004 compliance data, Appendix F). This compares with 41 percent of samples in the pooled historic compliance data set (since July 1989) and 26 percent of samples in the background data set (see Table 4).

As explained above, with the background data set and the size of the compliance data set fixed, the outcome of the Two-Sample Test of Proportions is dependent only on the proportion of compliance samples greater than the site standard. Trials of the Two-Sample Test of Proportions made with Zone 1 compliance datasets having differing numbers of site standard exceedances indicate that that a significant difference from background will be determined if three or more of the five compliance samples exceed the site standard. This has occurred in 20 of the 62 quarters of data (32 percent) collected in Zone 1 since July 1989. However, after the first quarter of 1996, the frequency has reduced to 6 of 35 quarters (17 percent), and after the First Quarter of 2002, the frequency has been 0 of 11 quarters (0 percent). The following table of frequencies of site standard exceedances illustrates the relative decline of radium concentrations in the individual compliance wells:

Table 5
Percentages of Zone 1 Compliance Well Samples Exceeding the Site Standard for Combined Radium

Period	604	614	EPA 04	EPA 05	EPA 07
3rd Qtr 89-1st Qtr 96	100%	33%	33%	15%	85%
2nd Qtr 96 - 1st Qtr 02	96%	25%	38%	8%	8%
2nd Qtr 02 - 4th Qtr 04	82%	0%	18%	0%	9%

This suggests two important conclusions: First, that groundwater quality improved during active remediation and has continued to improve since the termination of active pumping in 1999. Second, it must be realized that the improvements can only continue up to the point where background water quality characteristics are attained. With the exception of Well 604, this appears to have happened.

United Nuclear Corporation
Radium Technical Analysis Report
Section 4
Recommended Change to Method of Determining Exceedances of the Site Standard for Combined Radium in the Southwest Alluvium and Zone 1

The statistical analyses do not provide a clear rationale for changing the current site standard for combined radium, which is the same as the federal MCL for drinking water. (A possible approach to this might be the essentially non-statistical argument that the current site standard should be replaced by the maximum combined radium result from the background sample sets from each hydrostratigraphic unit.)

The Two-Sample Test of Proportions is proposed as a replacement for the current method of comparing combined radium concentrations in compliance well samples to the site standard. Unlike the current method, this proposed alternative would account for the fact that the site standard lies well within the background concentration ranges of combined radium in the Southwest Alluvium and Zone 1, and that the site standard occupies very different positions in those background sample distributions. As the Two-Sample Test of Proportions is a group-wise comparison, the Kruskal-Wallis method is proposed to be used concurrently to compare combined radium results from individual compliance wells to background water. The Kruskal-Wallis method requires a minimum number of samples per well to make individual well comparisons. These requirements are a minimum of four samples for the seven Southwest Alluvium compliance wells and six samples for the five Zone 1 compliance wells. Therefore, applications of the Kruskal-Wallis test would employ lumped compliance well data from the preceding four quarters in the Southwest Alluvium and from the preceding six quarters in Zone 1.

To reiterate, the Two-Sample Test of Proportions will be used quarterly to test whether the proportion of exceedances of the site standard in the compliance well samples, *as a group*, is significant relative to exceedances in background water. The Kruskal-Wallis method will be used quarterly to test whether combined radium concentrations from individual compliance wells are significantly elevated relative to background water. The Two-Sample Test of Proportions will be applied to compliance data collected from the most recent quarter, while the Kruskal-Wallis test will be applied to compliance data lumped from the most recent four quarters in the Southwest Alluvium and the most recent six quarters in Zone 1.

Application of this proposed alternative incorporates the fact that the recognized background water quality in both hydrostratigraphic units has historically demonstrated sporadic "spikes" above 5 pCi/L that are unrelated to tailings seepage impact (in this sense, such historic exceedances are spurious). At the same time,

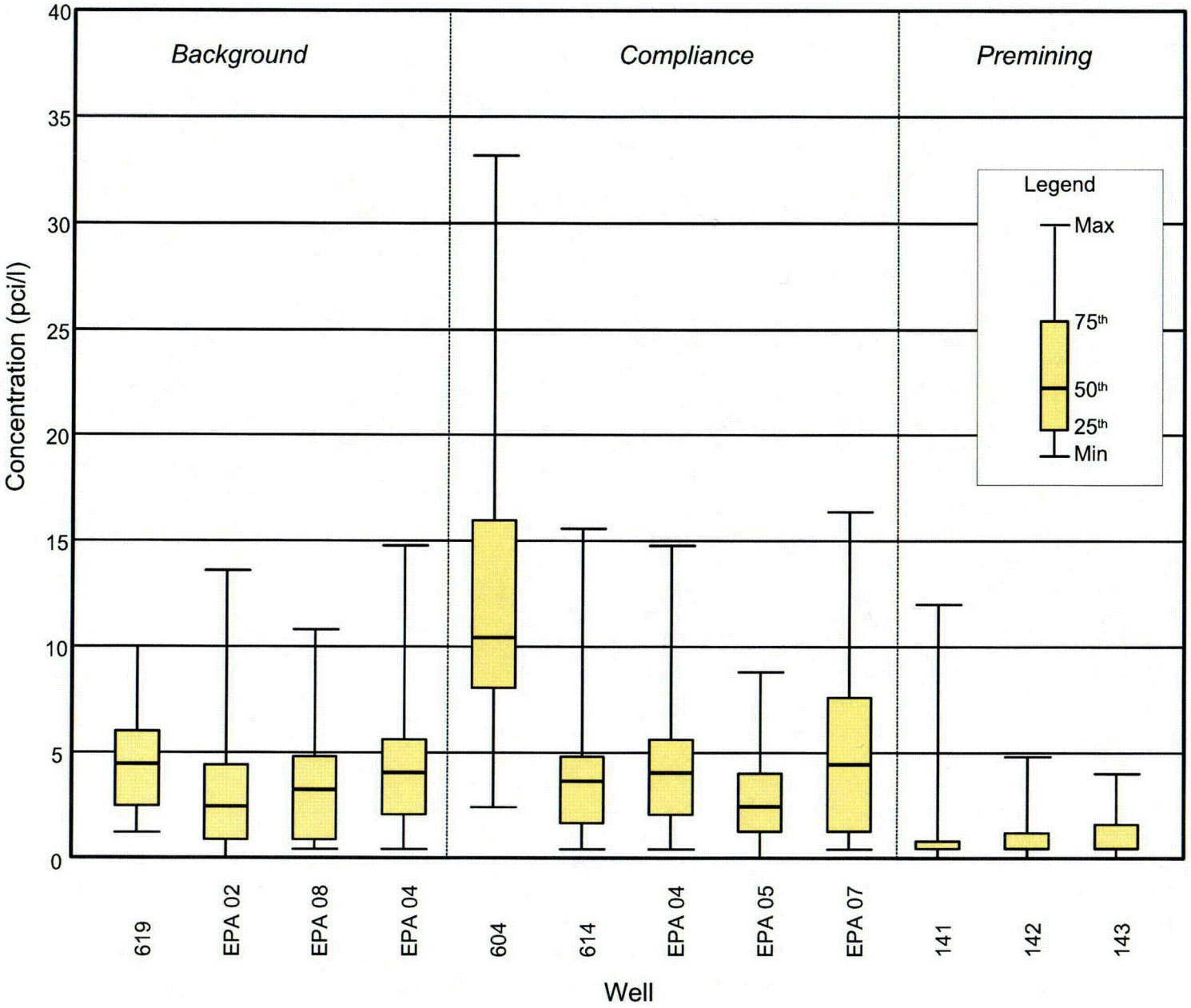
this alternative testing method allows for the statistical determination of "valid" exceedances of the site standard (i.e., those related to seepage impact), while incorporating the statistically delineated differences in combined radium background water quality between the Southwest Alluvium and Zone 1.

NA WATERSYSTEMS

Figures

VEOLIA Water

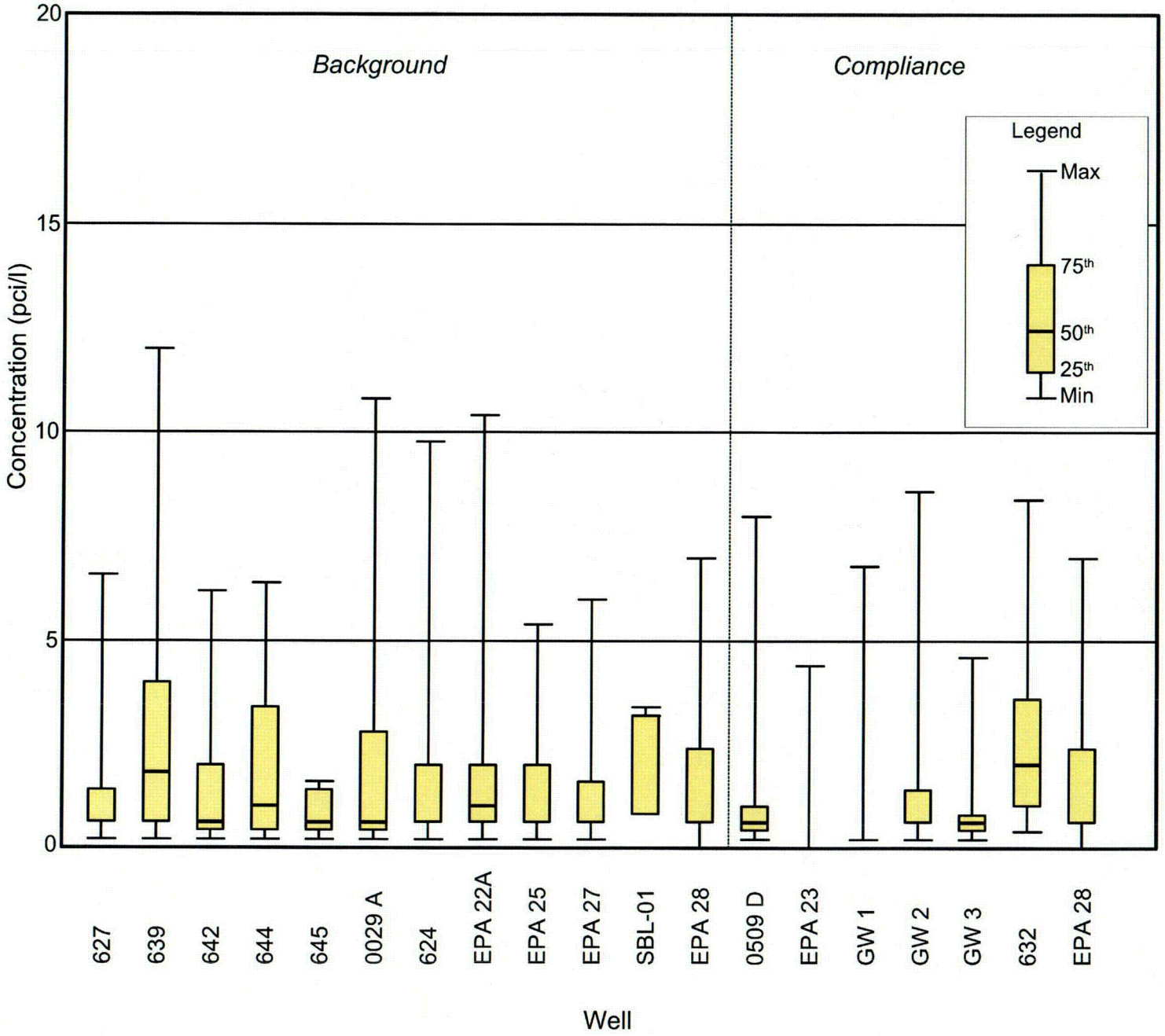
FIGURE 1
Box and whisker plot of combined radium in samples from Zone 1 Wells



col

FIGURE 2

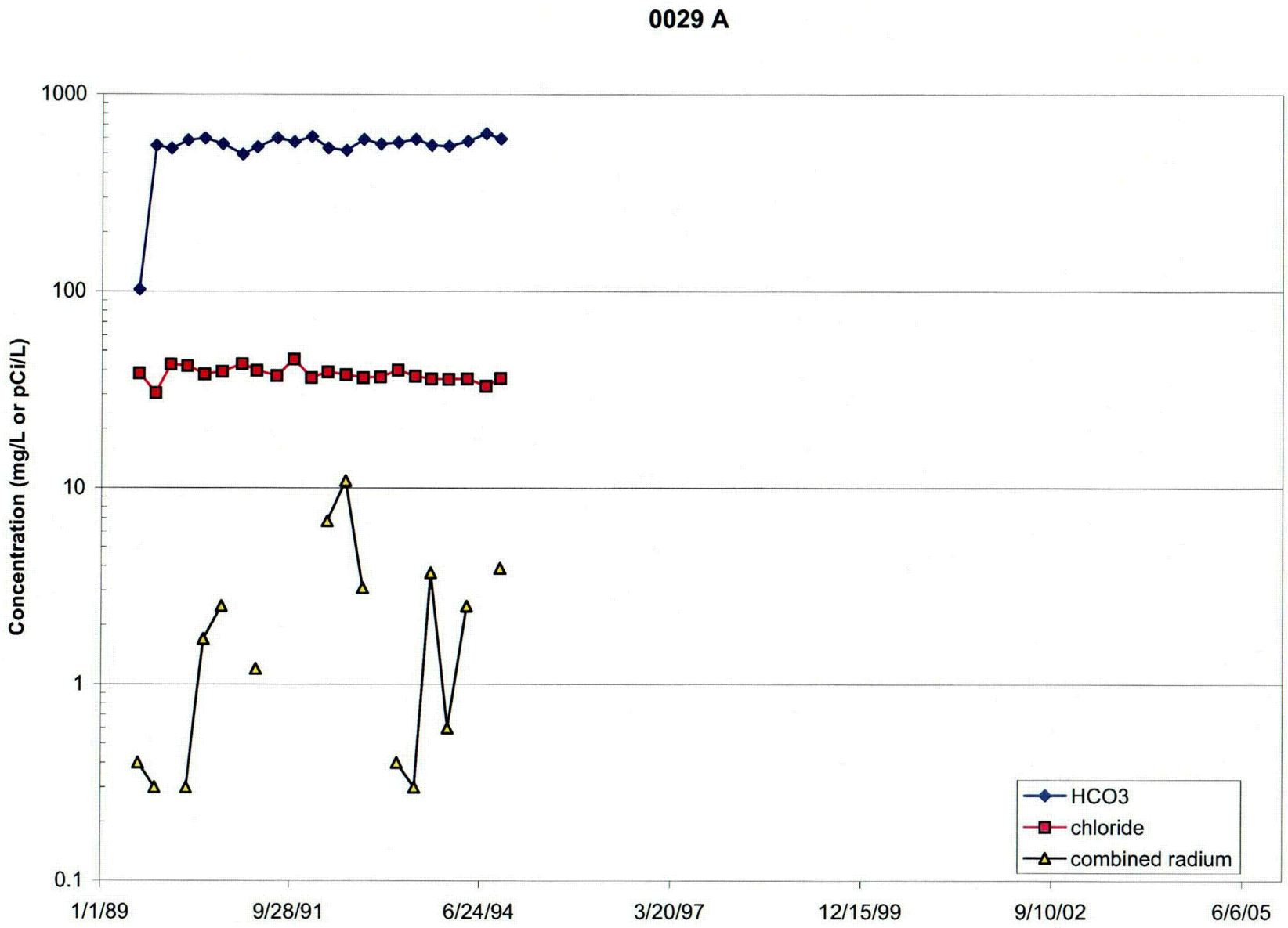
Box and whisker plot of combined radium in samples from Southwest Alluvium Wells



C02

Appendix A
Part 1

Time Series of Bicarbonate, Chloride, and Combined Radium for Wells in the Southwest Alluvium (July 1989 – October 2004)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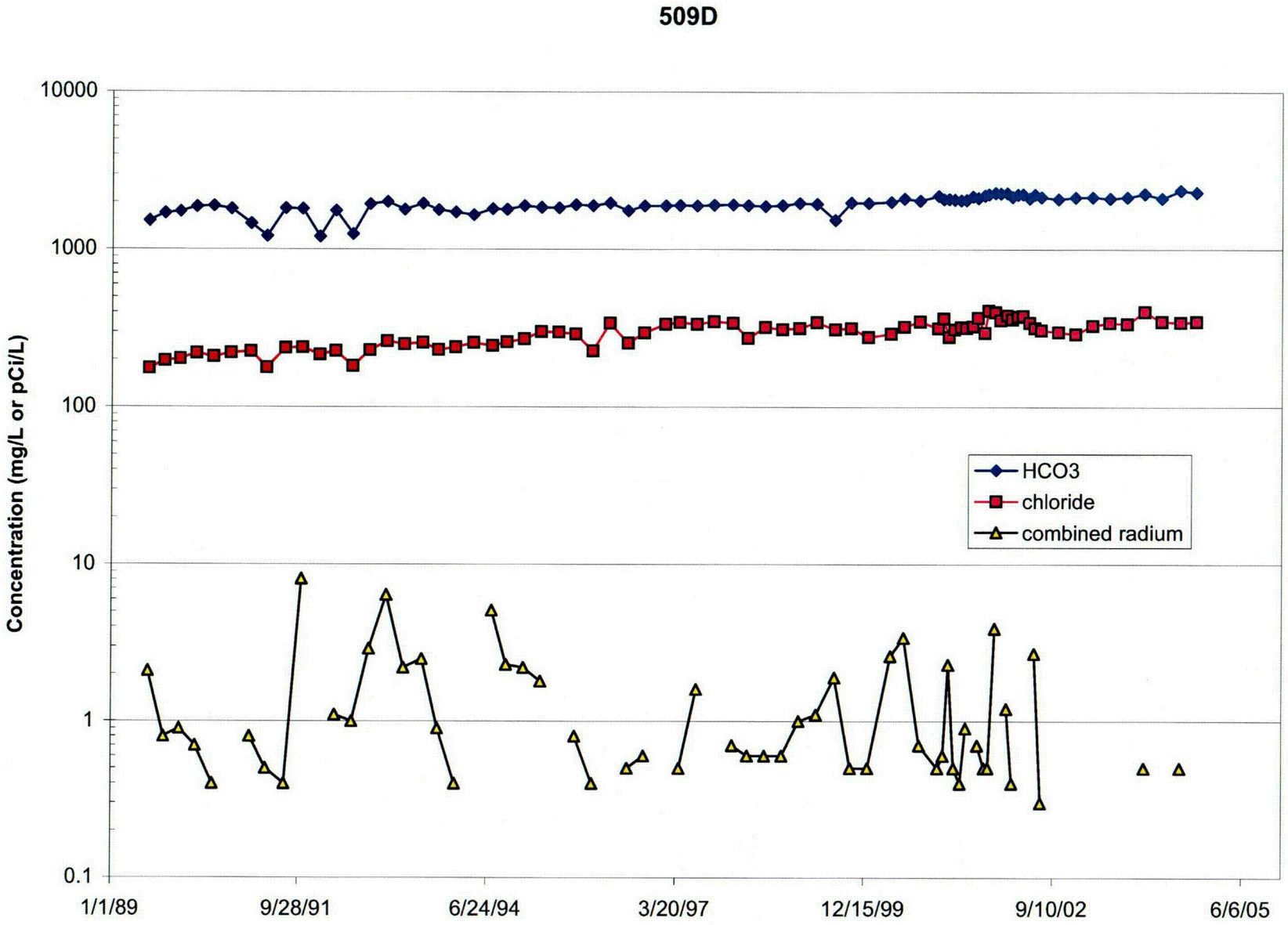
1000
100
10
1
0.1
Concentration (mg/L or pCi/L)
1/1/89
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

C03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chloride
combined radium
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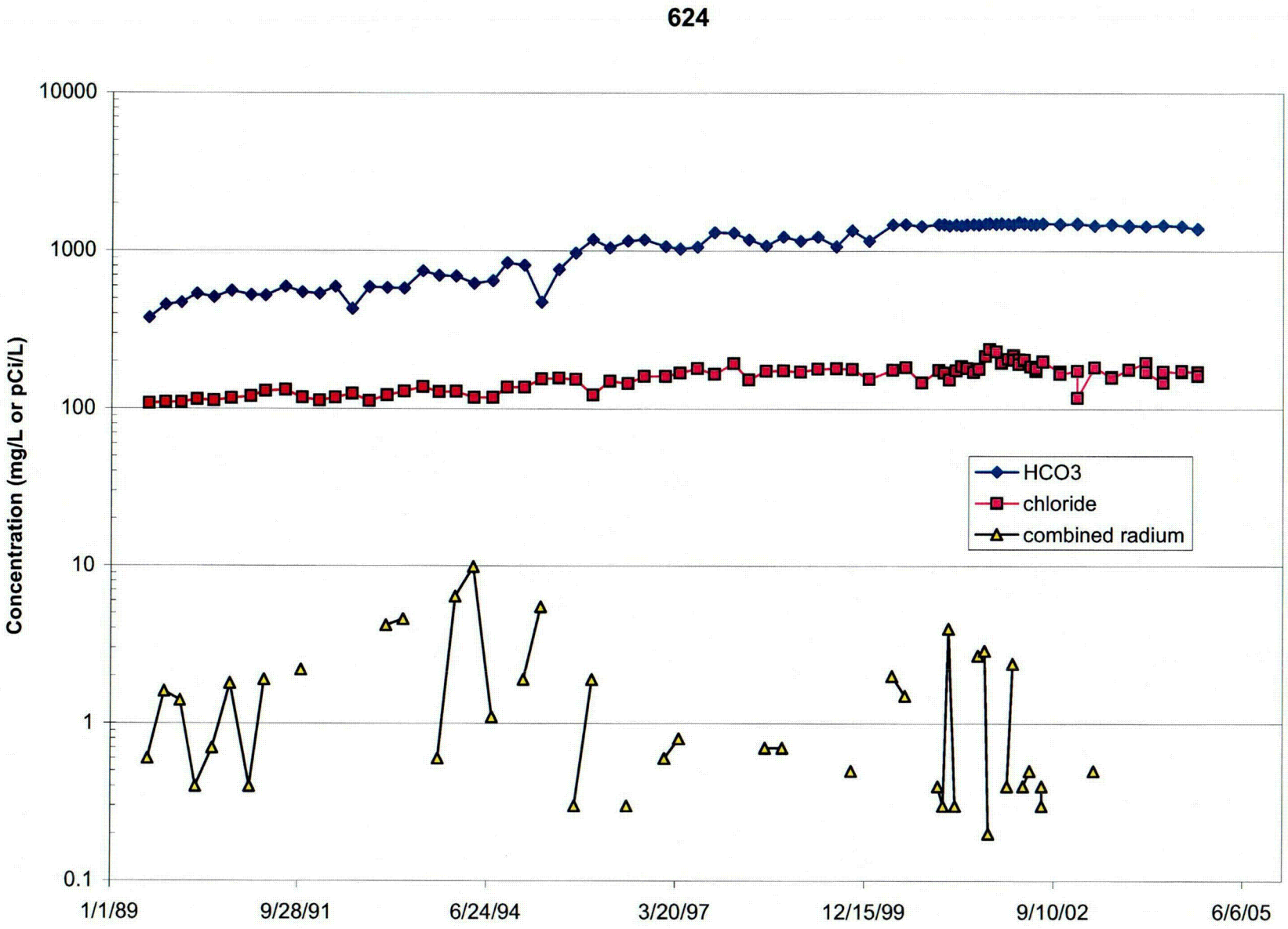
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05

