Designated Original

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February 22, 2006

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

Dear Mr. Janosko:

On September 30, 2005 Unite Nuclear Corporation (UNC) requested an amendment to Source Materials License SUA-1475, Condition 30.B. to revise the method by which compliance with the groundwater protection standard for combined radium-226 and 228 is evaluated in the Southwest Alluvium and Zone 1. By letter dated January 23, 2006, the Nuclear Regulatory Commission (NRC) forwarded the meeting report from the January 18, 2006 meeting that was held to support the license amendment request. NRC requested that UNC re-evaluate the statistical tests by considering the 95th percentile of the background data distribution. This revised submission contains the results of the action items that were requested from the meeting.

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 to the original license amendment request 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), Revised February 2006). 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 **in Zone 3, 5.2 pCi/l in the Southwest Alluvium, and 9.4 pCi/l in Zone 1;** 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 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, lumped from the most recent two quarters. If one or more of the quarterly applications of the Two-Sample Test of Proportions indicates a statistically significant exceedance in the course of a year, the test will be applied to data lumped from all four quarters in the fourth quarter of that year.

Please contact me if you have any questions.

Sincerely,

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

enc.
cc: Paul Michalak, NRC
Mark Purcell, USEPA
Larry Bush, UNC
Mark Jancin, NA Water Systems (w/out encl.)

NA WaterSystems

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Document/Drawing Transmittal

To: Gary Janosko, US NRC

Date: February 23, 2006

Project No: 56006821

RE: Revised license amendment request for changing the GWPS for radium in Source Materials License SUA-1475 (TAC LU0092) groundwater corrective action -- Church Rock site, New Mexico

Attention:

We are sending herewithin:

- ☐ Drawings
- ☒ Documents
- ☐ ______

Copies	Drawing No.	Description
1		Revised radium license amendment request & technical analysis report

These are transmitted as checked below:

- ☐ For Your Use
- ☐ For Review & Comment
- ☐ Contractor Coordination Req'd
- ☐ As Requested
- ☒ For Approval
- ☐ Drawing Revision Forthcoming
- ☐

Remarks: Submitted on behalf of United Nuclear Corporation.

Copies to:
Paul Michalak, US NRC
Mark Purcell, US EPA
Larry Bush, UNC
Roy Blickwedel, GE