C04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Concentration (mg/L or pCi/L)
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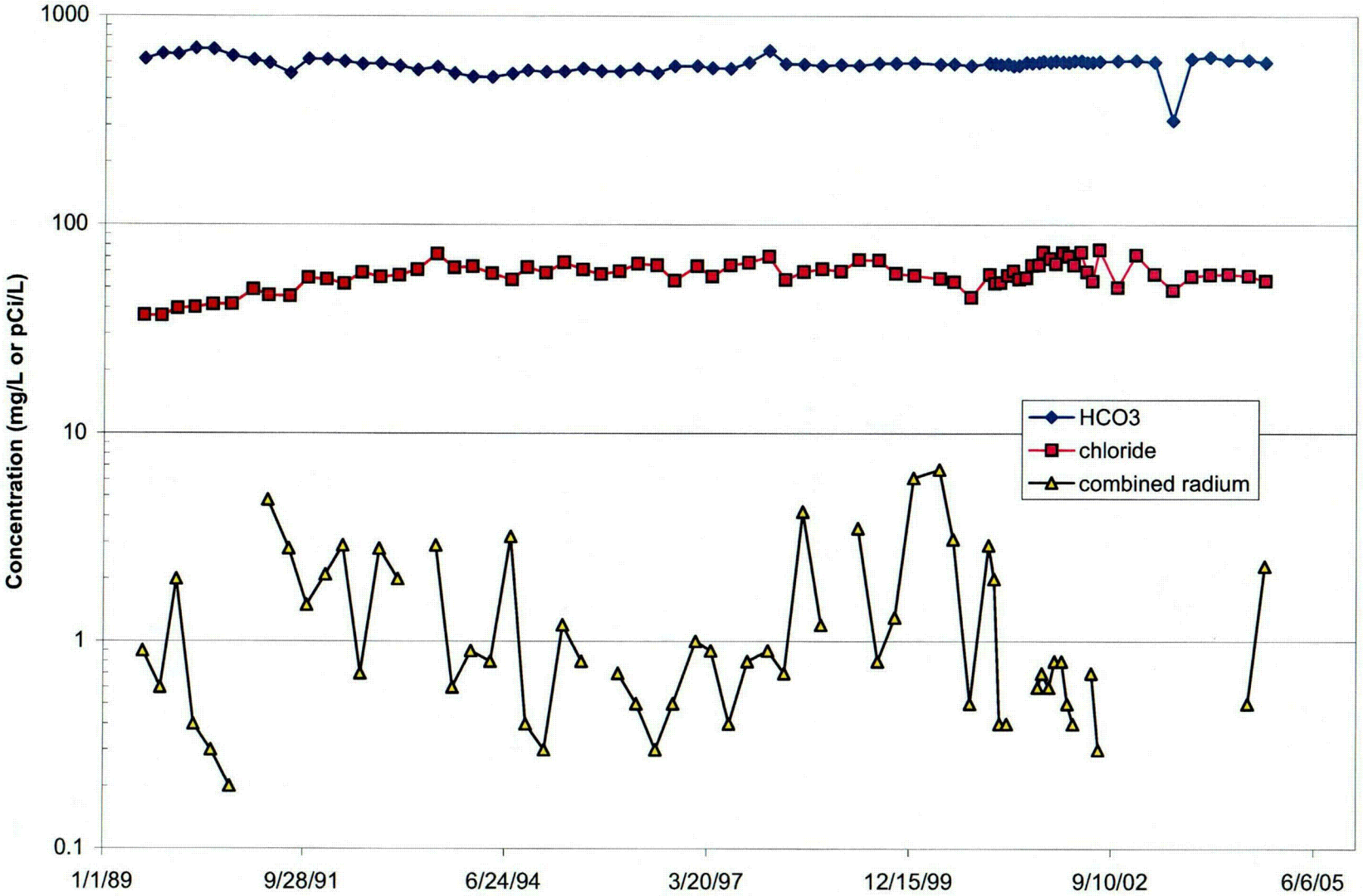
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

C05

627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1
0.1
Concentration (mg/L or pCi/L)
1/1/89
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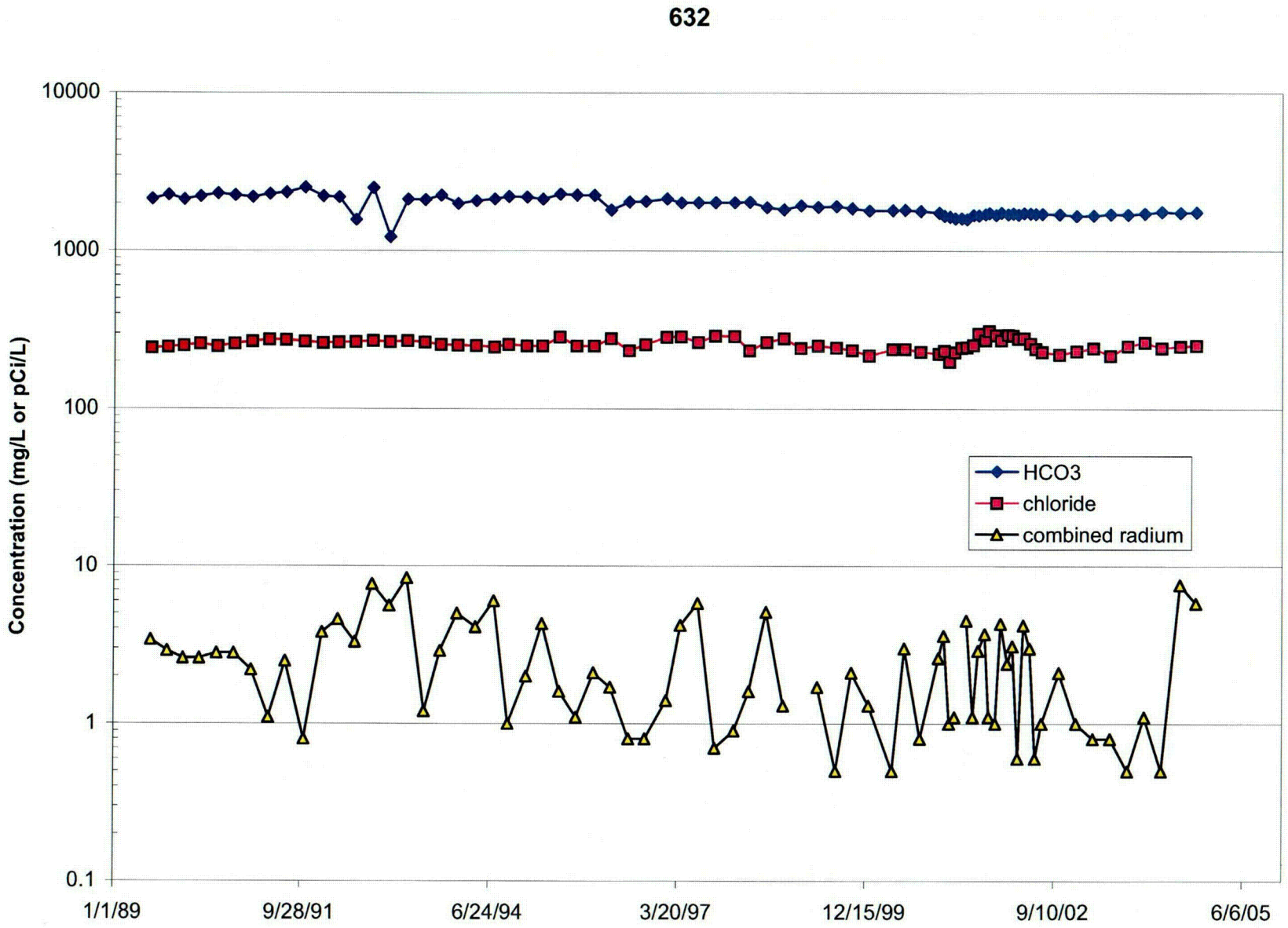
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

C06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9/28/91
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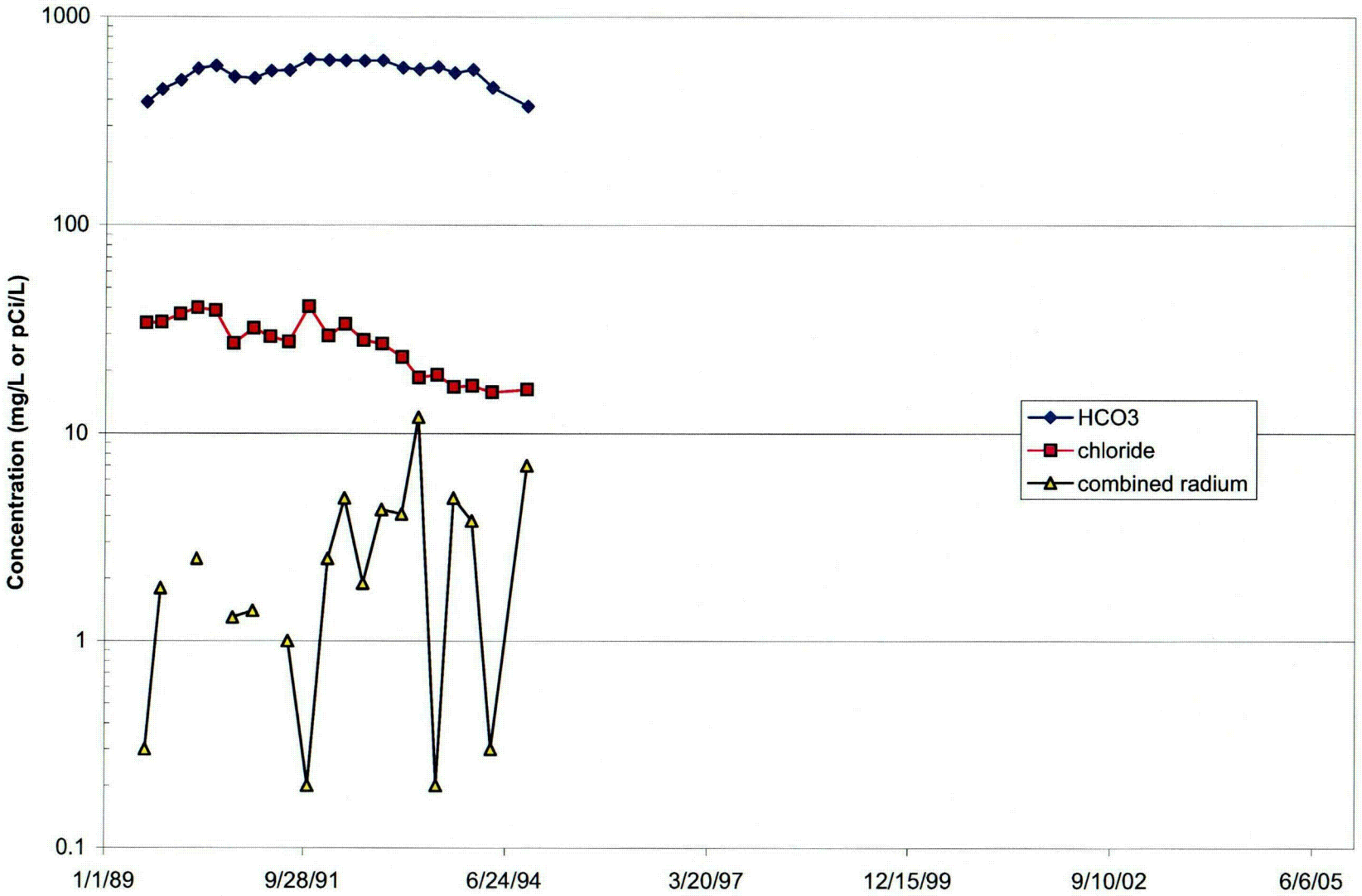
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

C07

639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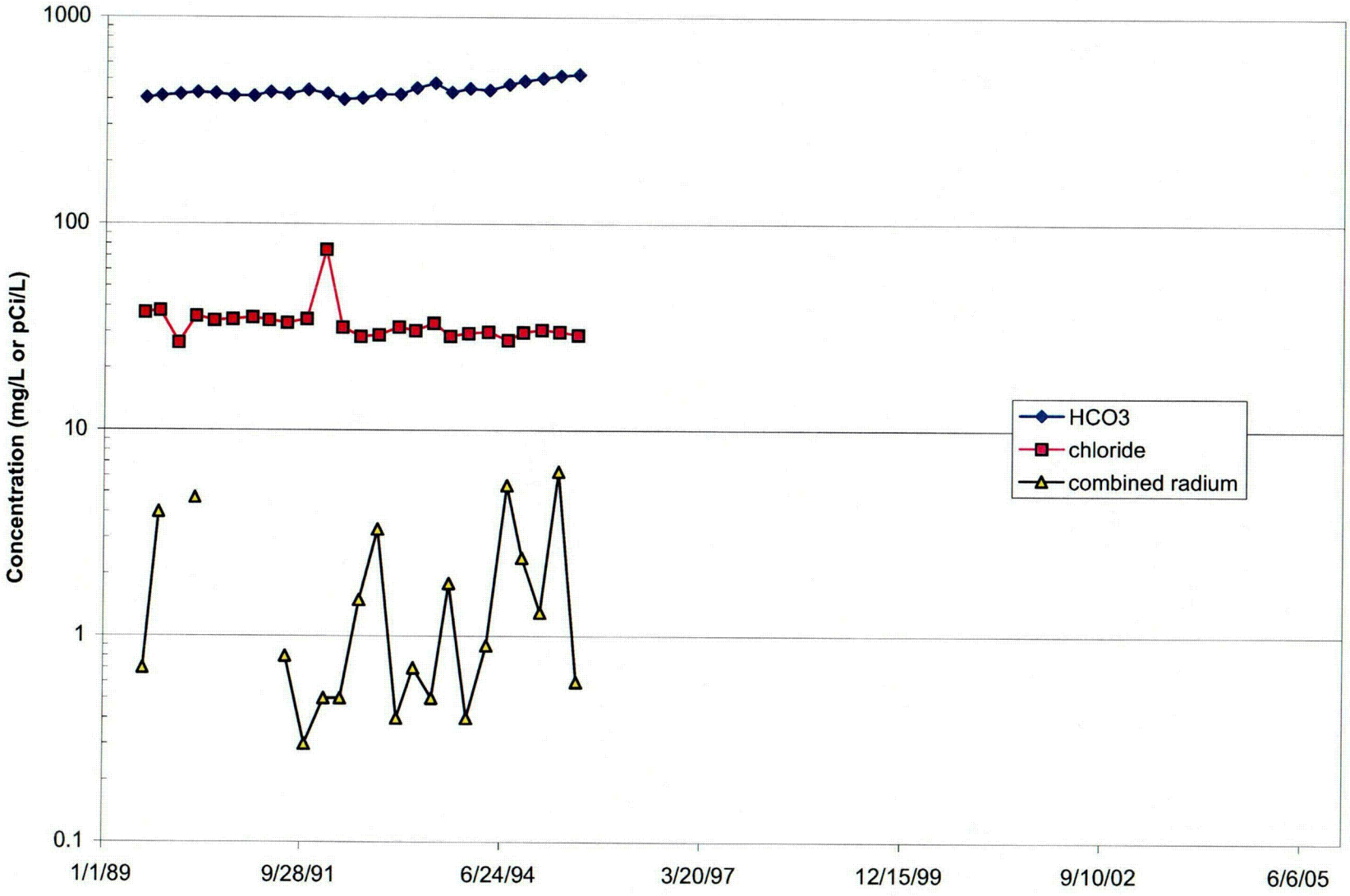
1
0.1
Concentration (mg/L or pCi/L)
1/1/89
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

C08

642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Concentration (mg/L or pCi/L)
1/1/89
9/28/91
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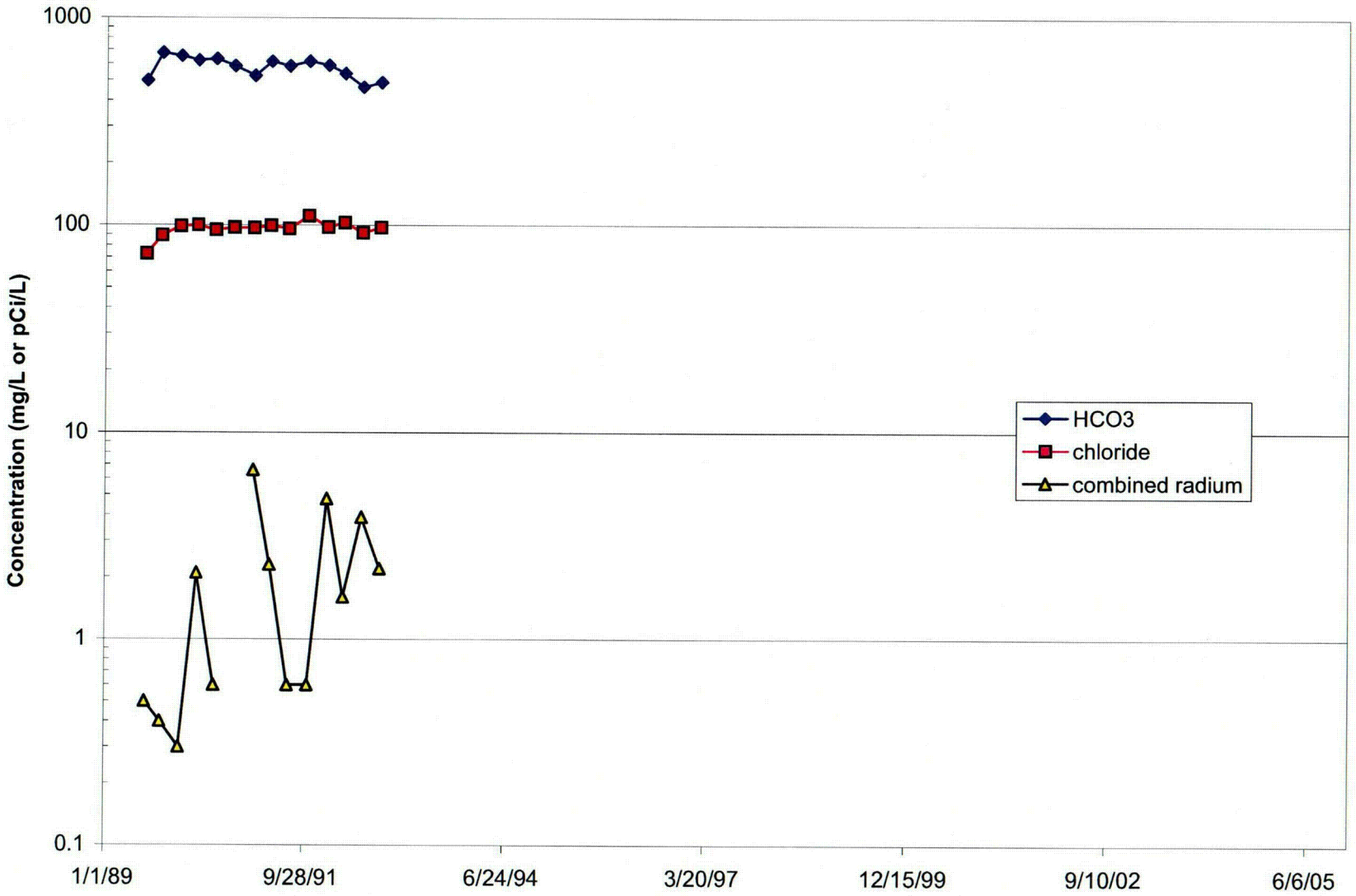
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

C09

644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0.1
Concentration (mg/L or pCi/L)
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9/28/91
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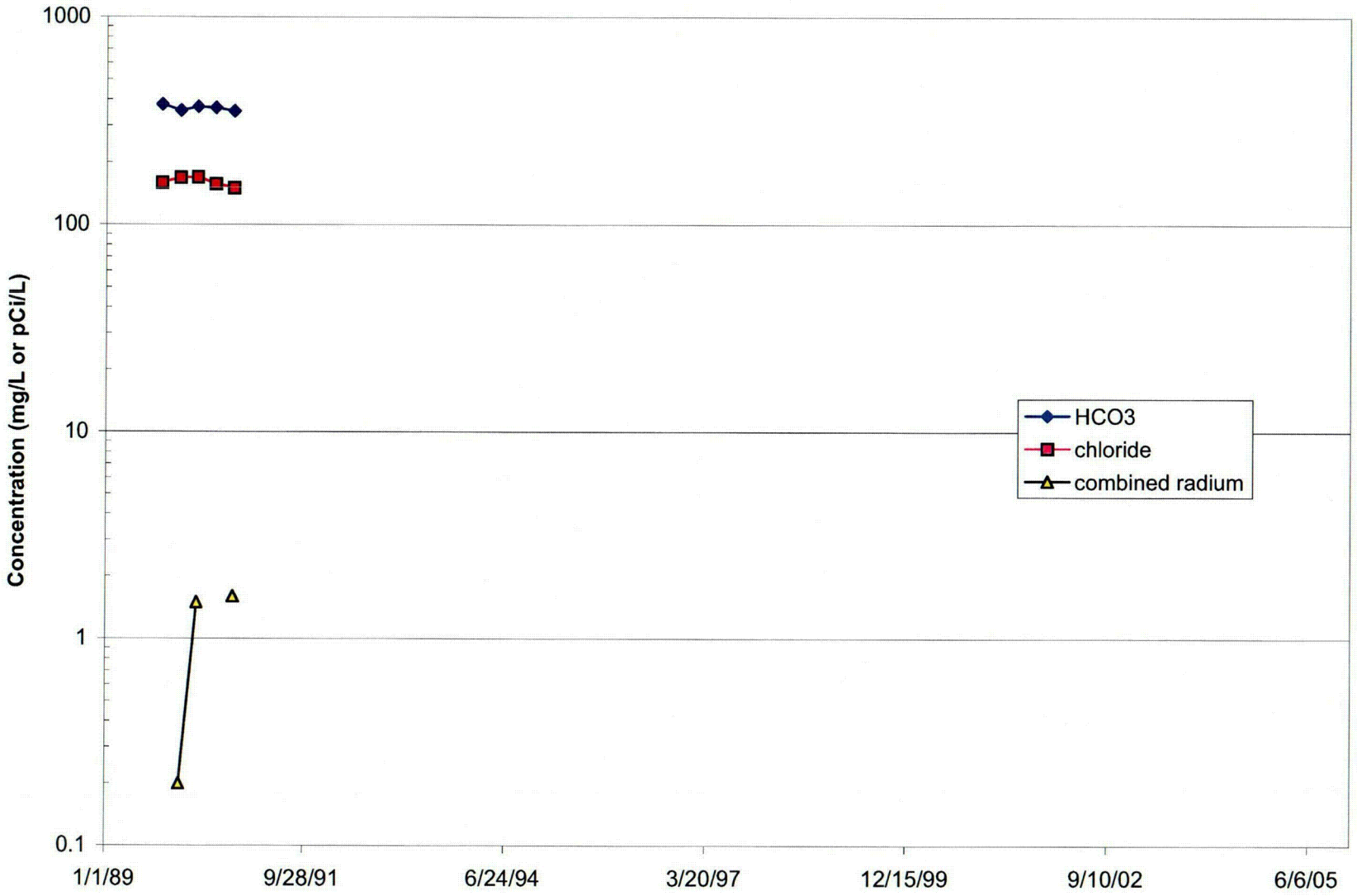
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

C10

645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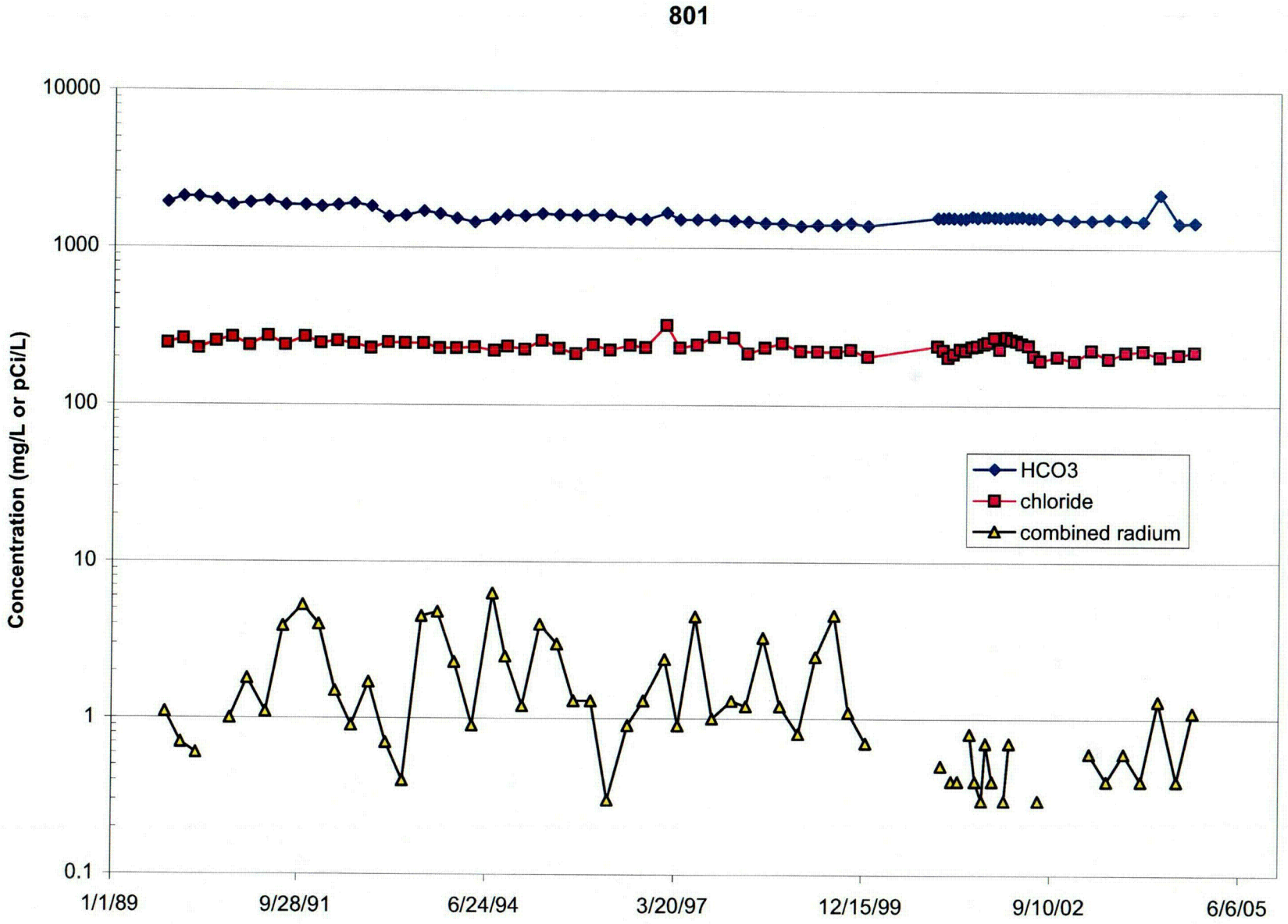
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

C11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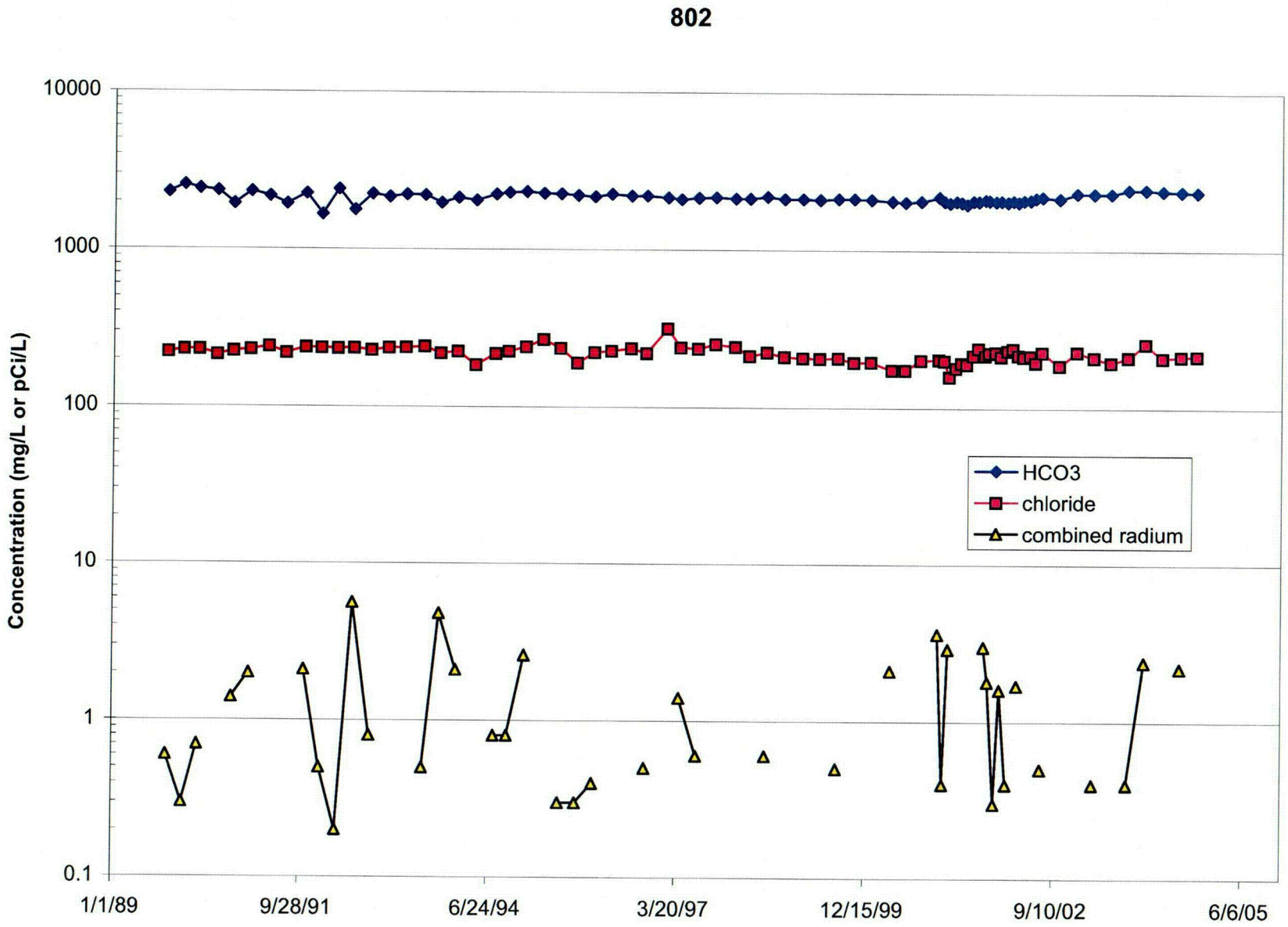
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

C12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10
1
0.1
Concentration (mg/L or pCi/L)
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chloride
combined radium
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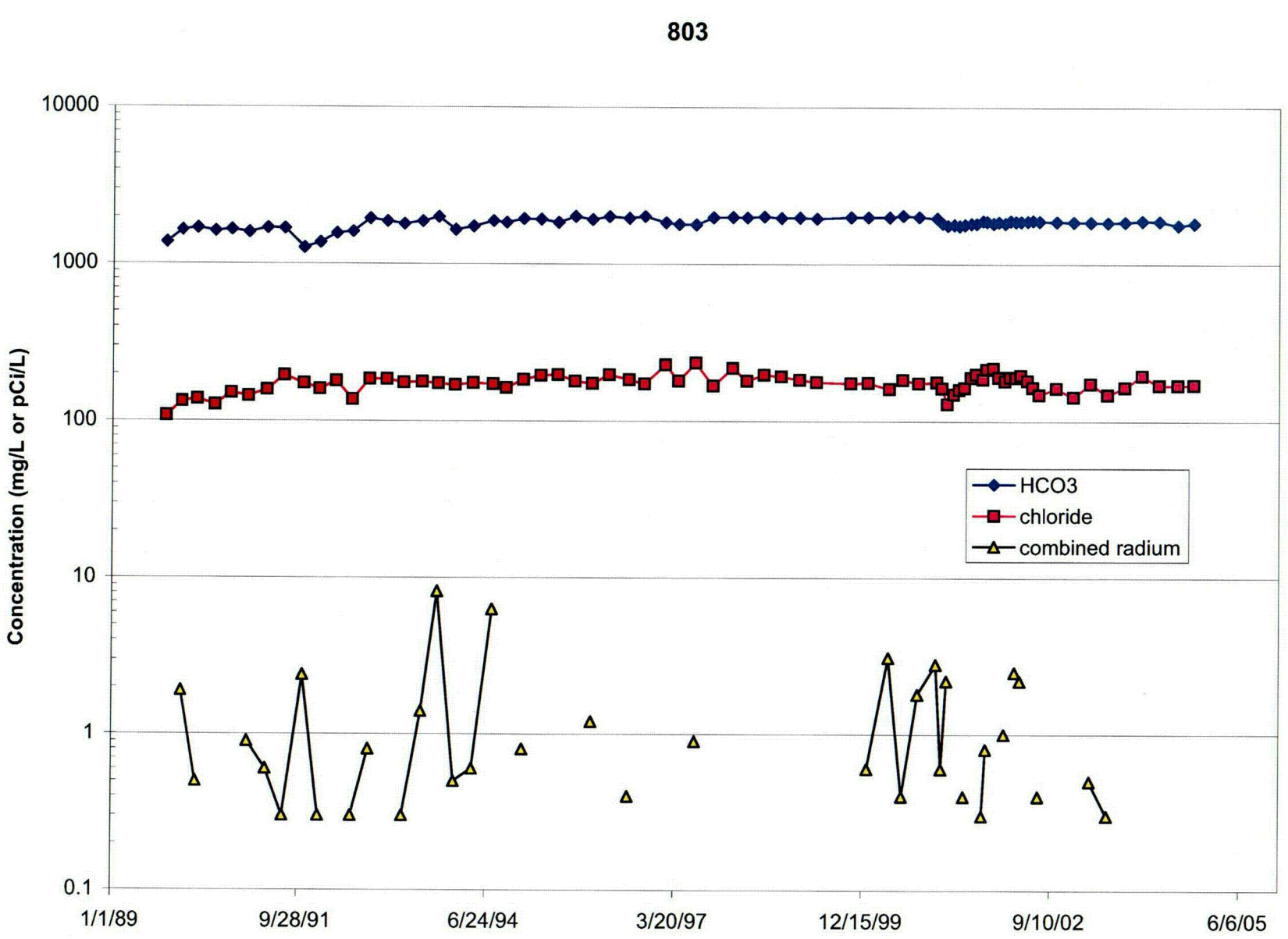
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05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0.1
Concentration (mg/L or pCi/L)
HCO3
chloride
combined radium
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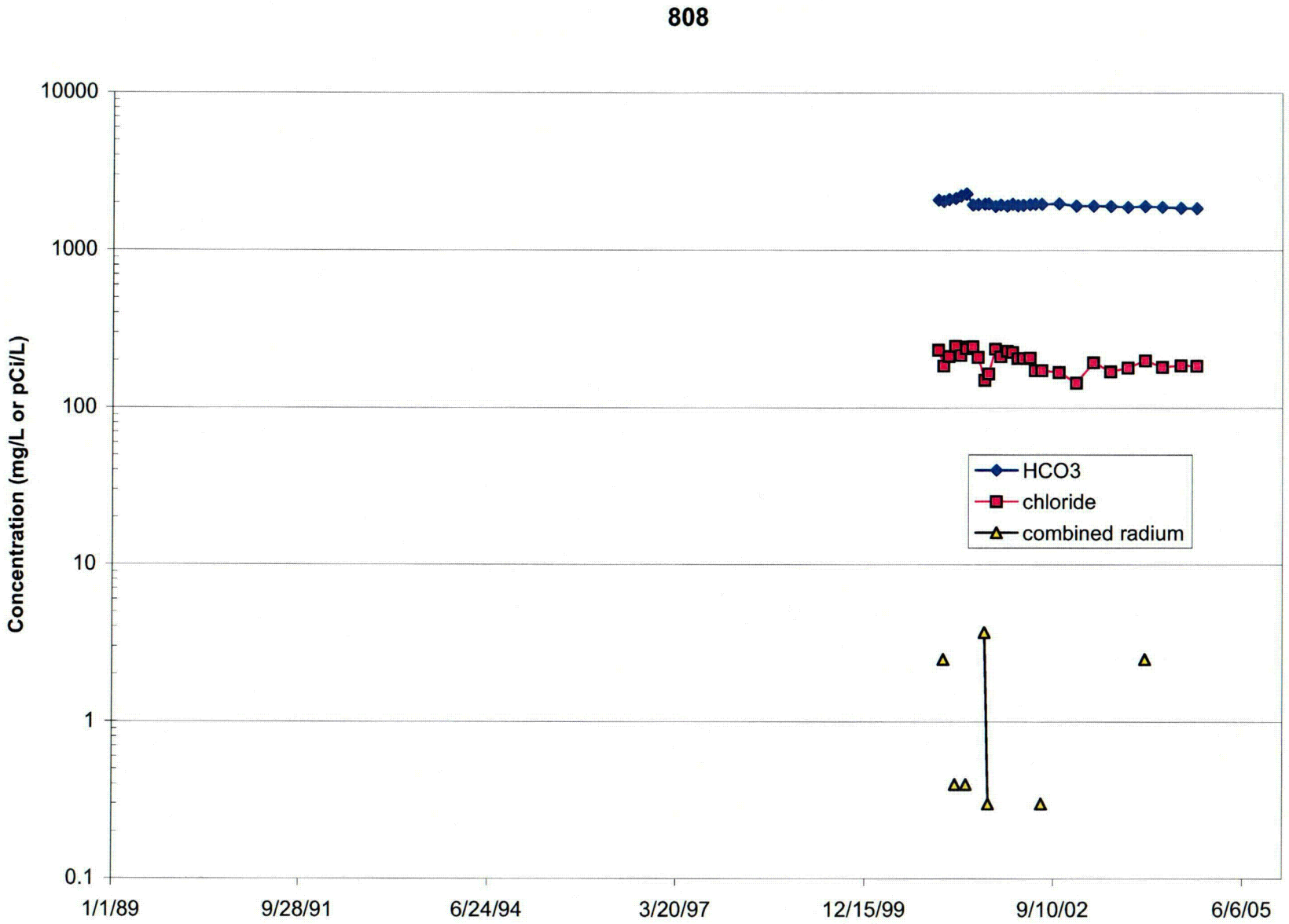
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05

C14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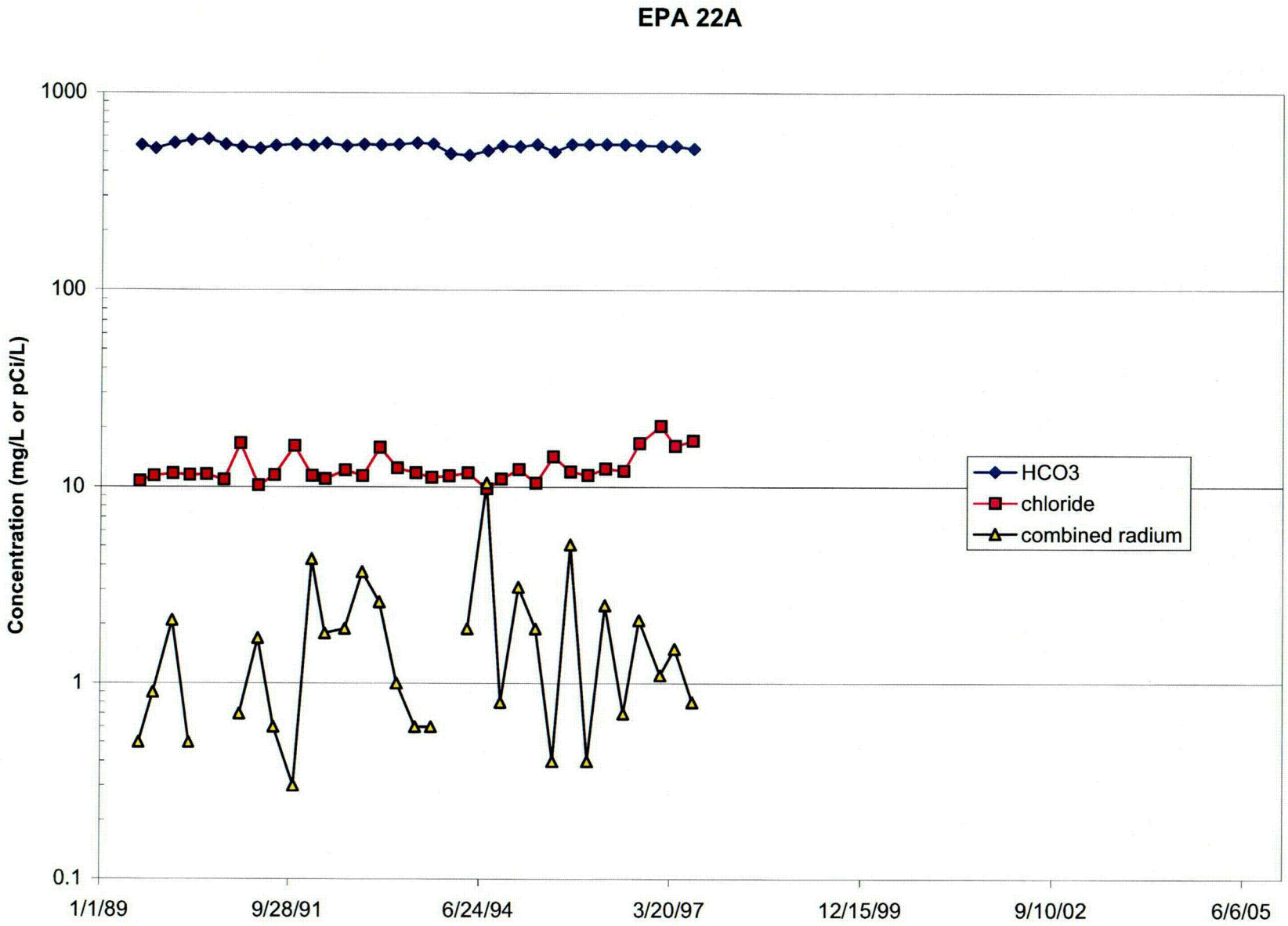
0.1
Concentration (mg/L or pCi/L)
1/1/89
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium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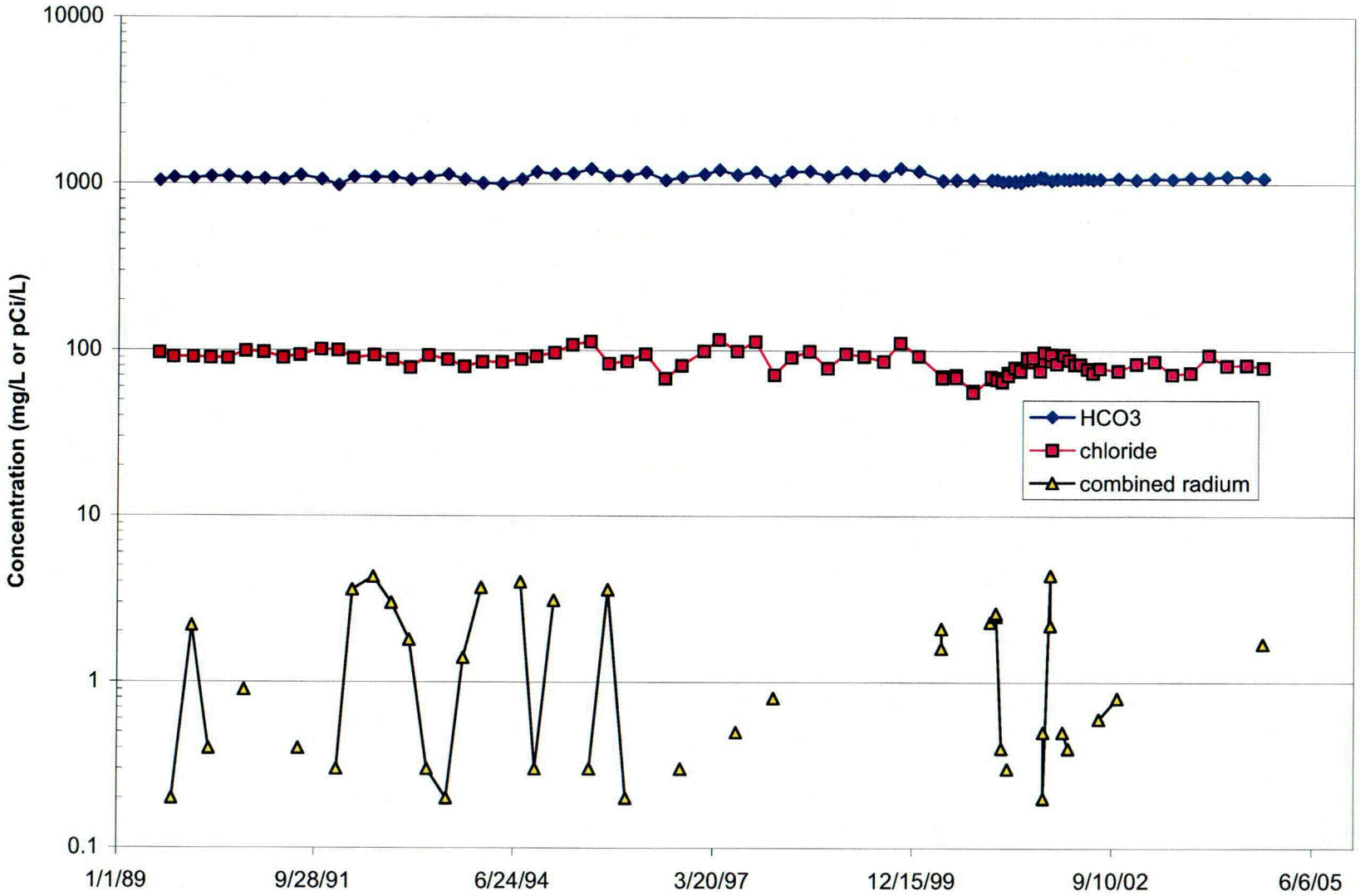
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

EPA 23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0.1
Concentration (mg/L or pCi/L)
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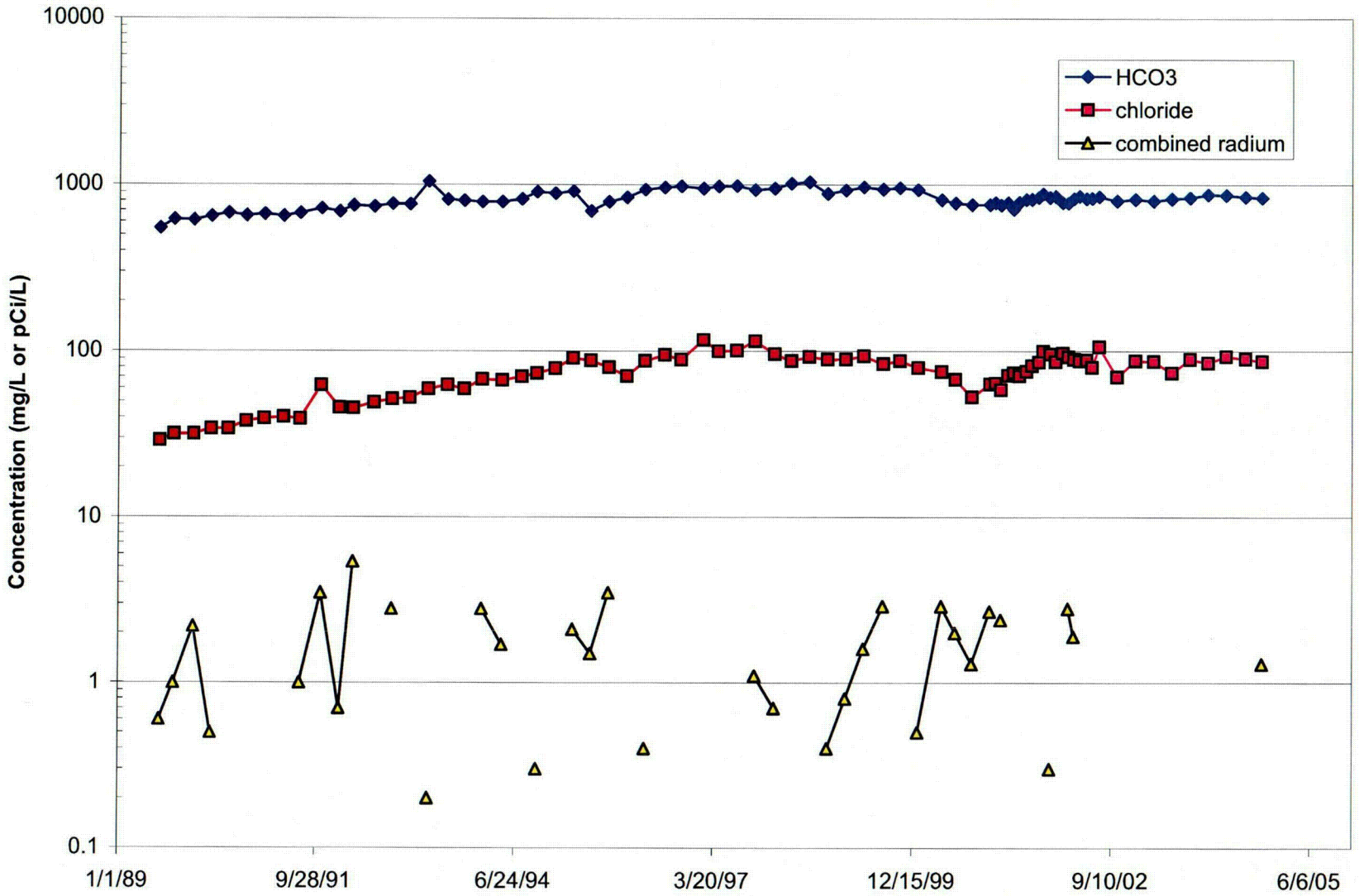
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium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combined radium
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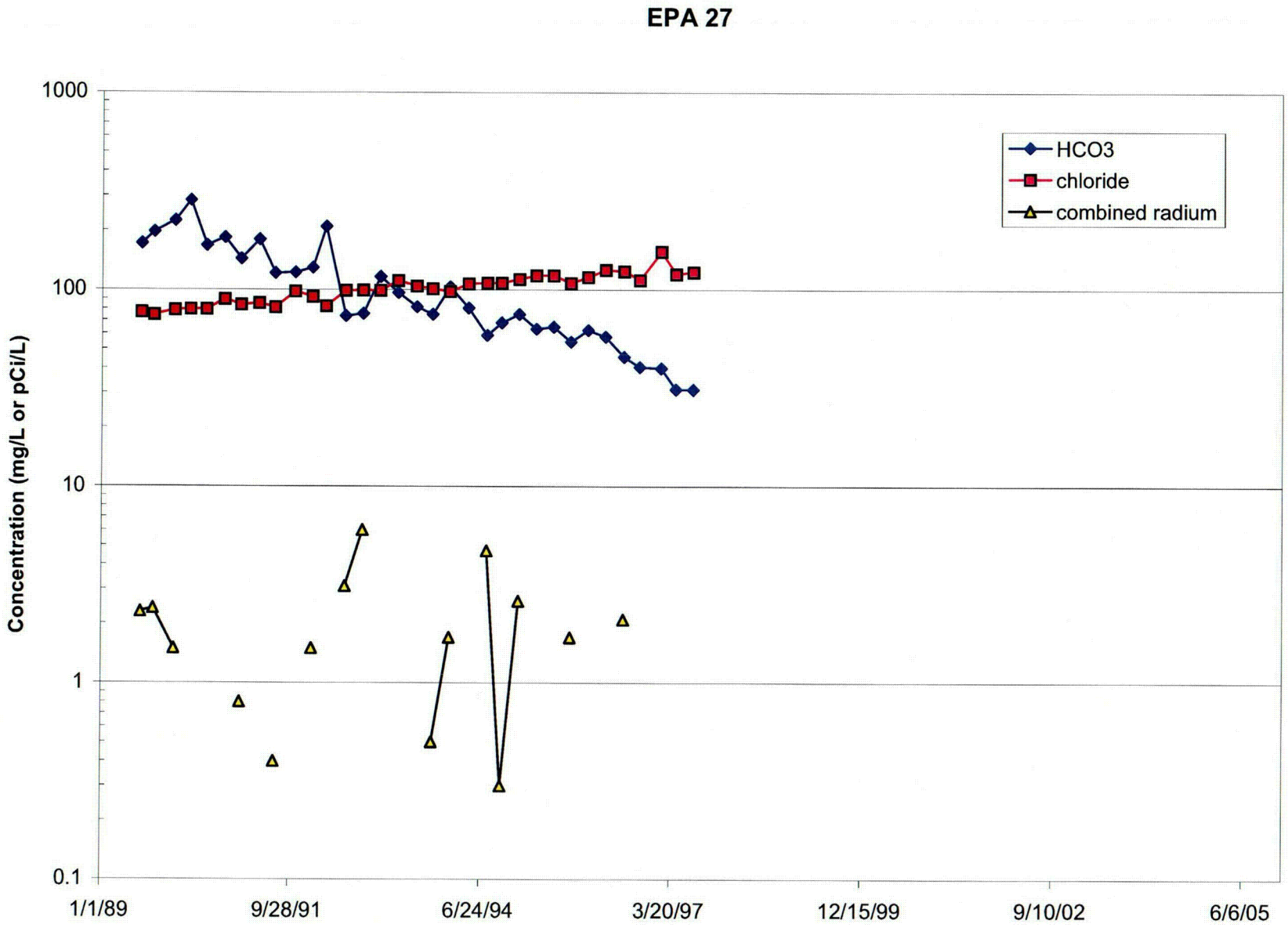
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05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Concentration (mg/L or pCi/L)
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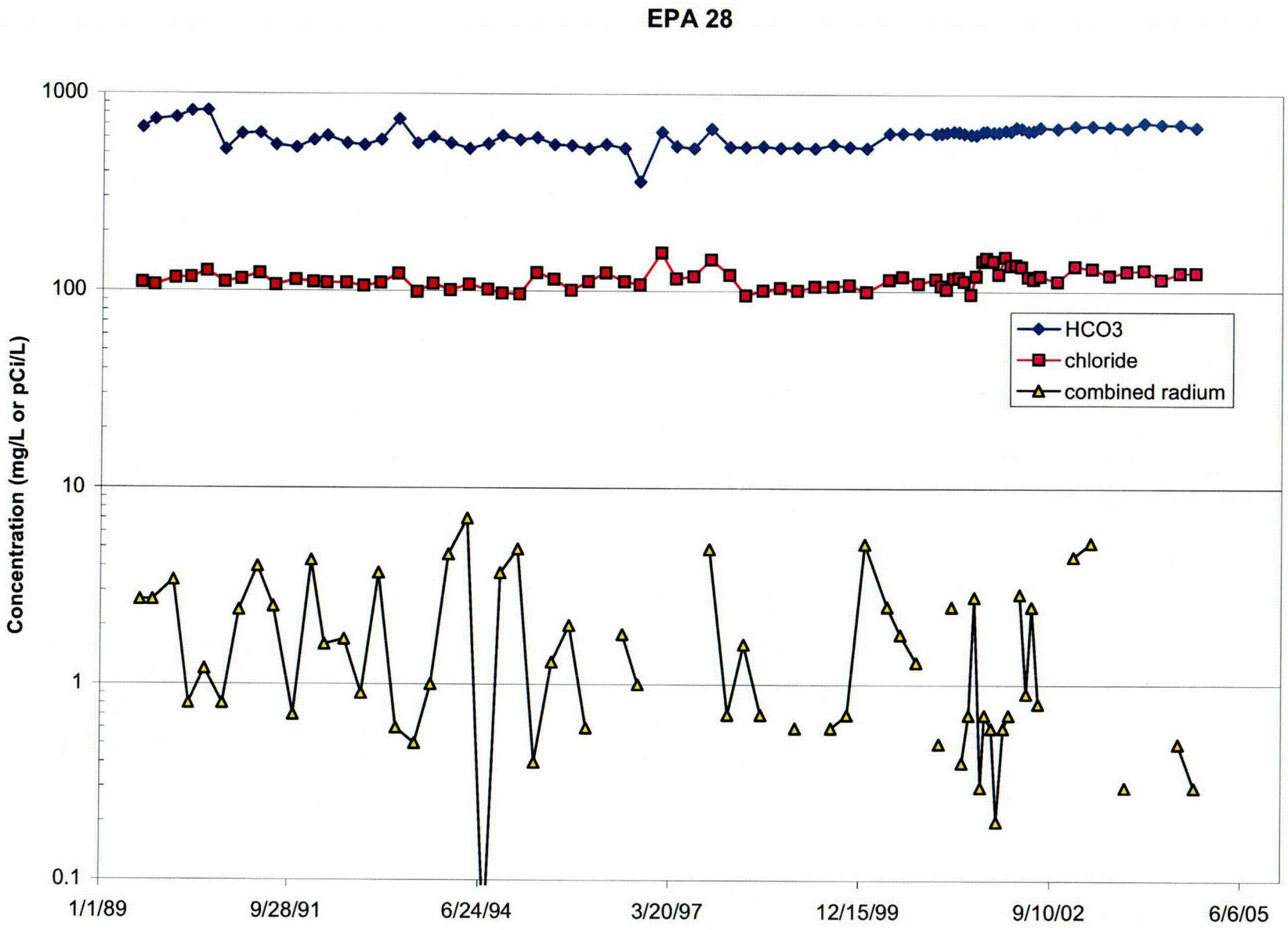
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