Very truly yours,

Veolia Water Systems

by: [signature]
Mark Jancin

United Nuclear Corporation
Gallup, New Mexico

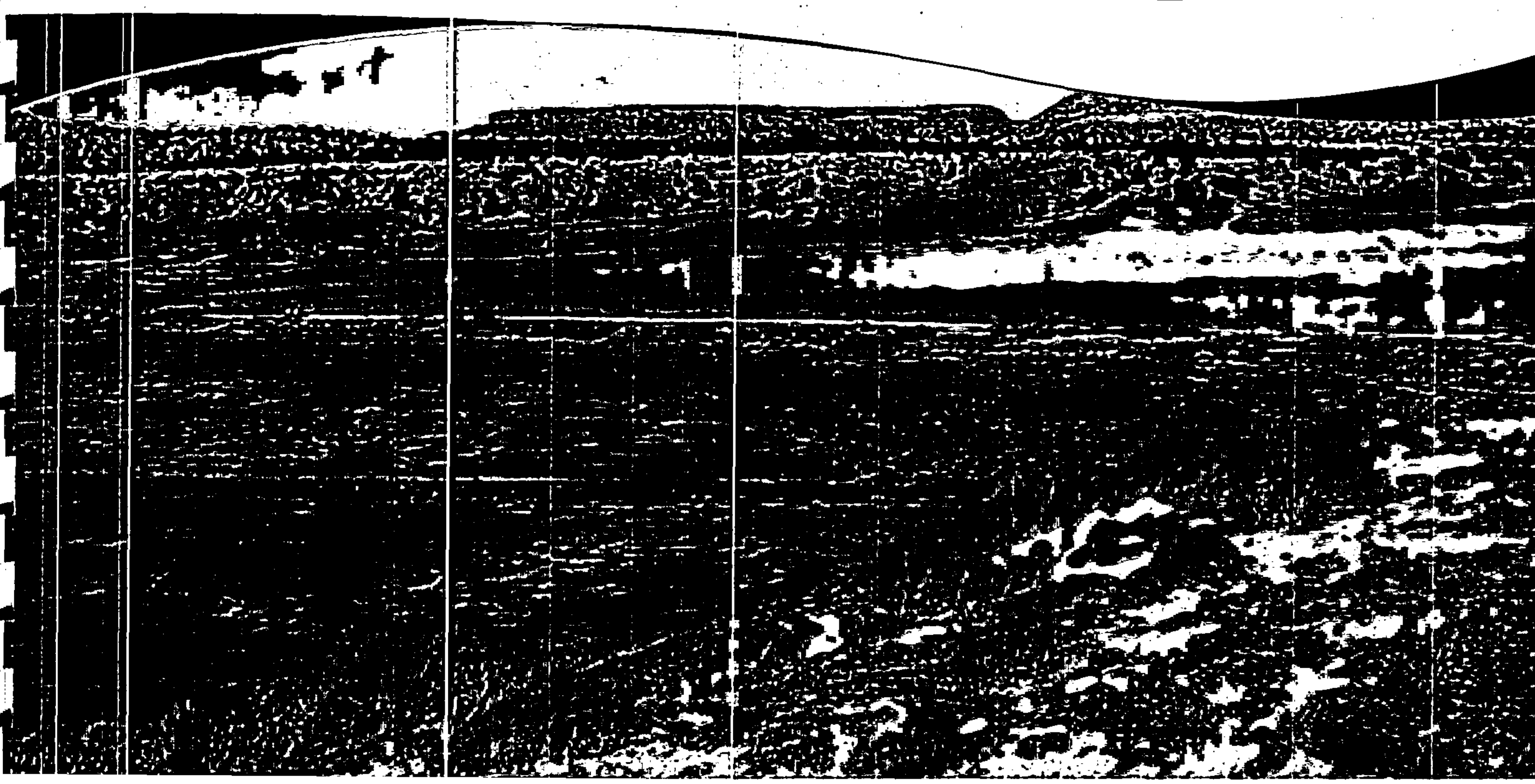
Technical Analysis Report in Support of License Amendment Request for Changing the Method of Determining Exceedances of the Combined Radium Groundwater Protection Standard in Source Materials License SUA-1475 (TAC LU0092)

Groundwater Corrective Action Program

Church Rock Site, Church Rock, New Mexico

Revised February 2006

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

REVISED FEBRUARY 2006

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United Nuclear Corporation
Radium Technical Analysis Report
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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 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.

This report revises a previous submittal to the U.S. Nuclear Regulatory Commission (NRC) made in support of a license amendment request (GE, September 30, 2005). Based on subsequent discussions with the NRC and a meeting with them on January 18, 2006, this revised report and resubmittal supersedes the earlier draft.

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 differ 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 site standard was based on a graphical analysis of a very limited number of background samples available in 1988 (Nuclear Regulatory Commission, Docket No. 40-8907, SUA-1475, Amendment No. 4, January 1989). The present method of comparison to this standard 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 examined as potential alternatives to the current method. Based on this analysis, the Two-Sample Test of Proportions is proposed to be used quarterly to compare combined radium results from compliance wells to revised standards. New standards for combined-radium are proposed for the Southwest Alluvium and Zone 1, on the basis of statistical analyses of the differing background water quality in those hydrostratigraphic units. 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 section 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 Appendices A and C 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 between July 1989 and October 2004. 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 2005 site annual review report, N.A. Water Systems, December 2005). 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 for individual wells and for pooled historic data are shown in Figures 1 and 2 for Zone 1 and in Figures 3 and 4 for the Southwest Alluvium.

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 (see Figure 2). 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.

Box and whisker plots illustrate the sample distributions of combined radium in Zone 1 (Figures 1 and 2) and the Southwest Alluvium (Figures 3 and 4). 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 through 4 and in all of the statistical analyses presented in this report (see following section).