C19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10
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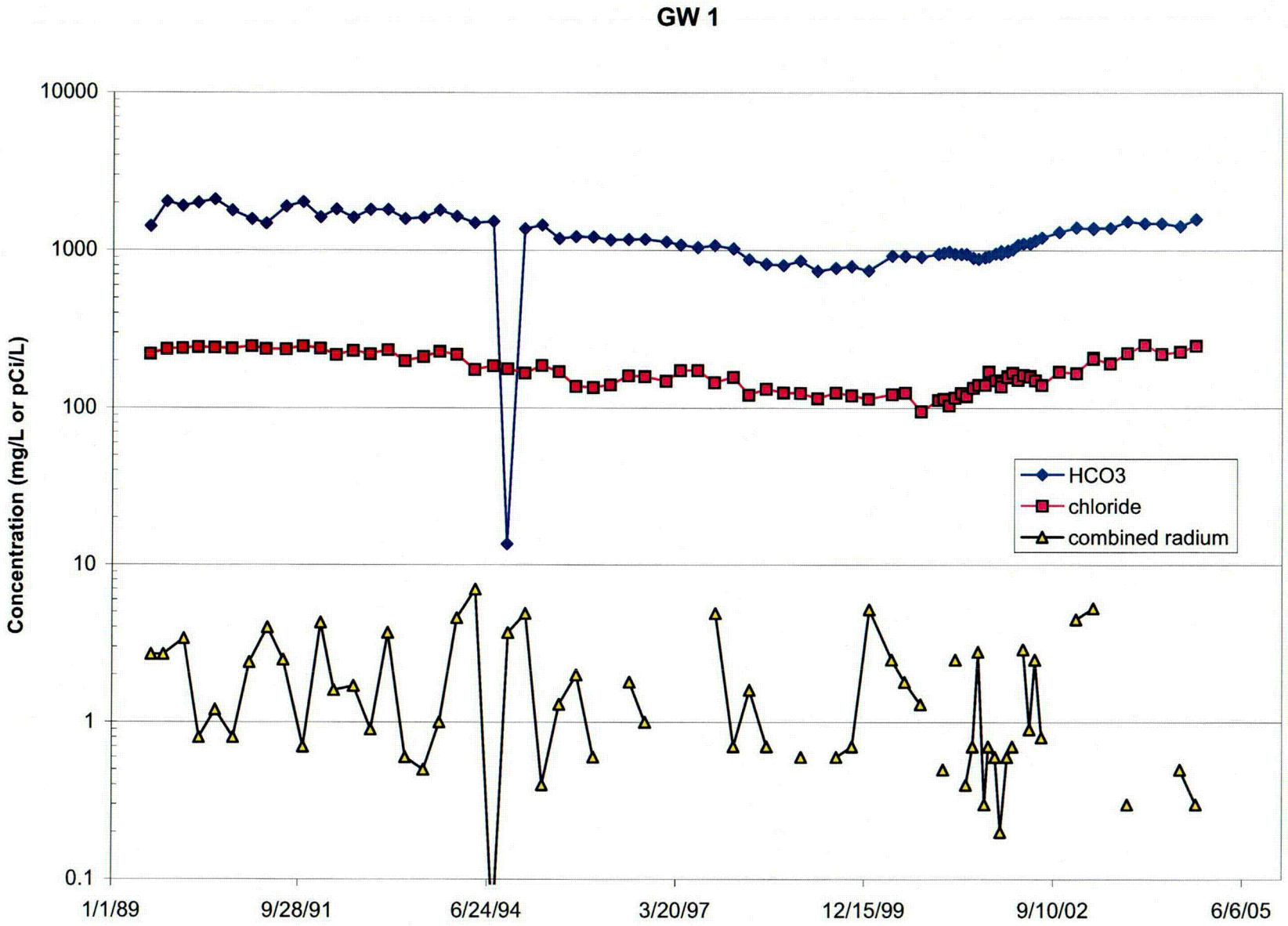
0.1
Concentration (mg/L or pCi/L)
HCO3
chloride
combined radium
1/1/89
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05


GW 1
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Concentration (mg/L or pCi/L)
HCO3
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combined radium
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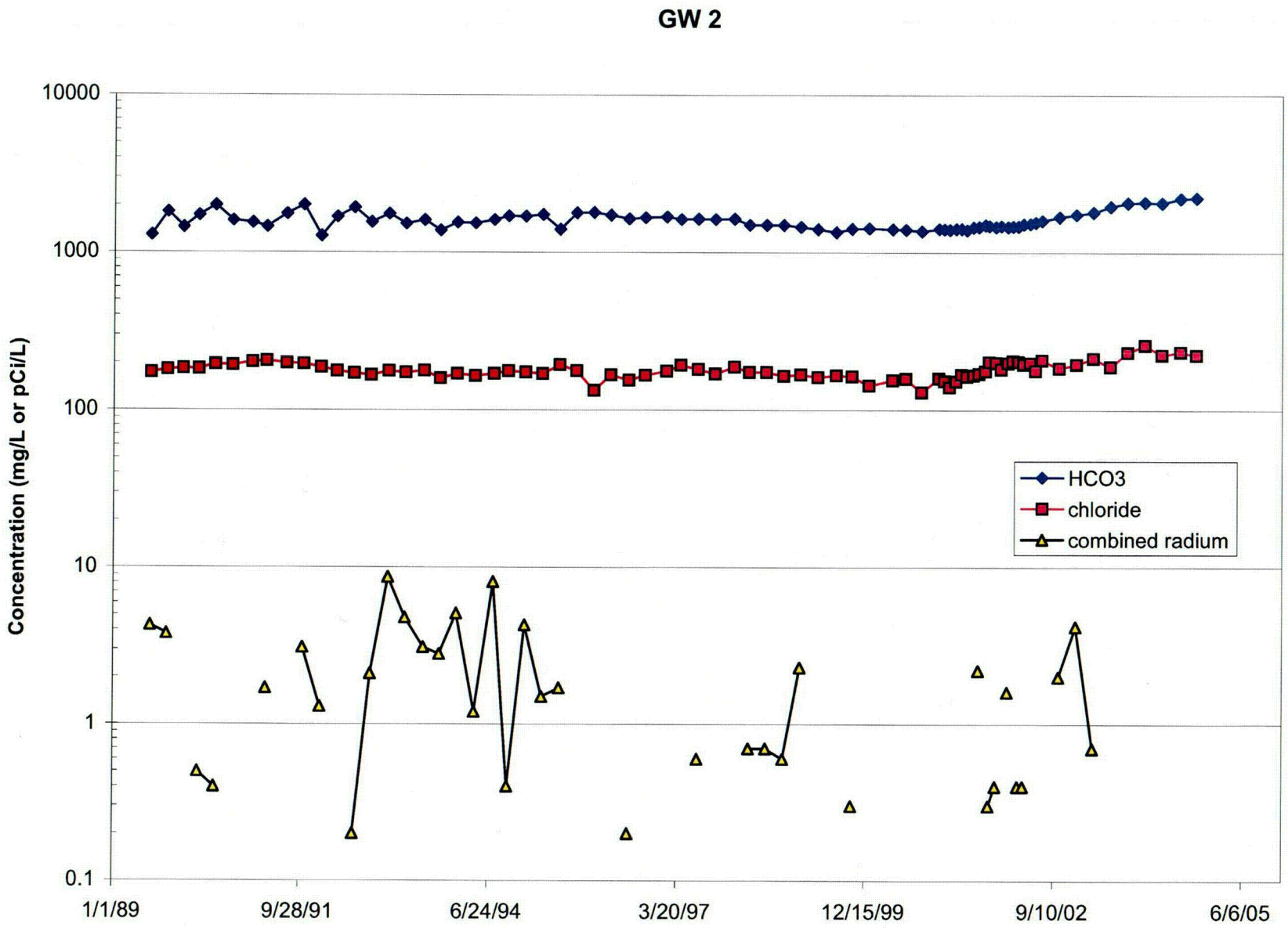
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05

C21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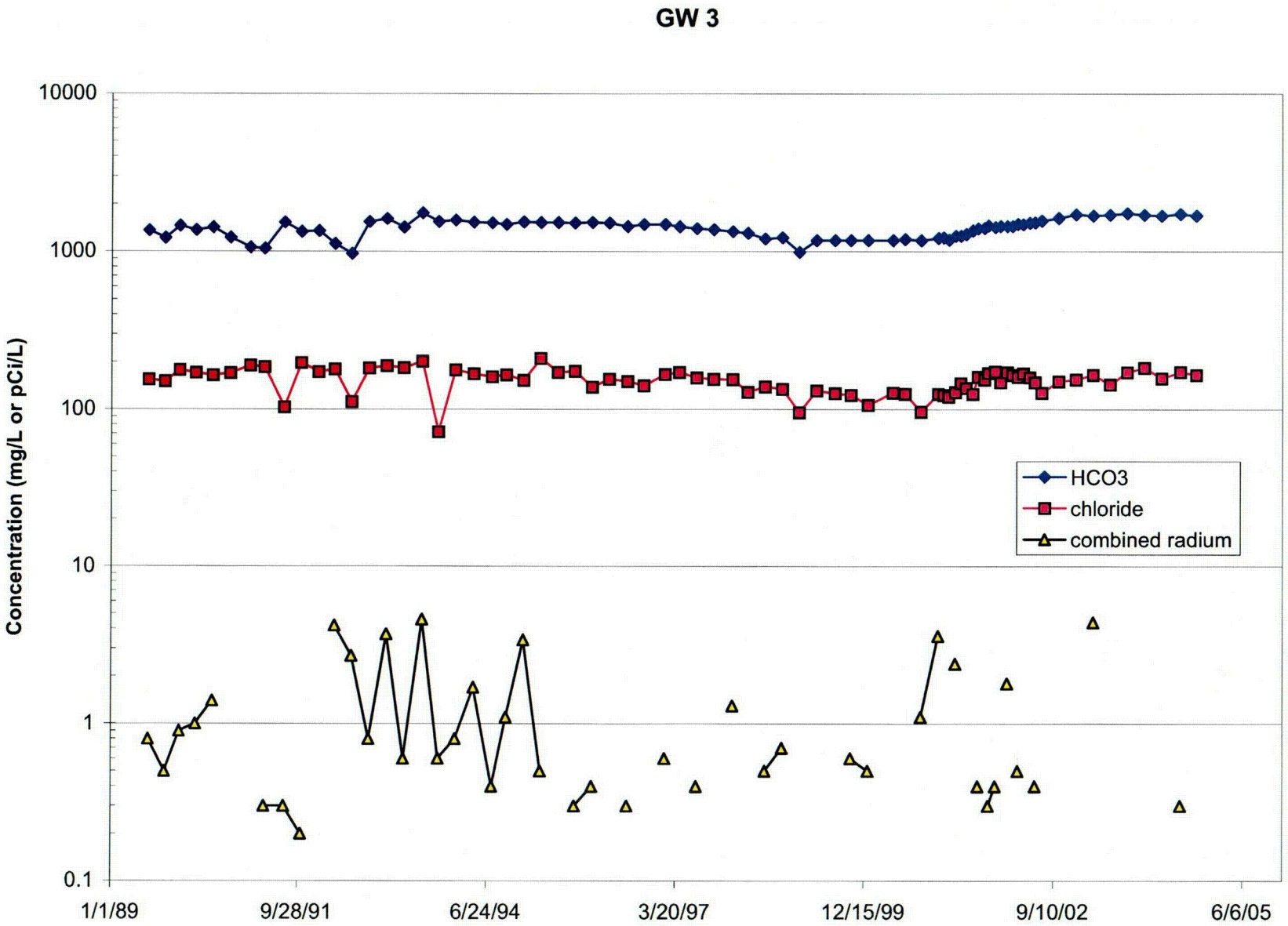
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

C22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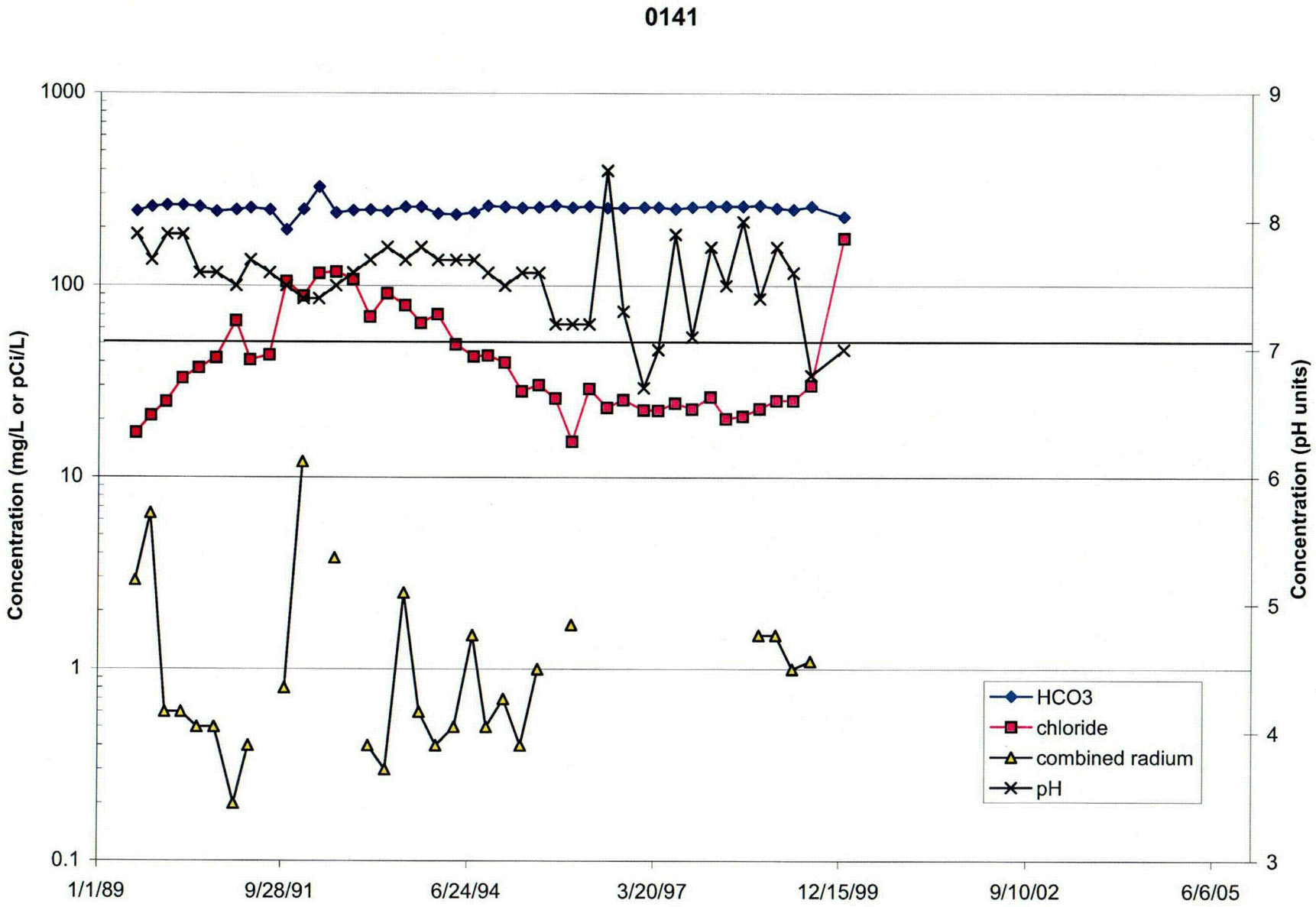
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

Appendix A
Part 2

Time Series of Bicarbonate, Chloride, and Combined Radium for Wells in Zone 1
(July 1989 – October 2004)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0.1
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8
7
6
5
4
3
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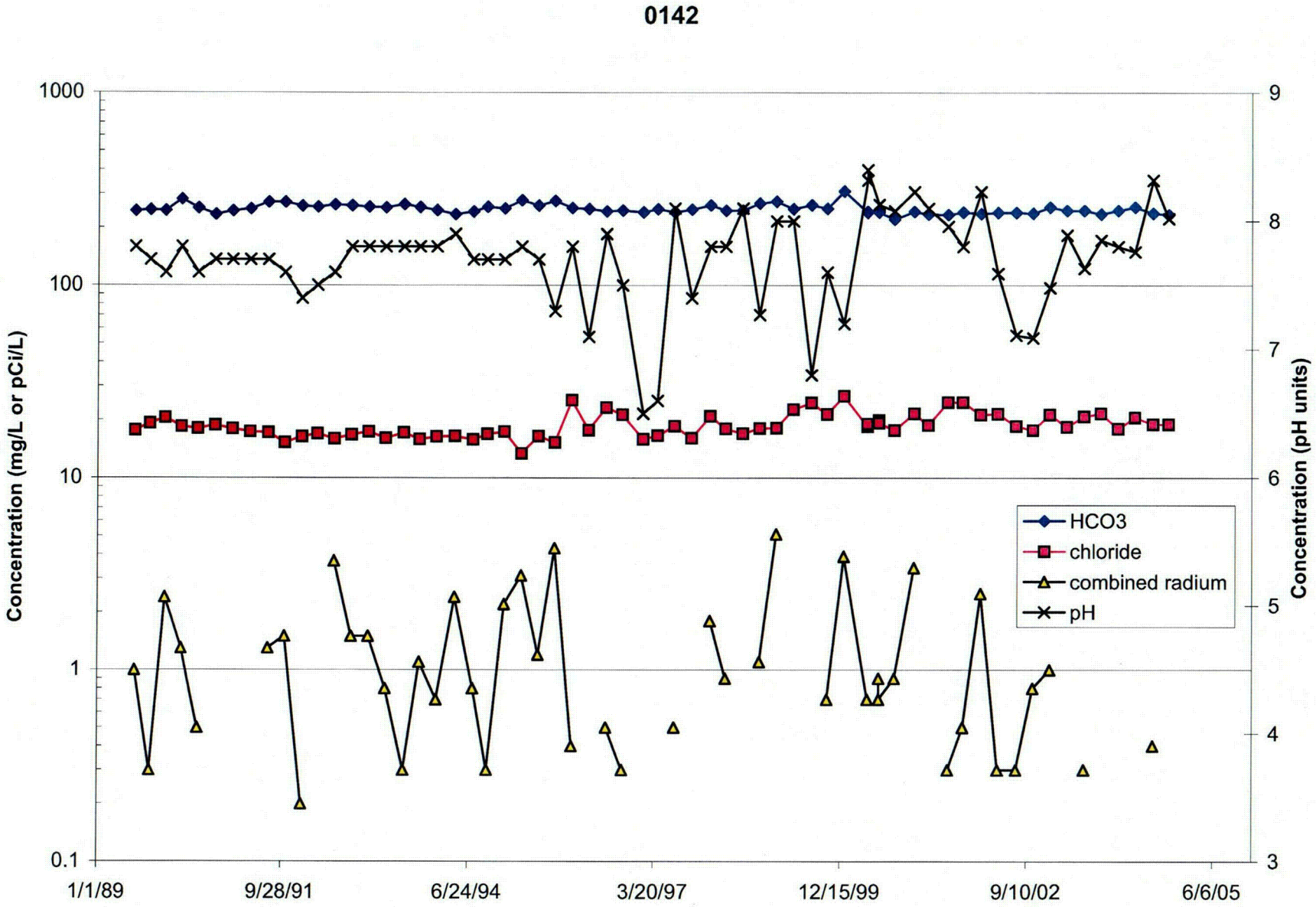
1/1/89
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium
pH

C24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6
5
4
3
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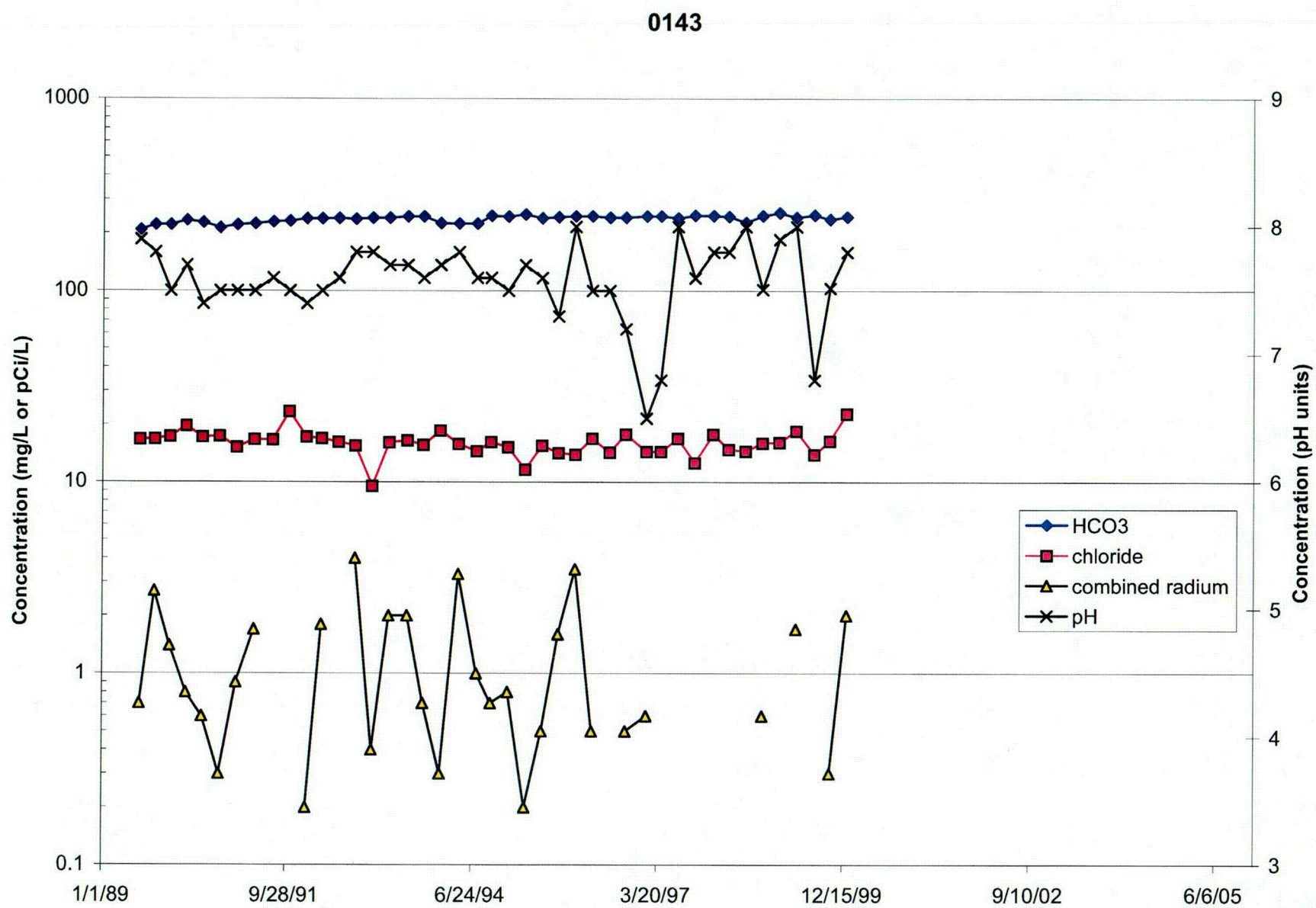
1/1/89
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium
pH

C25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1000
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1
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Concentration (mg/L or pCi/L)
9
8
7
6
5
4
3
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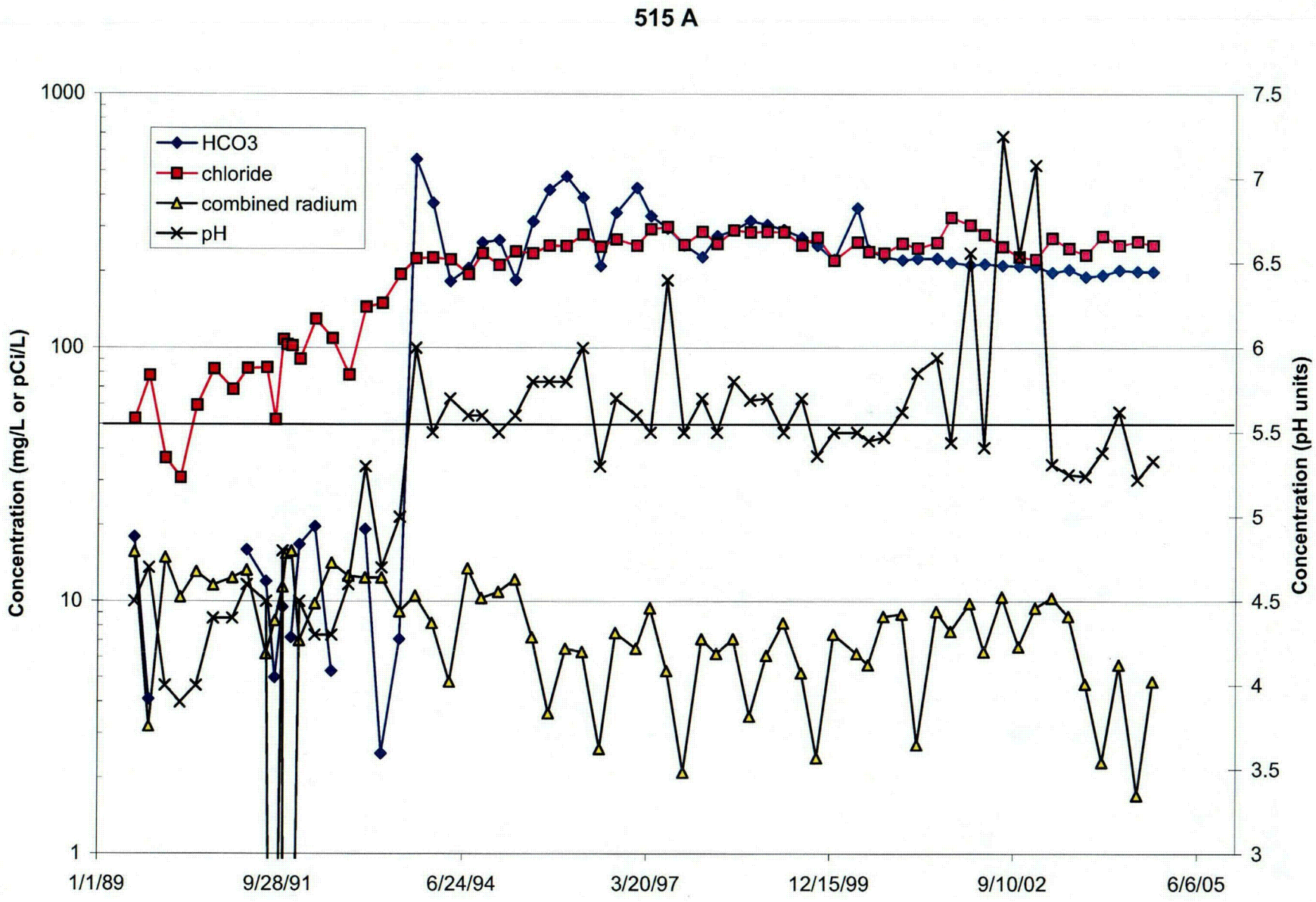
1/1/89
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium
pH

C26


515 A
HCO3
chloride
combined radium
pH
Concentration (mg/L or pCi/L)
Concentration (pH units)
1000
100
10
1
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6.5
6
5.5
5
4.5
4
3.5
3
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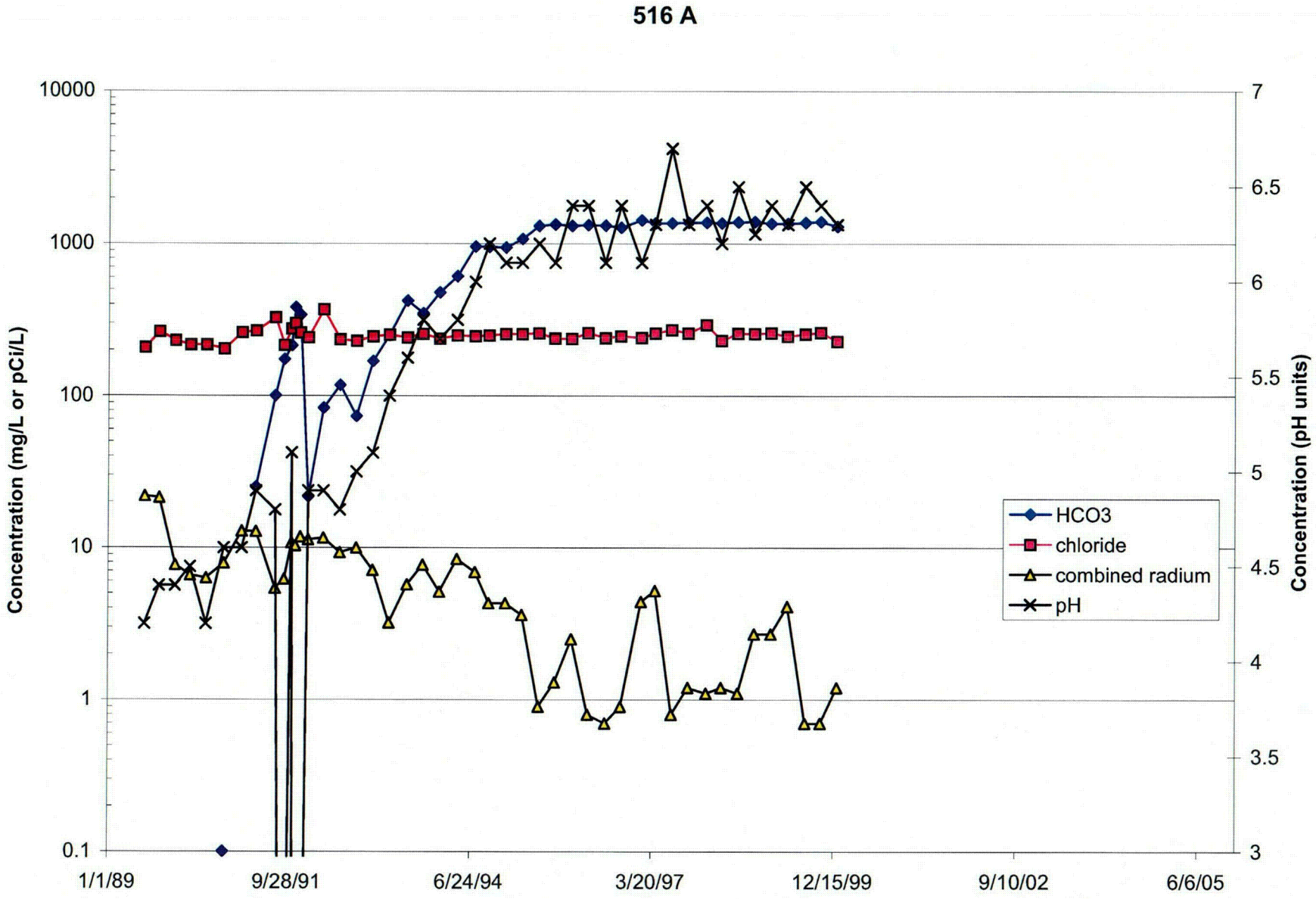
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05

CZ7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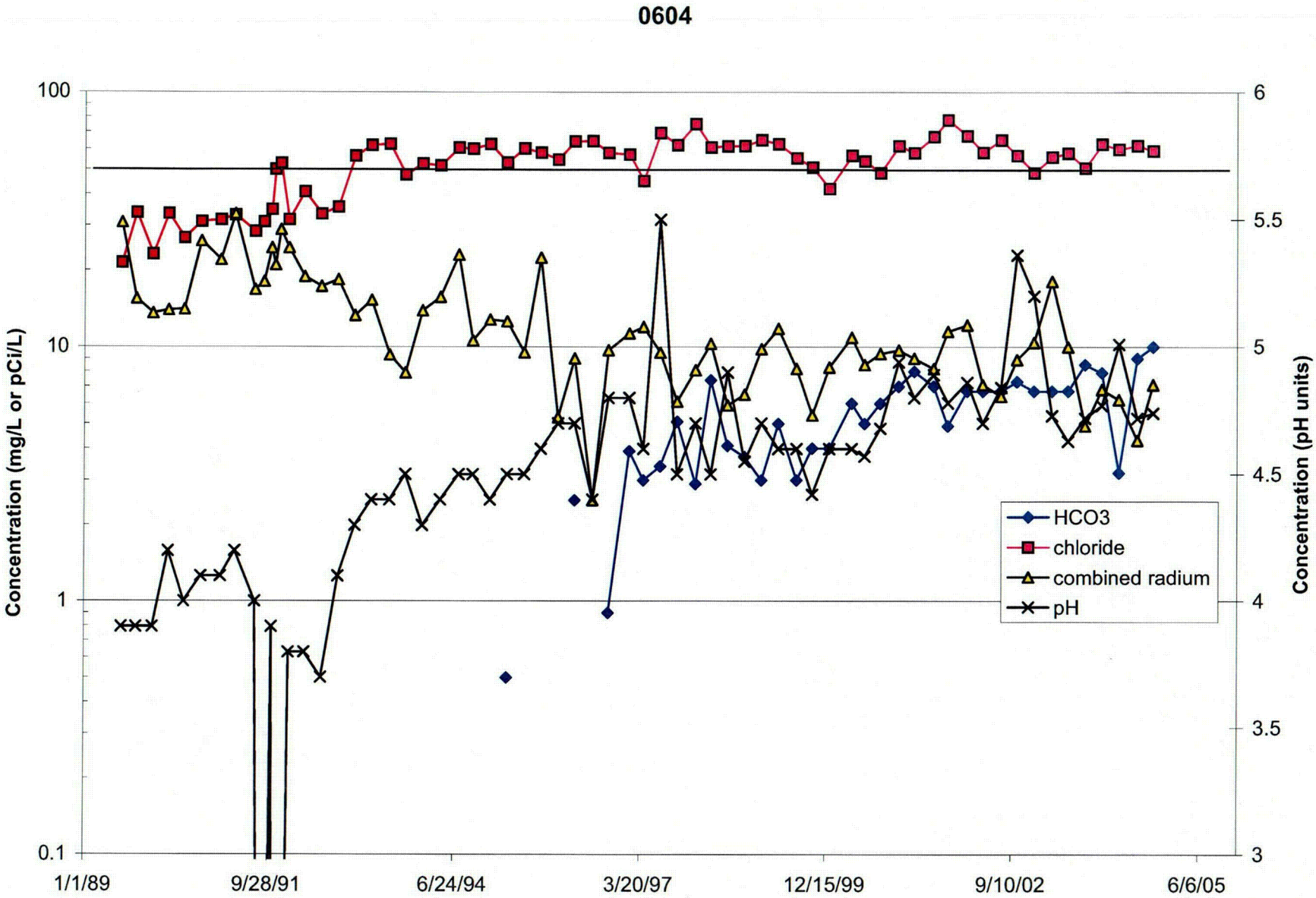
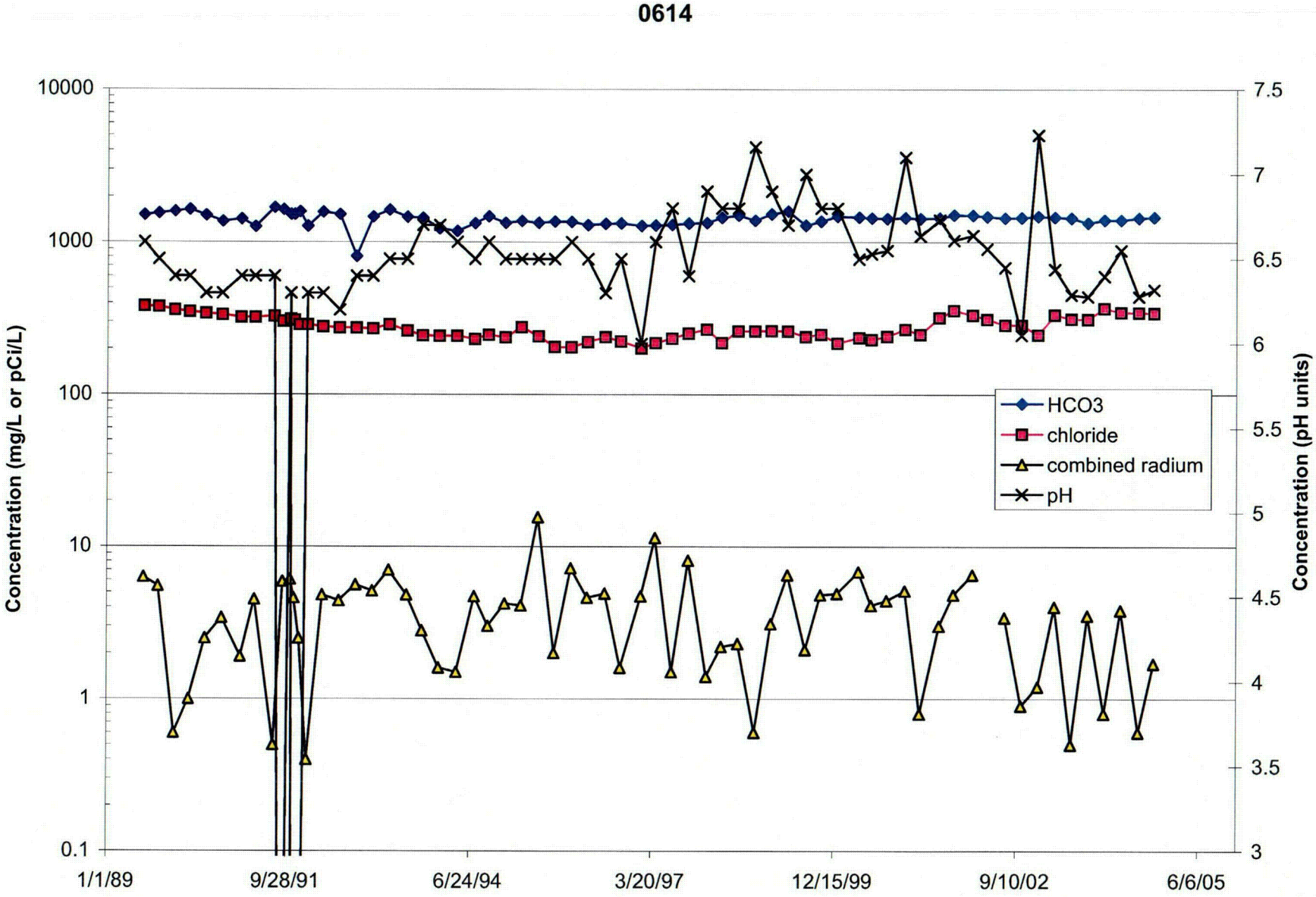
1000
100
10
1
0.1
Concentration (mg/L or pCi/L)
7
6.5
6
5.5
5
4.5
4
3.5
3
Concentration (pH units)
1/1/89
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium
pH

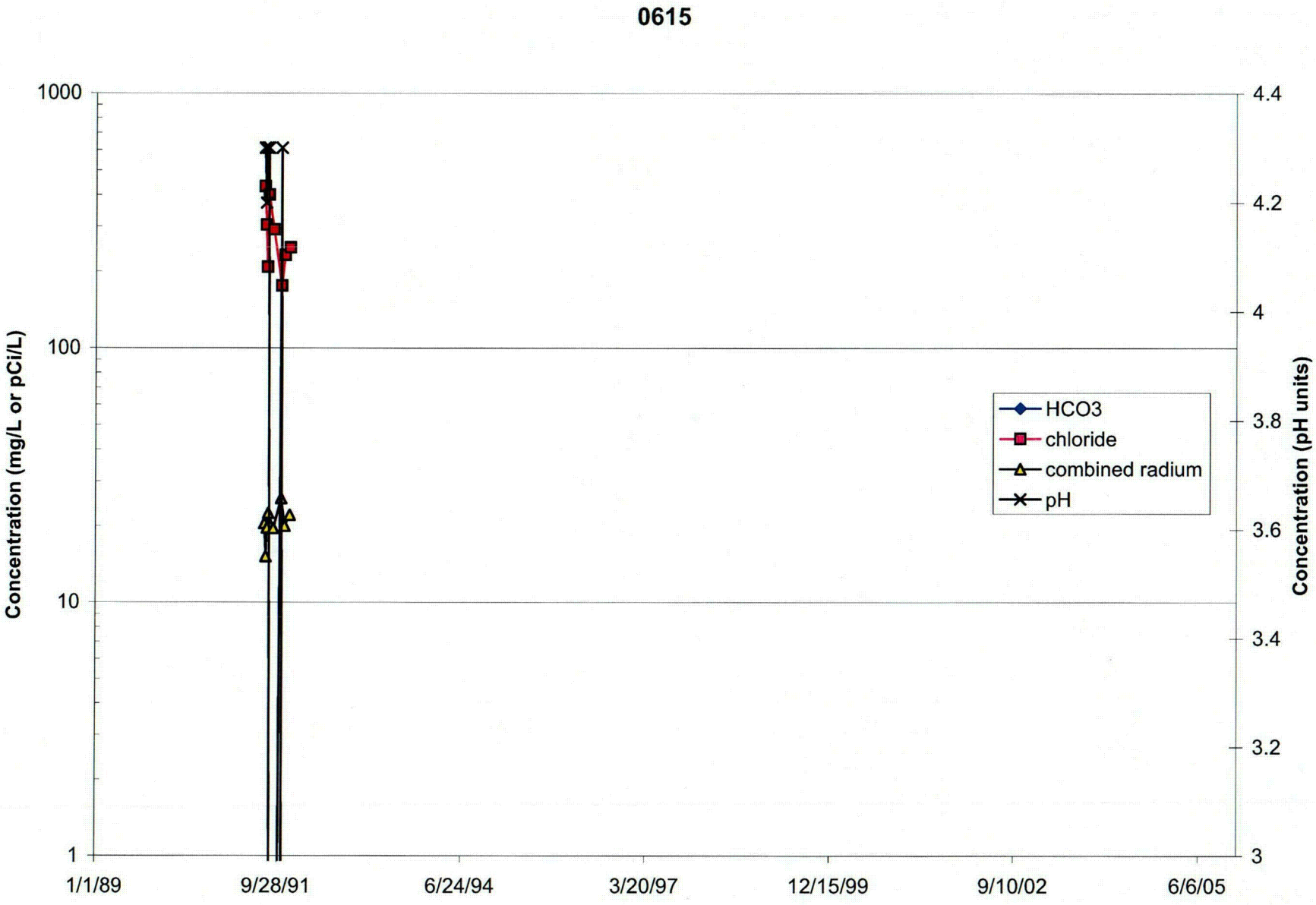
C28

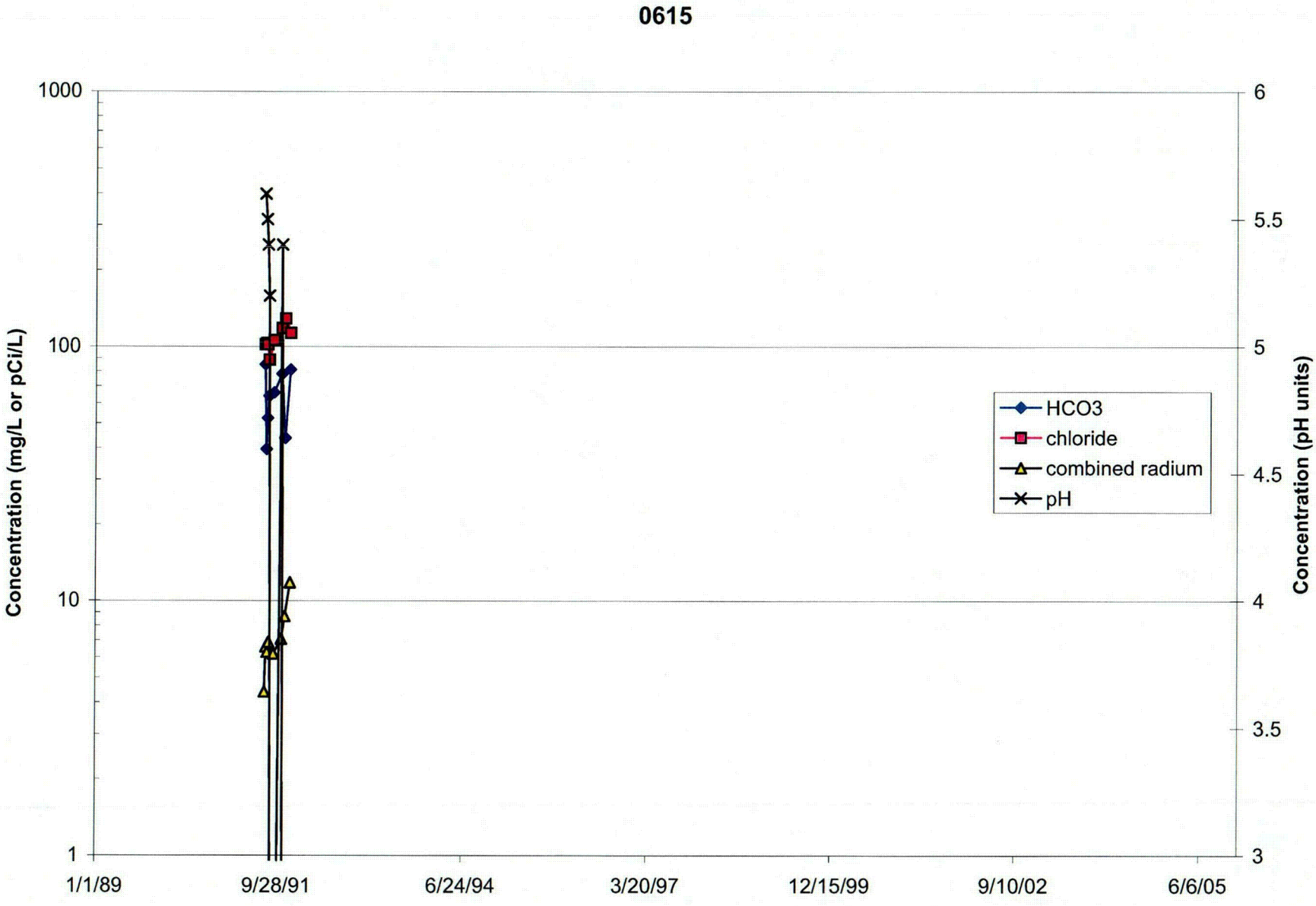

0604
100
10
1
0.1
6
5.5
5
4.5
4
3.5
3
1/1/89
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05
Concentration (mg/L or pCi/L)
Concentration (pH units)
HCO3
chloride
combined radium
pH