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Table 4
Summary Statistics for Combined Radium

	Southwest Alluvium	Zone 1
Pooled		
Total Measurements	890	546
Total Non-Detects	281 (31.6%)	5 (0.9%)
Pooled Mean	1.48	5.01
Pooled Std Dev	1.63	4.56
Compliance		
Measurements	536	319
Non-Detects	194 (36%)	3 (0.94%)
Mean	1.38	5.8
Std Dev	1.5	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	354	227
Non-Detects	87 (25%)	2 (0.09%)
Mean	1.64	3.9
Std Dev	1.81	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 historic 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 Kruskal-Wallis test ranks each of sample concentrations in the background and compliance data sets. The method incorporates procedures recommended by EPA guidance (EPA, 1992) for tied results and non-detects. The test compares the rank mean of the compliance well sample set to that of the background sample set. The null hypothesis of this test is that the compliance and background distributions are the same. A finding of statistical significance indicates that the null hypothesis should be rejected, because the two distributions are different. This could mean that one distribution is shifted relative to the other (translation) or than the shapes of the distributions are different (skewness or kurtosis).

The second part of the Kruskal-Wallis test compares rank means of the compliance well sample sets, individually by well, to that of the background sample set. The null hypothesis is the same as for the group-wise comparison, except that the results apply individually to each compliance well data 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.

The results of the Kruskal-Wallis tests for the Southwest Alluvium and Zone 1 are provided in Appendix D. The test results for Zone 1 indicate that as a group, the compliance wells have statistically significant differences from the background data. The box and whisker plot in Figure 2 illustrates the reason for this outcome. While the compliance and background sample distributions are approximately similar at the lower concentration ranges, the upper half of the compliance sample distribution extends to higher concentrations than the background sample distribution. The individual well comparisons indicate one Zone 1 compliance well sample data set, 604, was significantly elevated relative to the background data. It is apparent from the box and whisker plot in Figure 1 that the sample data from well 604 is largely responsible for the finding of significant differences in the group-wise comparison.

The test results for the Southwest Alluvium also indicate a statistically significant difference between the compliance and background data sets in the group-wise comparison. However, as illustrated by Figure 4, the reason for this outcome is different than was the case for Zone 1. In this case, it is the upper half of the background sample distribution that extends to higher concentrations than the compliance data set. In the individual well comparisons, 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 EPA guidance for the Kruskal-Wallis test (EPA, 1992) implicitly assumes that a finding of significance in the group-wise comparison and consequent rejection of the

null hypothesis is evidence of contamination (i.e., that the compliance data are significantly elevated relative to the background data). The guidance directs attention to the individual well comparisons to determine which wells were responsible for the exceedance. These assumptions are reasonable in many of the circumstances in which the EPA guidance might be used (e.g. groundwater contamination at RCRA facilities). However, statistical results should be interpreted in the context of site conditions. The singular circumstance at the Church Rock site is that the background groundwater was derived primarily from a source (mine water discharge) having relatively high concentrations of several constituents of concern, combined-radium included. Therefore, the implicit assumption of the EPA guidance is not applicable to usage of the Kruskal-Wallis test at the Church Rock site. For example, the results of the group-wise comparison for the Southwest Alluvium properly should be interpreted as an indication that the background sample distribution is elevated relative to the compliance sample distribution. Yet the second part of the test found that the sample data from compliance well 632 was elevated with respect to the background. Taken as a whole, the test results are ambiguous.

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) and to more statistically meaningful and consistent reference points equal to the 95th percentile of the background concentrations in the respective hydrostratigraphic units. 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.

Similar results are obtained with the Two-Sample Test of Proportions if the 95th percentile of the background sample distribution is used as the comparison level instead of the site standard. The reason for this similar outcome is that the 95th percentile of the background samples is 5.2 pCi/L (see Table 4), which is very close to the site standard. As shown in Table 4, only 2.4 percent of compliance samples exceeded this level compared with 5 percent of the background samples. An advantage of using the 95th percentile instead of the current site standard is that it ties the point of comparison to a consistent concentration relative to the high end of the background distribution. This difference is relatively small in the Southwest Alluvium but more significant in Zone 1, as shown in the next section.