C29

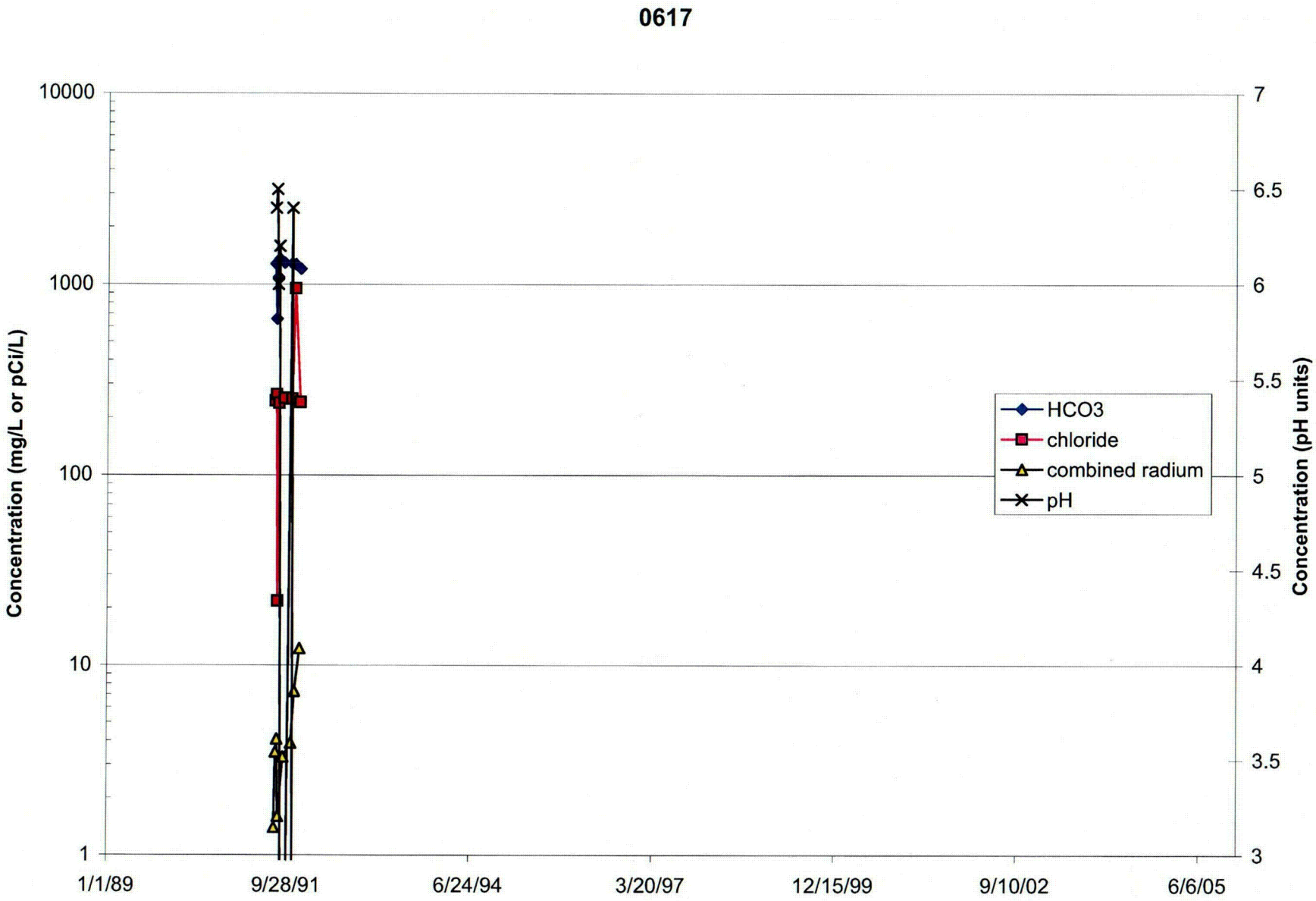

0614
10000
1000
100
10
1
0.1
Concentration (mg/L or pCi/L)
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
Concentration (pH units)
1/1/89
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium
pH

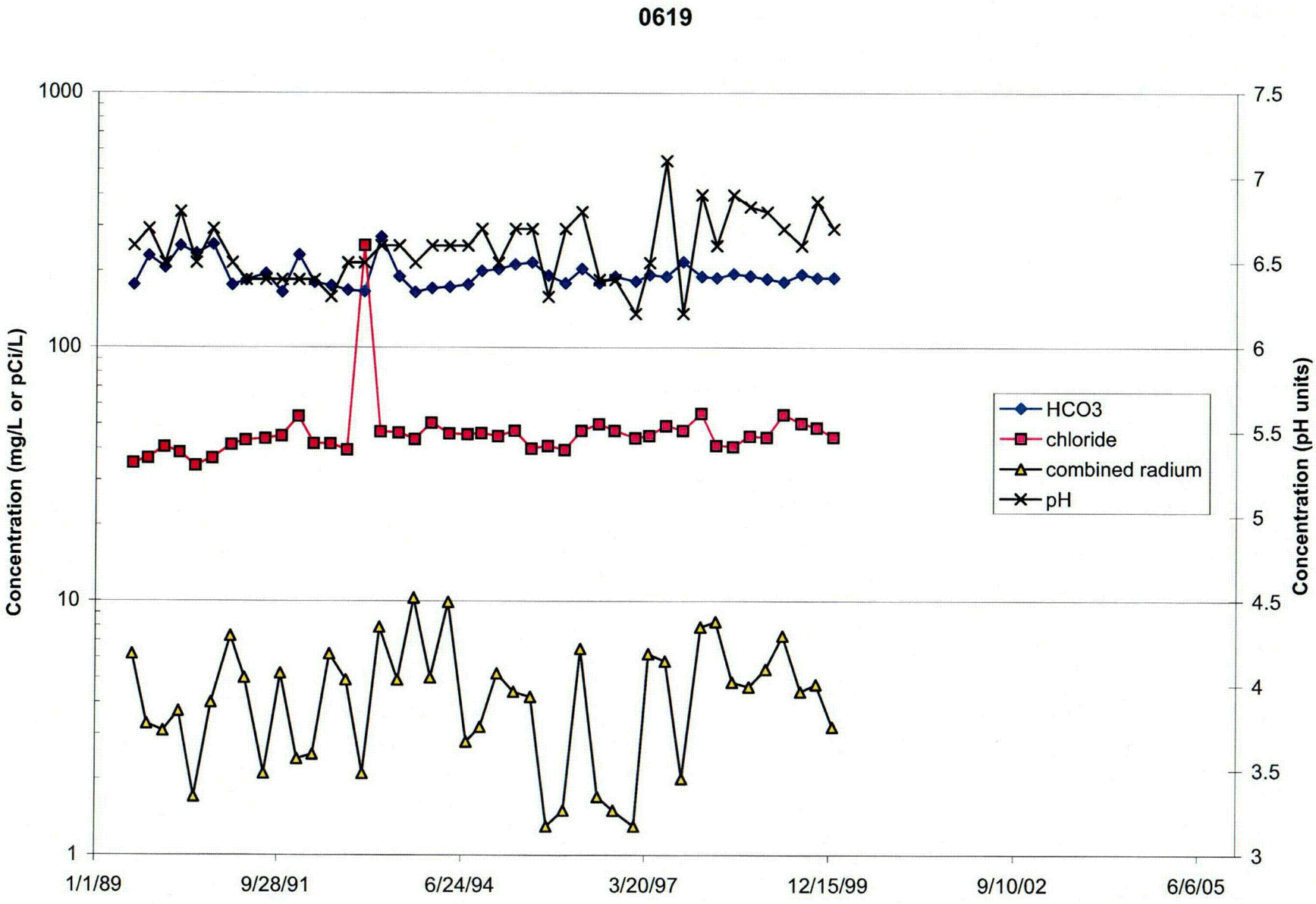
C30


0615
1000
100
10
1
4.4
4.2
4
3.8
3.6
3.4
3.2
3
Concentration (mg/L or pCi/L)
Concentration (pH units)
HCO3
chloride
combined radium
pH
1/1/89
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05

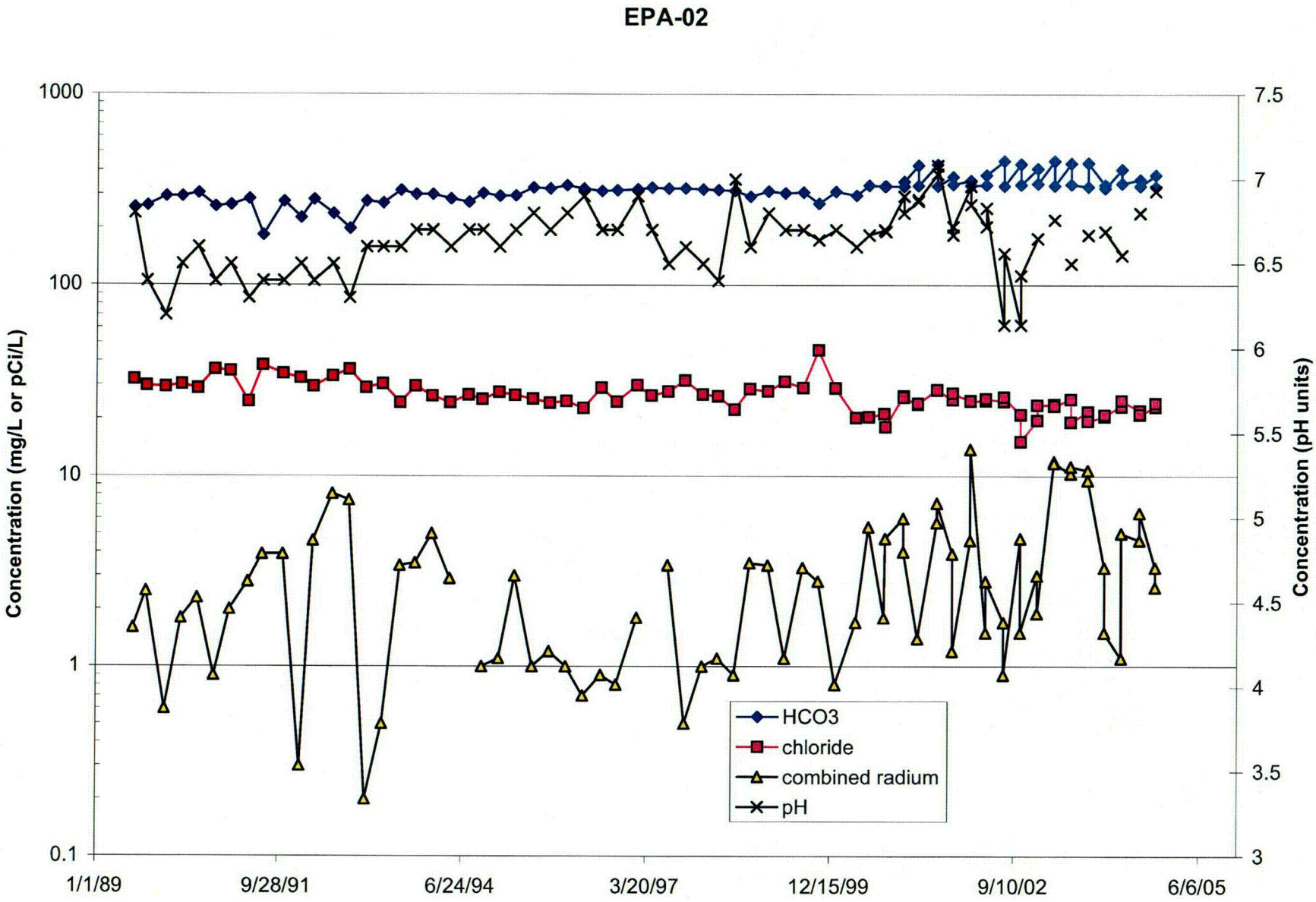

0615
1000
100
10
1
6
5.5
5
4.5
4
3.5
3
Concentration (mg/L or pCi/L)
Concentration (pH units)
1/1/89
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium
pH

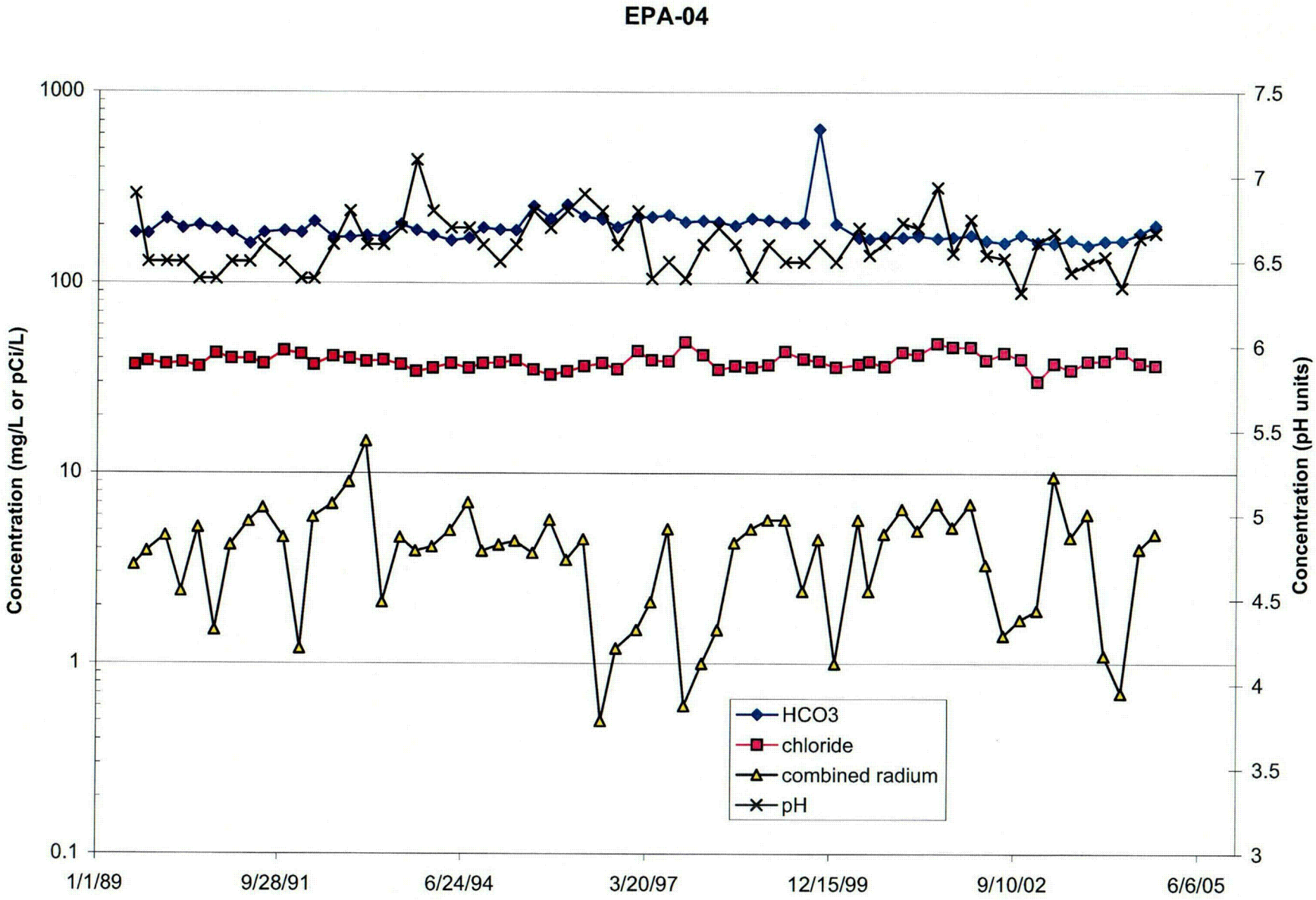
C32


0617
10000
1000
100
10
1
7
6.5
6
5.5
5
4.5
4
3.5
3
Concentration (mg/L or pCi/L)
Concentration (pH units)
HCO3
chloride
combined radium
pH
1/1/89
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05

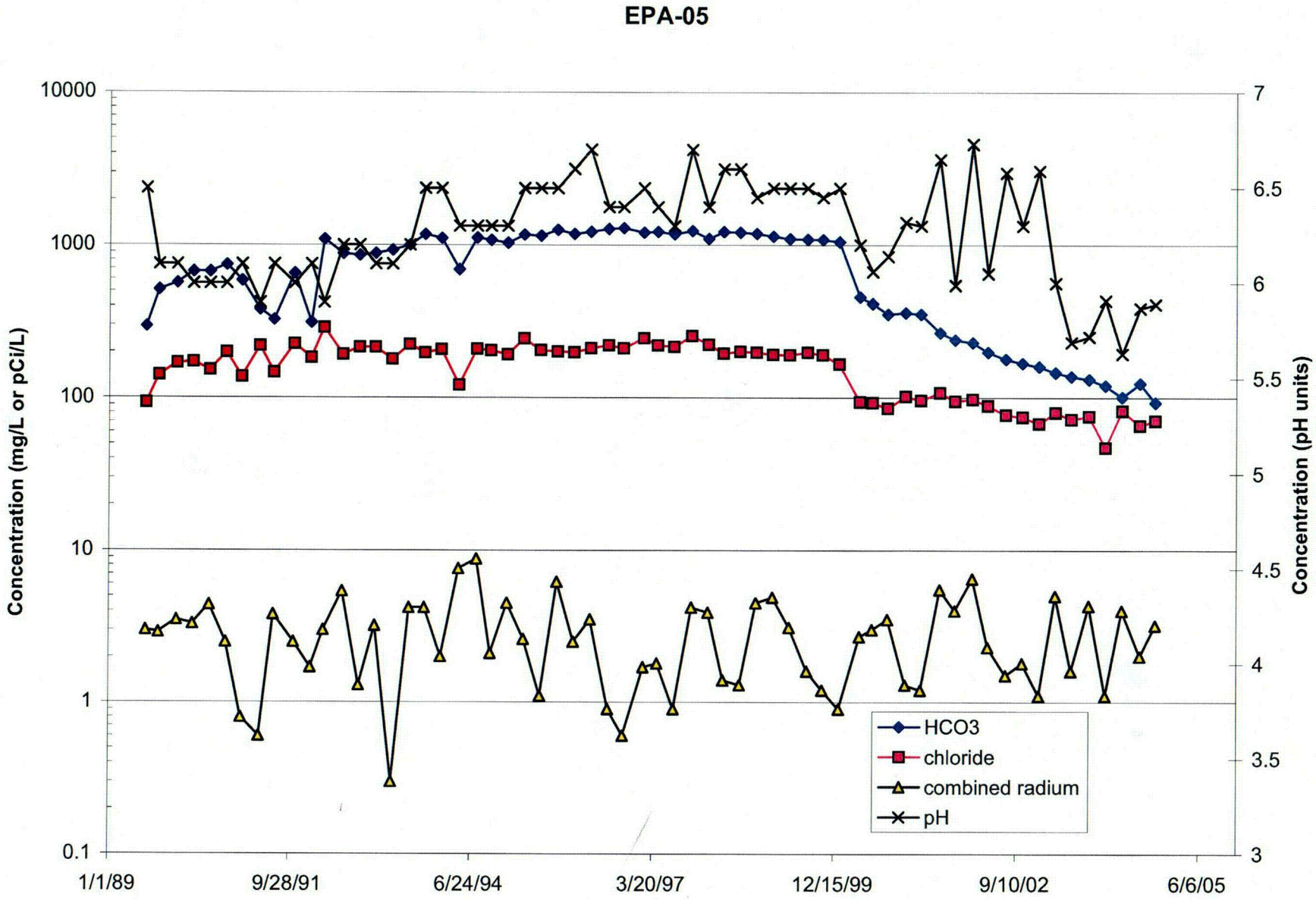

0619
1000
100
10
1
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
Concentration (mg/L or pCi/L)
Concentration (pH units)
HCO3
chloride
combined radium
pH
1/1/89
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05

C34

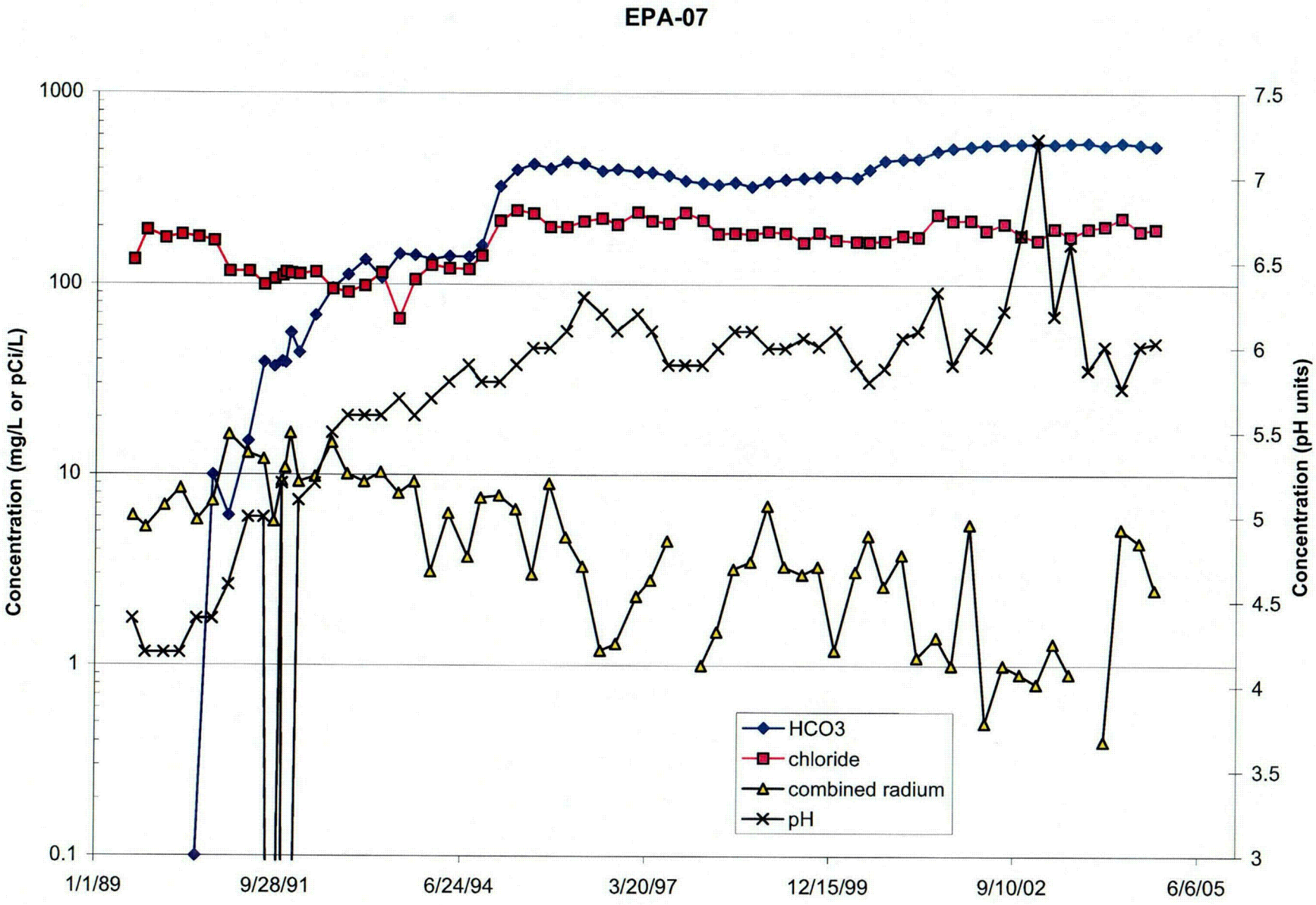

EPA-02
Concentration (mg/L or pCi/L)
Concentration (pH units)
1000
100
10
1
0.1
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
1/1/89
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium
pH

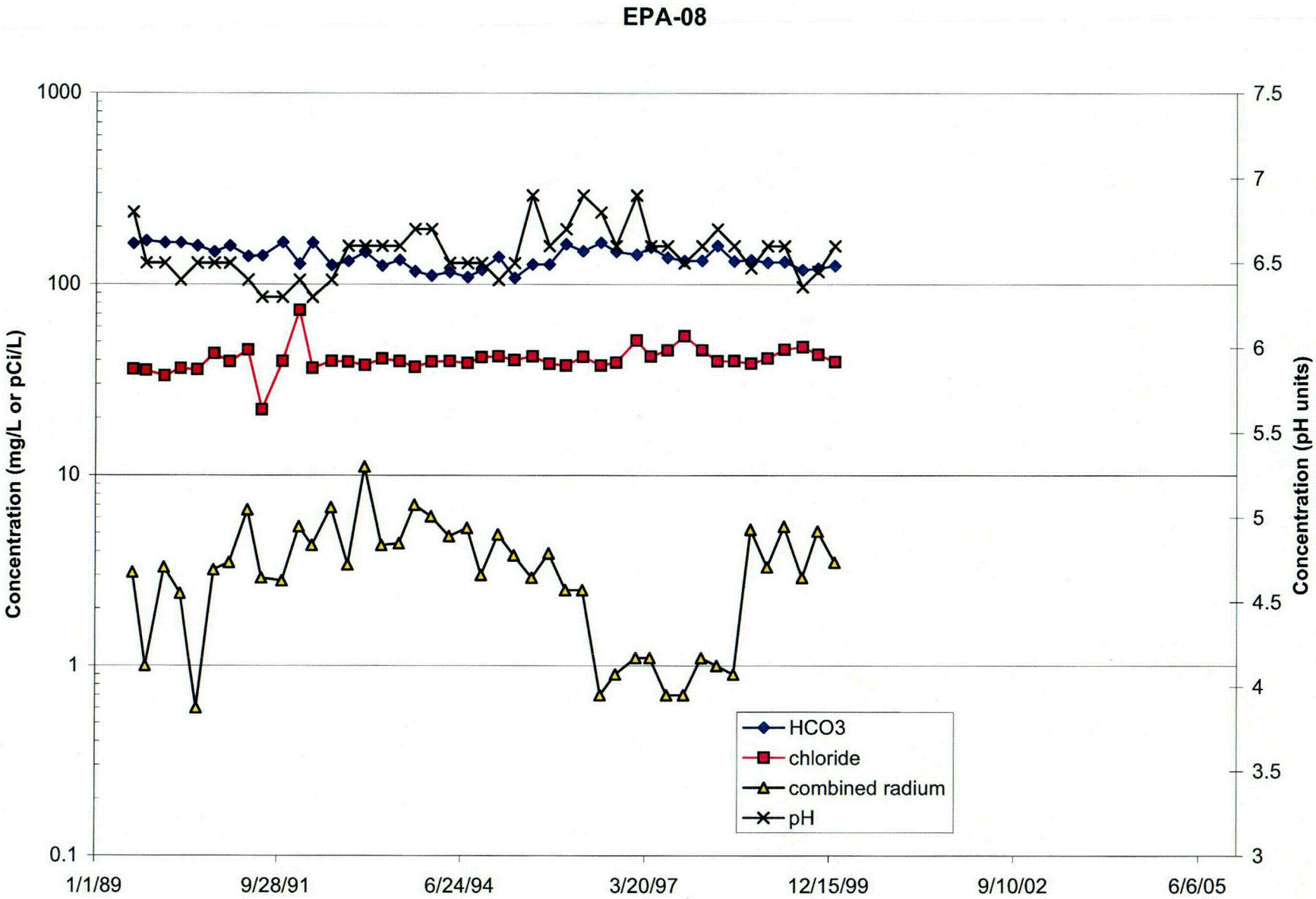

EPA-04
Concentration (mg/L or pCi/L)
Concentration (pH units)
1000
100
10
1
0.1
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
1/1/89
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium
pH

C36


EPA-05
Concentration (mg/L or pCi/L)
Concentration (pH units)
10000
1000
100
10
1
0.1
7
6.5
6
5.5
5
4.5
4
3.5
3
1/1/89
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium
pH

C37


EPA-07
1000
100
10
1
0.1
Concentration (mg/L or pCi/L)
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
Concentration (pH units)
1/1/89
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium
pH


EPA-08
Concentration (mg/L or pCi/L)
Concentration (pH units)
1000
100
10
1
0.1
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
1/1/89
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium
pH

Appendix B
Basic Statistics Output from Chemstat

Basic Statistics for Combined Radium

Southwest Alluvium

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL

Background Locations

There are 12 background locations

Location	Meas.	Non-Detects	% ND	Total
0029 A	22	7	31.8	42.8
624 B	26	8	30.8	50.3
EPA 22A	33	3	9.1	58.4
EPA 25	26	10	38.5	35.8
EPA 27	33	18	54.5	42.4
627	75	16	21.3	99.8
639	21	3	14.3	56.2
642	25	5	20.0	40.0
644	14	1	7.1	27.1
645	5	2	40.0	4.5
EPA 28	75	14	18.7	120.5
SBL-01	2	0	0.0	6.7

Location	Mean	Std Dev	Std Err	Rank Sum	Rank Mean
0029 A	1.95	2.59	0	9956	452.5
624 B	1.93	2.33	0	12417	477.5
EPA 22A	1.77	1.97	0	18340	555.7
EPA 25	1.38	1.28	0	11153	428.9
EPA 27	1.28	1.29	0	12084	366
627	1.33	1.45	0	34675	462
639	2.68	2.88	0	12145	578
642	1.60	1.74	0	12245	489.8
644	1.94	1.93	0	7824	558.8
645	0.90	0.62	0	1833	366.6
EPA 28	1.61	1.54	0	38479	788
SBL-01	3.20	0.00	0	1576	788

Compliance Locations

There are 7 compliance location

Location	Obs.	Non-Detects	% ND	Total
EPA 23	88	48	54.5	87.72
0509 D	75	19	25.3	90.3
632	75	2	2.7	188.7
GW 1	79	42	53.2	85.7
GW 2	75	38	50.7	99.9
GW 3	75	32	42.7	71.1
EPA 28	75	14	18.7	120.45

Location	Mean	Std Dev	Dif From Bkg	Std Err	Rank Sum	Rank Mean
EPA 23	0.99	1.01	-0.64	0.19	28532	320.5
0509 D	1.21	1.37	-0.43	0.20	33430	445.7
632	2.52	1.88	0.88	0.20	50633	675
GW 1	1.08	1.27	-0.55	0.20	26395	334
GW 2	1.33	1.66	-0.31	0.20	27575	367.6
GW 3	0.95	1.00	-0.69	0.20	26938	359
EPA 28	1.61	1.54	-0.03	0.20	39220	522.9

Basic Statistics for Combined Radium

Zone 1

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL

Background Locations
There are 4 background locations

Location	Meas.	Non-Detects	% ND	Total
EPA 4	62	0	0.00	261
619	43	0	0.00	196
EPA 02	79	2	2.53	268
EPA 08	43	0	0.00	149

Location	Mean	Std Dev	Std Err	Rank Sum	Rank Mean
EPA 4	4.21	2.49	0	16764	270
619	4.56	2.31	0	12526	291
EPA 02	3.39	3.09	0	15716	199
EPA 08	3.47	2.18	0	9626	224

Compliance Locations
There are 5 compliance locations

Location	Obs.	Non-Detects	% ND	Total
604	65	0	0.00	834
614	65	1	1.54	245
EPA 04	62	0	0.00	261
EPA 05	62	0	0.00	180
EPA 07	65	2	3.08	341

Location	Mean	Std Dev	Dif From Bkg	Std Err	Rank Sum	Rank Mean
604	12.82	6.79	8.97	0.49	31330	482
614	3.77	2.69	-0.08	0.49	15553	239
EPA 04	4.21	2.49	0.36	0.50	16951	273
EPA 05	2.90	1.79	-0.95	0.50	12104	195
EPA 07	5.24	4.06	1.39	0.49	18761	289

Appendix C
Normal Probability Plots and Tests of Normality

FIGURE C-1
Probability Plot of Combined Radium Values for Background Wells in the Southwest Alluvium

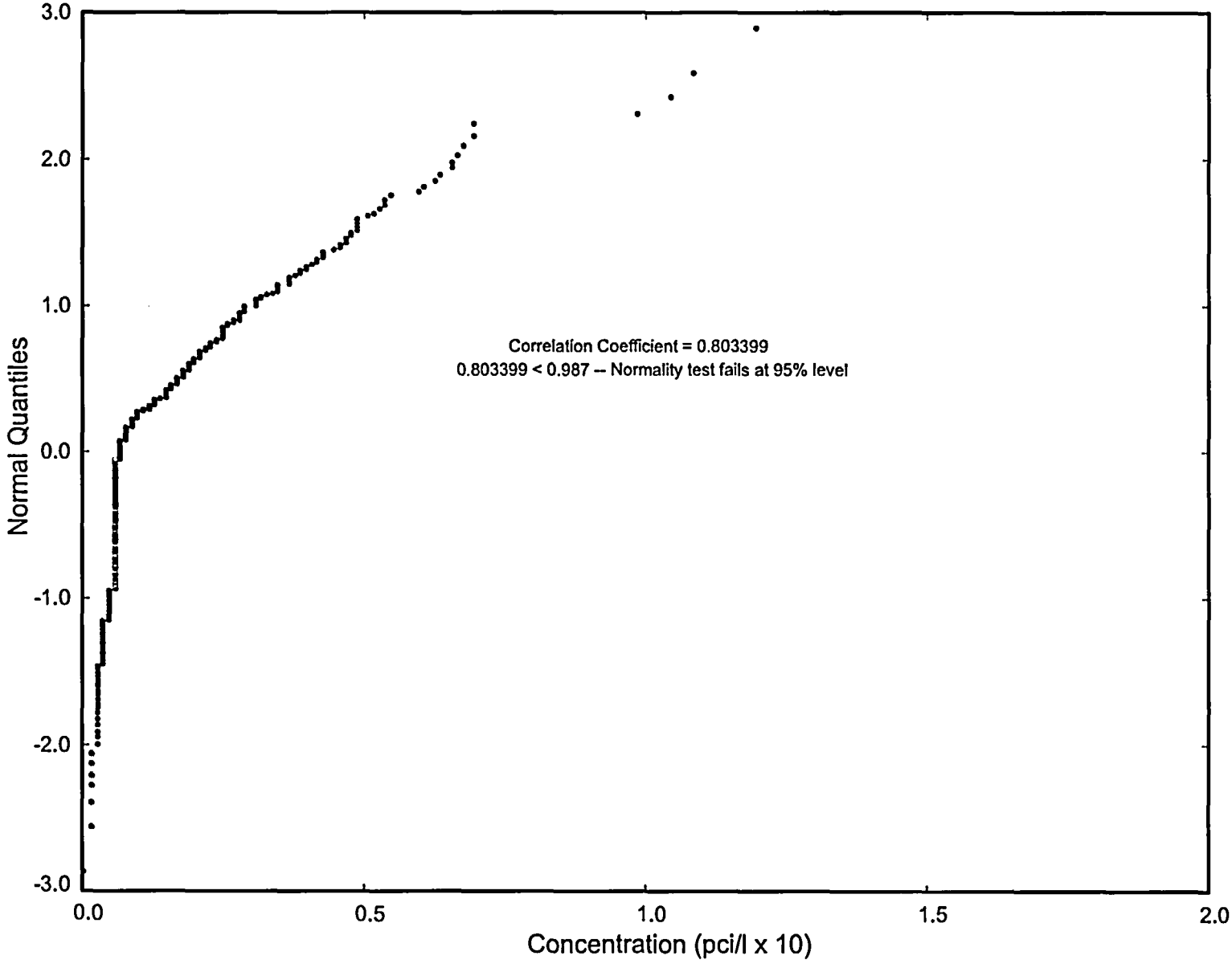


FIGURE C-2
Probability Plot of Combined Radium Values for Compliance Wells in the Southwest Alluvium

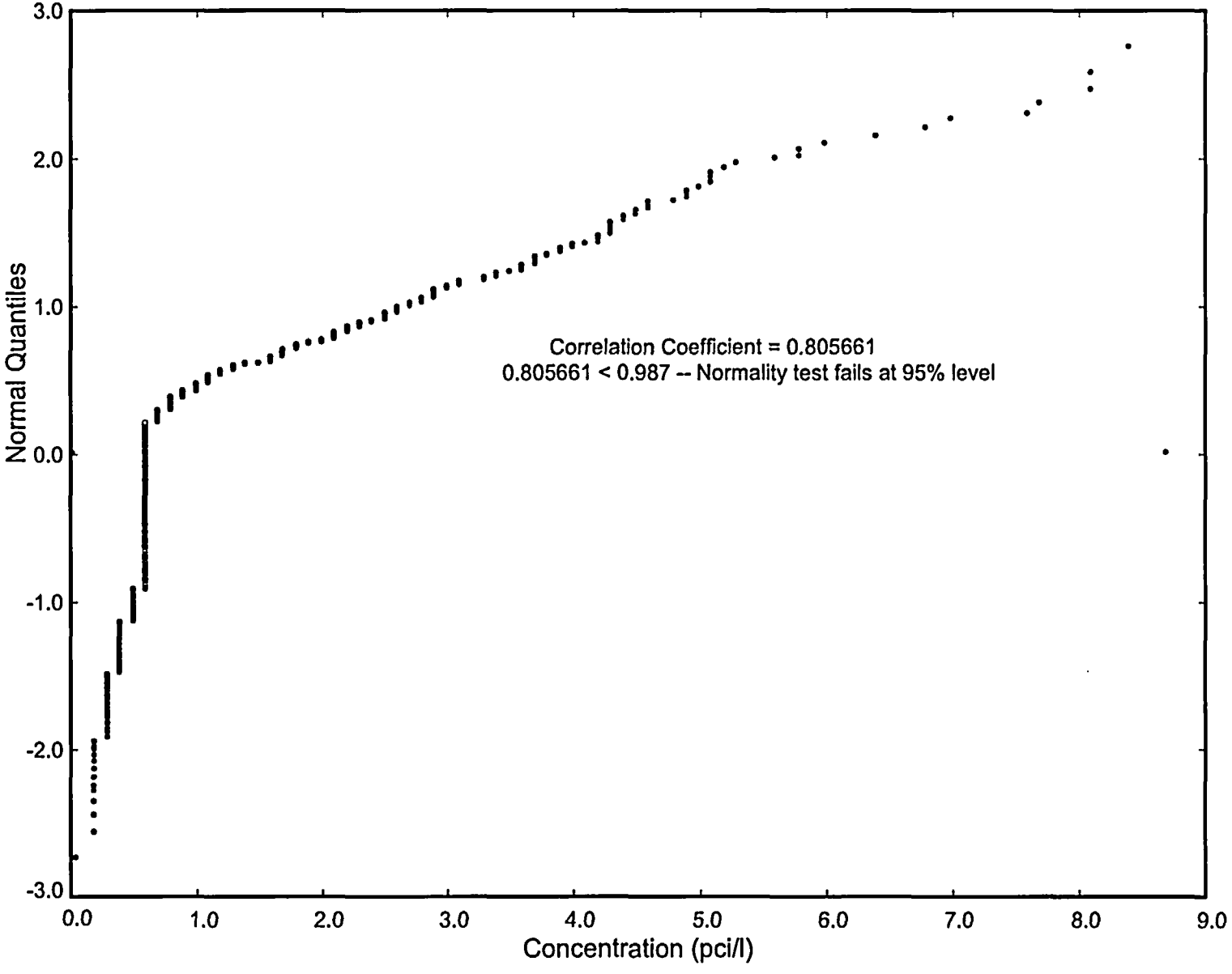


FIGURE C-3
Probability Plot of Combined Radium Values for Background Wells in Zone 1

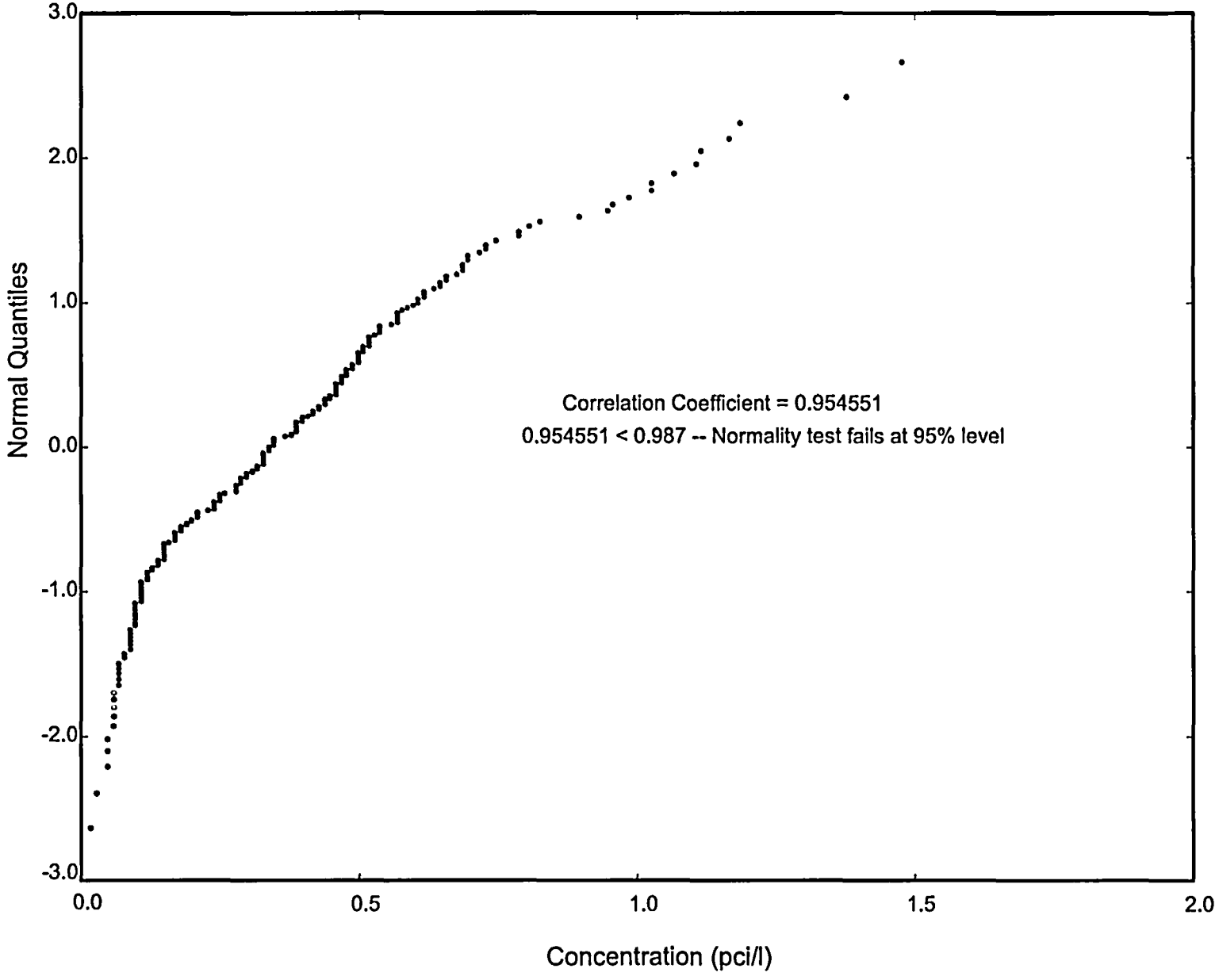
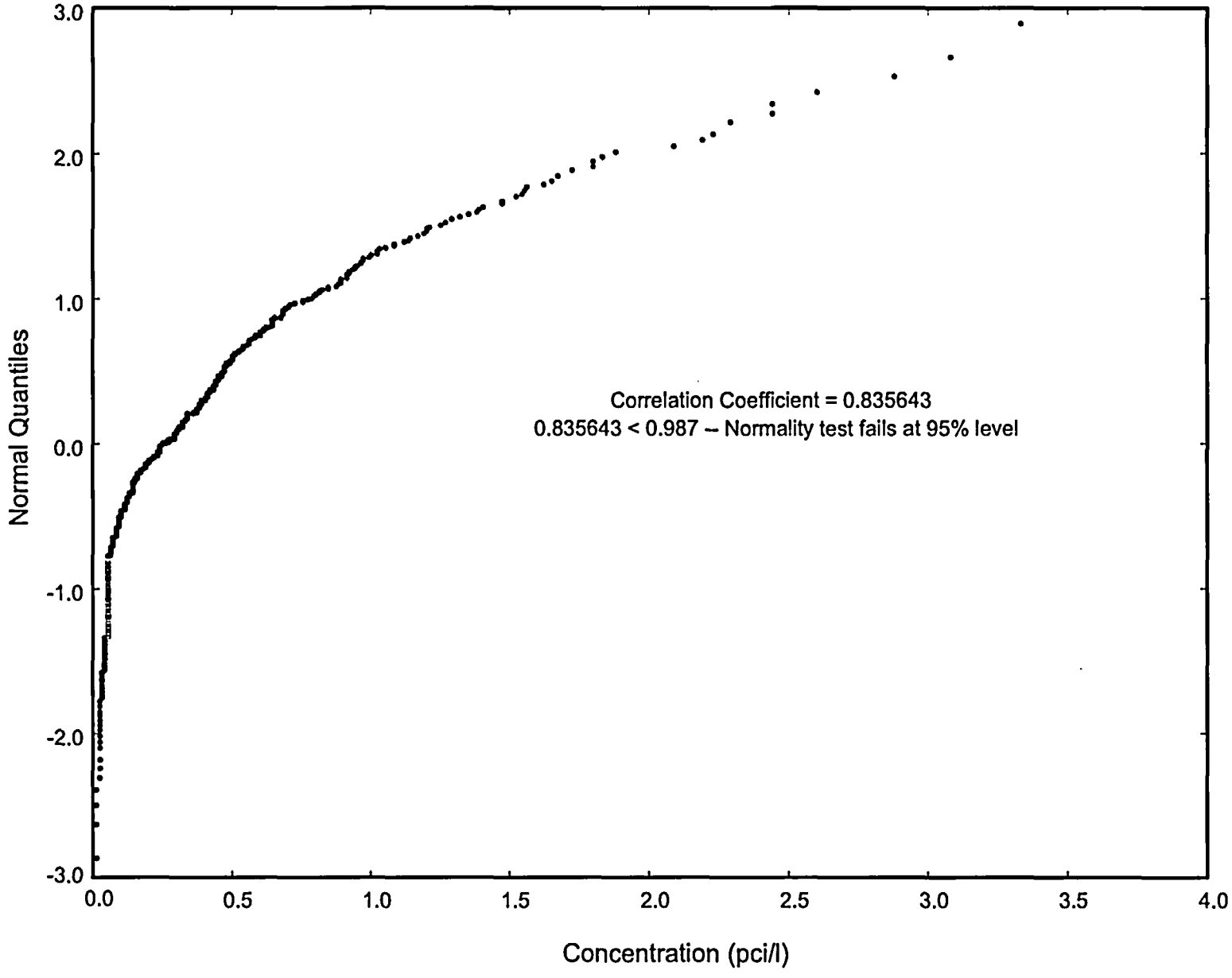


FIGURE C-4
Probability Plot of Combined Radium Values for Compliance Wells in Zone 1



Shapiro-Francia Test of Normality
Southwest
Alluvium

Parameter: radium

Background Locations

Normality Test of Parameter
Concentrations
Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL
Total Number of Measurements = 357

Data Set Standard Deviation = 1.81
Numerator = 286727
Denominator = 409020
W Statistic = 0.701 = 286727 / 409020

5% Critical value of 0.976 exceeds 0.701
Evidence of non-normality at 95% level of significance

1% Critical value of 0.967 exceeds 0.701

Evidence of non-normality at
99% level of significance

Compliance Locations

Normality Test of Parameter
Concentrations
Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL
Total Number of Measurements = 543

Data Set Standard Deviation = 1.492
Numerator = 406449
Denominator = 626943
W Statistic = 0.6483 = 406449 / 626943

5% Critical value of 0.976 exceeds 0.6483
Evidence of non-normality at 95% level of significance

1% Critical value of 0.967 exceeds 0.6483
Evidence of non-normality at 99% level of significance

Shapiro-Francia Test of Normality
Zone 1

Parameter: radium-combined

Background Locations

Normality Test of Parameter
Concentrations
Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL
Total Number of Measurements = 227

Data Set Standard Deviation = 2.66
Numerator = 319896
Denominator = 351230
W Statistic = 0.911 = 319896 / 351230

5% Critical value of 0.976 exceeds 0.911
Evidence of non-normality at 95% level of significance

1% Critical value of 0.967 exceeds 0.911
Evidence of non-normality at 99% level of significance

Compliance Locations

Normality Test of Parameter
Concentrations
Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL
Total Number of Measurements = 319

Data Set Standard Deviation = 5.38224
Numerator = 2.28287e+006
Denominator = 2.8665e+006
W Statistic = 0.796396 = 2.28287e+006 / 2.8665e+006

5% Critical value of 0.976 exceeds 0.796396
Evidence of non-normality at 95% level of significance

1% Critical value of 0.967 exceeds 0.796396
Evidence of non-normality at 99% level of significance

Appendix D
Nonparametric Comparisons of Radium Data from Compliance Wells to Background Wells

Kruskal-Wallis Non-Parametric Test

Southwest Alluvium

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL

Calculation Results:

Kruskal-Wallis H Statistic = 118.7
Kruskal-Wallis H Statistic (adjusted for tied non-detects) = 122.508
95% Confidence comparison value is 14.0671 at 7 degrees of freedom
118.7 > 14.0671 indicating a significant group difference at 5% significance level
122.508 > 14.0671 indicating a significant group difference at 5% significance level when adjusted for ties

Individual Well Comparisons at 1% Significance Level per Comparison
1% Z score is 2.32634
Mean background rank is 483.83

Well	Mean Rank	Dif from Bkg	Critical Value
EPA 23	321	-163	72
0509 D	447	-37	77
632	671	187	77
GW 1	335	-148	75
GW 2	369	-115	77
GW 3	362	-122	77
EPA 28	520	36	77

Individual Well Comparisons at Group-wise 5% Significance Level
(0.714286% Significance Level per comparison)
0.714286% Z score is 2.45727
Mean background rank is 483.8

Well	Mean Rank	Dif from Bkg	Critical Value
EPA 23	321	-163	77
0509 D	447	-37	81
632	671	187	81
GW 1	335	-148	79
GW 2	369	-115	81
GW 3	362	-122	81
EPA 28	520	36	81

Kruskal-Wallis Non-Parametric Test

Zone 1

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL

Calculation Results:

Kruskal-Wallis H Statistic = 142.28
Kruskal-Wallis H Statistic (adjusted for tied non-detects) = 142.28
95% Confidence comparison value is 11.0705 at 5 degrees of freedom
142.28 > 11.07 indicating a significant group difference at 5% significance level
142.28 > 11.07 indicating a significant group difference at 5% significance level when adjusted for ties

Individual Well Comparisons at 1% Significance Level per Comparison
1% Z score is 2.32634
Mean background rank is 241

Well	Mean Rank	Dif from Bkg	Critical Value
604	482	241	52
614	239	-1.4	52
EPA 04	273	33	53
EPA 05	195	-45	53
EPA 07	289	48	52

Individual Well Comparisons at Group-wise 5% Significance Level
(1% Significance Level per comparison)
1% Z score is 2.32634
Mean background rank is 241

Well	Mean Rank	Dif from Bkg	Critical Value
604	482	241	52
614	239	-1.4	52
EPA 04	273	33	53
EPA 05	195	-45	53
EPA 07	289	48	52

Appendix E
Comparison of Radium Data from Compliance Wells to the Site Standard
Two-Sample Test of Proportions

Two-Sample Test of Proportions

Southwest Alluvium

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL
Background measurements = 357
Compliance measurements = 543
Comparison Level =5

20 background measurements exceed 5

19 compliance measurements exceed 5

p background = 0.056 = 20 / 357
p compliance = 0.035 = 19 / 543
p total = 0.043 = 39 / 900

nPs = 19
mPb = 20
n(1-Ps) = 524
m(1-Pb = 337

Zp = -1.516 = -0.0210 / 0.01387
Z critical = 1.64485 at 95% confidence level
-1.51598 < 1.64485
TRUE
No Statistical Significance at 95% Confidence Level
When Compared to Compliance Limit = 5

Two-Sample Test of Proportions

Zone 1

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL
Background measurements = 227
Compliance measurements = 319
Comparison Level = 5

59 background measurements exceed 5

132 compliance measurements exceed 5

p background = 0.26 = 59 / 227
p compliance = 0.41 = 132 / 319
p total = 0.35 = 191 / 546

nPs = 132
mPb = 59
n(1-Ps) = 187
m(1-Pb = 168

Zp = 3.716 = 0.1539 / 0.0414
Z critical = 1.64485 at 95% confidence level

3.716 > 1.64485
Significance is Indicated at 95% Confidence Level
When Compared to Compliance Limit = 5

Appendix F
Example Applications of the Krusakal-Wallis and Two-Sample Test of Proportions with 2004 Quarterly and Multiple Quarter Compliance Sample Data Sets from the Southwest Alluvium and Zone 1

First Quarter 2004

Southwest Alluvium

Kruskal-Wallis Non-Parametric Test

Parameter: radium

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL

Kruskal Wallis Ranks

Background Wells

Background Rank Sum = 65820.5
Background Rank Mean = 184.371

Compliance Wells

Well ID	Date	Result	Rank
0509 D	1/5/2004	0.5	153
EPA 23	1/5/2004	ND<0.6	46.5
GW 1	1/6/2004	ND<0.6	46.5
GW 2	1/5/2004	ND<0.6	46.5
GW 3	1/6/2004	ND<0.6	46.5
632	1/5/2004	1.1	224
EPA 28	1/6/2004	ND<0.6	46.5

Calculation Results:

Kruskal-Wallis H Statistic = 8.6999
Kruskal-Wallis H Statistic (adjusted for tied non-detects) = 8.84266
95% Confidence comparison value is 14.0671 at 7 degrees of freedom
8.6999 < 14.0671 indicating no significant group difference at 5% significance level
8.84266 < 14.0671 indicating no significant group difference at 5% significance level when adjusted for ties

First Quarter 2004

Southwest Alluvium

Two-Sample Test of Proportions

Parameter: radium

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL
Background measurements = 357
Compliance measurements = 7
Comparison Level = 5

20 background measurements exceed 5
0 compliance measurements exceed 5

p background = 0.0560224 = 20 / 357
p compliance = 0 = 0 / 7
p total = 0.0549451 = 20 / 364

nPs = 0 < 5.0
mPb = 20
n(1-Ps) = 7
m(1-Pb = 337

Zp = -0.644171 = -0.0560224 / 0.0869682
Z critical = 1.64485 at 95% confidence level

-0.644171 < 1.64485
No Statistical Significance at 95% Confidence Level
When Compared to Compliance Limit = 5

First Quarter 2004

Zone 1

Kruskal-Wallis Non-Parametric Test

Parameter: radium-combined

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL

Kruskal Wallis Ranks

Background Wells

Background Rank Sum = 26713
Background Rank Mean = 117.678

Compliance Wells

Well ID	Date	Result	Rank
604	1/7/2004	6.8	206
614	1/7/2004	0.8	19
EPA 04	1/13/2004	1.1	42
EPA 05	1/12/2004	1.1	43
EPA 07	1/12/2004	0.4	5

Calculation Results:

Kruskal-Wallis H Statistic = 9.14973
Kruskal-Wallis H Statistic (adjusted for tied non-detects) = 9.14973
95% Confidence comparison value is 11.0705 at 5 degrees of freedom
9.14973 < 11.0705 indicating no significant group difference at 5% significance level
9.14973 < 11.0705 indicating no significant group difference at 5% significance level when adjusted for ties

VEOLIA Water

First Quarter 2004

Zone 1

Two-Sample Test of Proportions

Parameter: radium-combined

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL
Background measurements = 227
Compliance measurements = 5
Comparison Level = 5

59 background measurements exceed 5
1 compliance measurements exceed 5

p background = 0.259912 = 59 / 227
p compliance = 0.2 = 1 / 5
p total = 0.258621 = 60 / 232

nPs = 1 < 5.0
mPb = 59
n(1-Ps) = 4 < 5.0
m(1-Pb = 168

Zp = -0.302632 = -0.0599119 / 0.197969
Z critical = 1.64485 at 95% confidence level

-0.302632 < 1.64485
No Statistical Significance at 95% Confidence Level
When Compared to Compliance Limit = 5

Second Quarter 2004

Southwest Alluvium

Kruskal-Wallis Non-Parametric Test

Parameter: radium
Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL

Kruskal Wallis Ranks

Background Wells
Background Rank Sum = 65994
Background Rank Mean = 184.857

Compliance Wells

Well ID	Date	Result	Rank
0509 D	4/5/2004	ND<0.6	47
EPA 23	4/5/2004	ND<0.6	47
GW 1	4/5/2004	ND<0.6	47
GW 2	4/5/2004	ND<0.6	47
GW 3	4/6/2004	ND<0.6	47
632	4/5/2004	0.5	154
EPA 28	4/6/2004	ND<0.6	47

Calculation Results:
Kruskal-Wallis H Statistic = 10.2024
Kruskal-Wallis H Statistic (adjusted for tied non-detects) = 10.3754
95% Confidence comparison value is 14.0671 at 7 degrees of freedom
10.2024 < 14.0671 indicating no significant group difference at 5% significance level
10.3754 < 14.0671 indicating no significant group difference at 5% significance level when adjusted for ties

Second Quarter 2004

Southwest Alluvium

Two-Sample Test of Proportions

Parameter: radium

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL
Background measurements = 357
Compliance measurements = 7
Comparison Level = 5

20 background measurements exceed 5
0 compliance measurements exceed 5

p background = 0.0560224 = 20 / 357
p compliance = 0 = 0 / 7
p total = 0.0549451 = 20 / 364

nPs = 0 < 5.0
mPb = 20
n(1-Ps) = 7
m(1-Pb = 337

Zp = -0.644171 = -0.0560224 / 0.0869682
Z critical = 1.64485 at 95% confidence level

-0.644171 < 1.64485
No Statistical Significance at 95% Confidence Level
When Compared to Compliance Limit = 5

Second Quarter 2004

Zone 1

Kruskal-Wallis Non-Parametric Test
Parameter: radium-combined
Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL

Kruskal Wallis Ranks

Background Wells
Background Rank Sum = 26375
Background Rank Mean = 116.189

Compliance Wells

Well ID	Date	Result	Rank
604	4/7/2004	6.2	200
614	4/7/2004	3.8	123
EPA 04	4/13/2004	0.7	16
EPA 05	4/13/2004	4	134
EPA 07	4/13/2004	5.2	180

Calculation Results:
Kruskal-Wallis H Statistic = 4.76731
Kruskal-Wallis H Statistic (adjusted for tied non-detects) = 4.76731
95% Confidence comparison value is 11.0705 at 5 degrees of freedom
4.76731 < 11.0705 indicating no significant group difference at 5% significance level
4.76731 < 11.0705 indicating no significant group difference at 5% significance level when adjusted for ties

Second Quarter 2004

Zone 1

Two-Sample Test of Proportions

Parameter: radium-combined

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL
Background measurements = 227
Compliance measurements = 5
Comparison Level = 5

59 background measurements exceed 5
2 compliance measurements exceed 5

p background = 0.259912 = 59 / 227
p compliance = 0.4 = 2 / 5
p total = 0.262931 = 61 / 232

nPs = 2 < 5.0
mPb = 59
n(1-Ps) = 3 < 5.0
m(1-Pb = 168

Zp = 0.70385 = 0.140088 / 0.199031
Z critical = 1.64485 at 95% confidence level

0.70385 < 1.64485
No Statistical Significance at 95% Confidence Level
When Compared to Compliance Limit = 5

Third Quarter 2004

Southwest Alluvium

Kruskal-Wallis Non-Parametric Test

Parameter: radium

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL

Kruskal Wallis Ranks

Background Wells

Background Rank Sum = 65512.5
Background Rank Mean = 183.508

Compliance Wells

Well ID	Date	Result	Rank
0509 D	7/12/2004	0.5	152
EPA 23	7/12/2004	ND<0.6	45.5
GW 1	7/12/2004	ND<0.6	45.5
GW 2	7/12/2004	ND<0.6	45.5
GW 3	7/13/2004	0.3	116
632	7/12/2004	7.6	360
EPA 28	7/13/2004	0.5	153

Calculation Results:

Kruskal-Wallis H Statistic = 8.52618
Kruskal-Wallis H Statistic (adjusted for tied non-detects) = 8.65702
95% Confidence comparison value is 14.0671 at 7 degrees of freedom
8.52618 < 14.0671 indicating no significant group difference at 5% significance level
8.65702 < 14.0671 indicating no significant group difference at 5% significance level when adjusted for ties

Third Quarter 2004

Southwest Alluvium

Two-Sample Test of Proportions

Parameter: radium

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL
Background measurements = 357
Compliance measurements = 7
Comparison Level = 5

20 background measurements exceed 5
1 compliance measurements exceed 5

p background = 0.0560224 = 20 / 357
p compliance = 0.142857 = 1 / 7
p total = 0.0576923 = 21 / 364

nPs = 1 < 5.0
mPb = 20
n(1-Ps) = 6
m(1-Pb = 337

Zp = 0.975822 = 0.0868347 / 0.0889862
Z critical = 1.64485 at 95% confidence level

0.975822 < 1.64485
No Statistical Significance at 95% Confidence Level
When Compared to Compliance Limit = 5

Third Quarter 2004

Zone 1

Kruskal-Wallis Non-Parametric Test

Parameter: radium-combined

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL

Kruskal Wallis Ranks

Background Wells

Background Rank Sum = 26523
Background Rank Mean = 116.841

Compliance Wells

Well ID	Date	Result	Rank
604	7/14/2004	4.3	142
614	7/14/2004	0.6	11
EPA 04	7/20/2004	4	134
EPA 05	7/20/2004	2	71
EPA 07	7/20/2004	4.4	147

Calculation Results:

Kruskal-Wallis H Statistic = 3.35512
Kruskal-Wallis H Statistic (adjusted for tied non-detects) = 3.35512
95% Confidence comparison value is 11.0705 at 5 degrees of freedom
3.35512 < 11.0705 indicating no significant group difference at 5% significance level
3.35512 < 11.0705 indicating no significant group difference at 5% significance level when adjusted for ties

Third Quarter 2004

Zone 1

Two-Sample Test of Proportions

Parameter: radium-combined

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL
Background measurements = 227
Compliance measurements = 5
Comparison Level = 5

59 background measurements exceed 5
0 compliance measurements exceed 5

p background = 0.259912 = 59 / 227
p compliance = 0 = 0 / 5
p total = 0.25431 = 59 / 232

nPs = 0 < 5.0
mPb = 59
n(1-Ps) = 5
m(1-Pb = 168

Zp = -1.32014 = -0.259912 / 0.196883
Z critical = 1.64485 at 95% confidence level

-1.32014 < 1.64485
No Statistical Significance at 95% Confidence Level
When Compared to Compliance Limit = 5

Fourth Quarter 2004

Southwest Alluvium

Kruskal-Wallis Non-Parametric Test

Parameter: radium

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL

Kruskal Wallis Ranks

Background Wells

Background Rank Sum = 65476.5
Background Rank Mean = 183.408

Compliance Wells

Well ID	Date	Result	Rank
0509 D	10/4/2004	ND<0.6	45.5
EPA 23	10/4/2004	1.7	252
GW 1	10/4/2004	ND<0.6	45.5
GW 2	10/4/2004	ND<0.6	45.5
GW 3	1/4/2005	0.2	98
632	10/4/2004	5.8	350
EPA 28	10/5/2004	0.3	117

Calculation Results:

Kruskal-Wallis H Statistic = 9.11498
Kruskal-Wallis H Statistic (adjusted for tied non-detects) = 9.25486
95% Confidence comparison value is 14.0671 at 7 degrees of freedom
9.11498 < 14.0671 indicating no significant group difference at 5% significance level
9.25486 < 14.0671 indicating no significant group difference at 5% significance level when adjusted for ties

Fourth Quarter 2004

Southwest Alluvium

Two-Sample Test of Proportions

Parameter: radium

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL
Background measurements = 357
Compliance measurements = 7
Comparison Level = 5

20 background measurements exceed 5
1 compliance measurements exceed 5

p background = 0.0560224 = 20 / 357
p compliance = 0.142857 = 1 / 7
p total = 0.0576923 = 21 / 364

nPs = 1 < 5.0
mPb = 20
n(1-Ps) = 6
m(1-Pb = 337

Zp = 0.975822 = 0.0868347 / 0.0889862
Z critical = 1.64485 at 95% confidence level

0.975822 < 1.64485
No Statistical Significance at 95% Confidence Level
When Compared to Compliance Limit = 5

Fourth Quarter 2004

Zone 1

Kruskal-Wallis Non-Parametric Test

Parameter: radium-combined
Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL

Kruskal Wallis Ranks

Background Wells
Background Rank Sum = 26402
Background Rank Mean = 116.308

Compliance Wells

Well ID	Date	Result	Rank
604	10/6/2004	7.1	211
614	10/6/2004	1.7	63
EPA 04	10/12/2004	4.8	163
EPA 05	10/12/2004	3.2	104
EPA 07	10/12/2004	2.5	85

Calculation Results:
Kruskal-Wallis H Statistic = 3.35465
Kruskal-Wallis H Statistic (adjusted for tied non-detects) = 3.35465
95% Confidence comparison value is 11.0705 at 5 degrees of freedom
3.35465 < 11.0705 indicating no significant group difference at 5% significance level
3.35465 < 11.0705 indicating no significant group difference at 5% significance level when adjusted for ties

Fourth Quarter 2004

Zone 1

Two-Sample Test of Proportions

Parameter: radium-combined

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL
Background measurements = 227
Compliance measurements = 5
Comparison Level = 5

59 background measurements exceed 5
1 compliance measurements exceed 5

p background = 0.259912 = 59 / 227
p compliance = 0.2 = 1 / 5
p total = 0.258621 = 60 / 232

nPs = 1 < 5.0
mPb = 59
n(1-Ps) = 4 < 5.0
m(1-Pb = 168

Zp = -0.302632 = -0.0599119 / 0.197969
Z critical = 1.64485 at 95% confidence level

-0.302632 < 1.64485
No Statistical Significance at 95% Confidence Level
When Compared to Compliance Limit = 5

Multiple Quarters 2003 - 2004

Southwest Alluvium

Kruskal-Wallis Non-Parametric Test

Parameter: radium

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL

Kruskal Wallis Ranks

Background Wells

Background Rank Sum = 71145
Background Rank Mean = 199.286

Compliance Wells

Well ID	Date	Result	Rank
0509 D	1/5/2004	0.5	168
	4/5/2004	ND<0.6	53
	7/12/2004	0.5	169
	10/4/2004	ND<0.6	53
Rank Sum = 443			
Rank Mean = 110.75			
EPA 23	1/5/2004	ND<0.6	53
	4/5/2004	ND<0.6	53
	7/12/2004	ND<0.6	53
	10/4/2004	1.7	272
Rank Sum = 431			
Rank Mean = 107.75			
GW 1	1/6/2004	ND<0.6	53
	4/5/2004	ND<0.6	53
	7/12/2004	ND<0.6	53
	10/4/2004	ND<0.6	53
Rank Sum = 212			
Rank Mean = 53			
GW 2	1/5/2004	ND<0.6	53
	4/5/2004	ND<0.6	53
	7/12/2004	ND<0.6	53
	10/4/2004	ND<0.6	53
Rank Sum = 212			
Rank Mean = 53			
GW 3	1/6/2004	ND<0.6	53
	4/6/2004	ND<0.6	53
	7/13/2004	0.3	131
	10/5/2004	ND<0.6	53
Rank Sum = 290			
Rank Mean = 72.5			

632	1/5/2004	1.1	242
	4/5/2004	0.5	170
	7/12/2004	7.6	381
	10/4/2004	5.8	370

Rank Sum = 1163
Rank Mean = 290.75

EPA 28	1/6/2004	ND<0.6	53
	4/6/2004	ND<0.6	53
	7/13/2004	0.5	171
	10/5/2004	0.3	132

Rank Sum = 409
Rank Mean = 102.25

Calculation Results:

Kruskal-Wallis H Statistic = 28.7689
Kruskal-Wallis H Statistic (adjusted for tied non-detects) = 29.3645
95% Confidence comparison value is 14.0671 at 7 degrees of freedom
28.7689 > 14.0671 indicating a significant group difference at 5% significance level
29.3645 > 14.0671 indicating a significant group difference at 5% significance level when adjusted for ties

Individual Well Comparisons at 1% Significance Level per Comparison

1% Z score is 2.32634
Mean background rank is 199.286

Well	Mean Rank	Dif from Bkg	Critical Value
0509 D	110.75	-88.5357	130.166
EPA 23	107.75	-91.5357	130.166
GW 1	53	-146.286	130.166
GW 2	53	-146.286	130.166
GW 3	72.5	-126.786	130.166
632	290.75	91.4643	130.166
EPA 28	102.25	-97.0357	130.166

Individual Well Comparisons at Groupwise 5% Significance Level (0.714286% Significance Level per comparison)

0.714286% Z score is 2.45727
Mean background rank is 199.286

Well	Mean Rank	Dif from Bkg	Critical Value
0509 D	110.75	-88.5357	137.492
EPA 23	107.75	-91.5357	137.492
GW 1	53	-146.286	137.492
GW 2	53	-146.286	137.492
GW 3	72.5	-126.786	137.492
632	290.75	91.4643	137.492
EPA 28	102.25	-97.0357	137.492

Multiple Quarters 2003 - 2004

Southwest Alluvium

Two-Sample Test of Proportions

Parameter: radium

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL
Background measurements = 357
Compliance measurements = 28
Comparison Level = 5

20 background measurements exceed 5
2 compliance measurements exceed 5

p background = 0.0560224 = 20 / 357
p compliance = 0.0714286 = 2 / 28
p total = 0.0571429 = 22 / 385

nPs = 2 < 5.0
mPb = 20
n(1-Ps) = 26
m(1-Pb = 337

Zp = 0.3382 = 0.0154062 / 0.0455534
Z critical = 1.64485 at 95% confidence level

0.3382 < 1.64485
No Statistical Significance at 95% Confidence Level
When Compared to Compliance Limit = 5

Multiple Quarters 2003 - 2004

Zone 1

Kruskal-Wallis Non-Parametric Test

Parameter: radium-combined

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL

Kruskal Wallis Ranks

Background Wells

Background Rank Sum = 29582
Background Rank Mean = 130.317

Compliance Wells

Well ID	Date	Result	Rank
604	7/9/2003	10	248
	10/8/2003	4.9	186
	1/7/2004	6.8	229
	4/7/2004	6.2	222
	7/14/2004	4.3	157
	10/6/2004	7.1	235
Rank Sum = 1277			
Rank Mean = 212.833			
614	7/9/2003	0.5	10
	10/8/2003	3.5	133
	1/7/2004	0.8	23
	4/7/2004	3.8	137
	7/14/2004	0.6	14
	10/6/2004	1.7	73
Rank Sum = 390			
Rank Mean = 65			
EPA 04	7/15/2003	4.6	173
	10/14/2003	6.1	218
	1/13/2004	1.1	47
	4/13/2004	0.7	20
	7/20/2004	4	148
	10/12/2004	4.8	182
Rank Sum = 788			
Rank Mean = 131.333			
EPA 05	7/9/2003	1.6	67
	10/14/2003	4.3	158
	1/12/2004	1.1	48
	4/13/2004	4	149
	7/20/2004	2	81
	10/12/2004	3.2	115
Rank Sum = 618			
Rank Mean = 103			

EPA 07	7/9/2003	0.9	30
	10/14/2003	ND<0.6	2
	1/12/2004	0.4	6
	4/13/2004	5.2	201
	7/20/2004	4.4	163
	10/12/2004	2.5	96

Rank Sum = 498
Rank Mean = 83

Calculation Results:

Kruskal-Wallis H Statistic = 15.1882
Kruskal-Wallis H Statistic (adjusted for tied non-detects) = 15.1883
95% Confidence comparison value is 11.0705 at 5 degrees of freedom
15.1882 > 11.0705 indicating a significant group difference at 5% significance level
15.1883 > 11.0705 indicating a significant group difference at 5% significance level when adjusted for ties

Individual Well Comparisons at 1% Significance Level per Comparison

1% Z score is 2.32634
Mean background rank is 130.317

Well	Mean Rank	Dif from Bkg	Critical Value
604	212.833	82.5162	71.5235
614	65	-65.3172	71.5235
EPA 04	131.333	1.01615	71.5235
EPA 05	103	-27.3172	71.5235
EPA 07	83	-47.3172	71.5235

Individual Well Comparisons at Groupwise 5% Significance Level (1% Significance Level per comparison)

1% Z score is 2.32634
Mean background rank is 130.317

Well	Mean Rank	Dif from Bkg	Critical Value
604	212.833	82.5162	71.5235
614	65	-65.3172	71.5235
EPA 04	131.333	1.01615	71.5235
EPA 05	103	-27.3172	71.5235
EPA 07	83	-47.3172	71.5235

Multiple Quarters 2003 - 2004

Zone 1

Two-Sample Test of Proportions

Parameter: radium-combined

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL
Background measurements = 227
Compliance measurements = 30
Comparison Level = 5

59 background measurements exceed 5
6 compliance measurements exceed 5

p background = 0.259912 = 59 / 227
p compliance = 0.2 = 6 / 30
p total = 0.252918 = 65 / 257

nPs = 6
mPb = 59
n(1-Ps) = 24
m(1-Pb = 168

Zp = -0.709489 = -0.0599119 / 0.0844437
Z critical = 1.64485 at 95% confidence level

-0.709489 < 1.64485
No Statistical Significance at 95% Confidence Level
When Compared to Compliance Limit = 5