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. However, 26 percent of the background samples exceeded the site standard in Zone 1 (see Table 4), which means that the site standard occupies a position much lower in the background distribution (74th percentile) than is the case in the Southwest Alluvium. A more consistent comparison is made if the 95th percentile of the Zone 1 background distribution (9.4 pCi/L, see Table 4) is used as the point of comparison.

The Two-Sample Test of Proportions indicates that the proportion of compliance samples that exceed 9.4 pCi/L is significantly greater than the proportion of background samples. This result is consistent with the fact that approximately 17 percent of the compliance samples fall into this group, as shown in Table 4. This outcome is more meaningful than that obtained using the site standard, because the comparison is focused on the upper 5 percent of the background distribution. Use of the 95th percentile of background has the added advantages of being both objectively and intrinsically applicable to each hydrostratigraphic unit.

United Nuclear Corporation Radium Technical Analysis Report Section 3 Discussion

In Section 2 of this report, the Two-Sample Test of Proportions and the Kruskal-Wallis test were used to compare historic (1989-2004) compliance sample data to background sample data. The Two-Sample Test of Proportions compared the proportions of each distribution that exceeded a reference concentration. When applied using the 95th percentile of the background sample distribution as the reference concentration, the Two-Sample Test of Proportions effectively focuses the comparison of compliance data to a fixed upper portion of the background distribution. In contrast, the Kruskal-Wallis test compares the entirety of the compliance and background distributions in a test of whether there are any significant differences between those distributions. As explained in Section 2, conditions at the Church Rock site can make interpretation of the Kruskal-Wallis test results ambiguous: a finding of significant difference could mean that the compliance data are elevated relative to background, or that the reverse condition is true. Further ambiguity is possible if the group-wise comparison and individual well comparisons reach apparently opposed outcomes. This ambiguous result was obtained in the test of historic data from the Southwest Alluvium.

The Kruskal-Wallis test is a useful adjunct to the other statistical methods used in Section 2 to examine differences between the historic compliance and background sample distributions. However, site conditions and the inherent ambiguity of the Kruskal-Wallis test make it problematic for regular testing of compliance data for evidence of standard exceedances. Findings of statistically significant differences (from the background distribution) cannot be taken *apriori* as evidence of exceedance. Furthermore, based on comparisons made with historic data from the Southwest Alluvium it is more likely that this would be the incorrect conclusion to draw from a finding of significant differences.

For the reasons outlined above, the recommendation is made in Section 4 of this report that the Two-Sample Test of Proportions is to be used for quarterly evaluations of compliance sample data. The reference concentrations for the test are proposed to be the 95th percentiles of the background distributions specific to Zone 1 and the Southwest Alluvium. For continuity, these new site standards for combined radium are recommended to be fixed, as they are presently based on the large pool of historic background samples, at 9.4 piC/L for Zone 1 and 5.2 piC/L for the Southwest Alluvium. The reason for the proposed change to different standards for the Southwest Alluvium and Zone 1 is that the 95th percentiles, as calculated in Section

2, provide well-documented, consistent points of reference near the upper tails of the very different background distributions in these two hydrostratigraphic units.

Unlike the Kruskal-Wallis test, the Two-Sample Test of Proportions does not explicitly compare samples from individual wells to the background distribution. However, this can be accomplished by a straightforward comparison of the quarterly compliance sample results from each well to the proposed new standards. In this way it will be obvious which well samples contributed to a finding of statistically significant exceedance.

It is informative to examine the application of the proposed tests to compliance sample data sets collected quarterly from the Southwest Alluvium and Zone 1. The example applications of the tests presented below are intended to illustrate the methodologies recommended in Section 4 of this report. Four quarterly sets of tests are presented. Each applies the Two-Sample Test of Proportions to recent (2004-2005) compliance data sets from the Southwest Alluvium and Zone 1. The 2005 data have been presented in Appendices A (Southwest Alluvium) and C (Zone 1) of the 2005 annual review report (N.A. Water Systems).

Unlike the historical data sets described in Section 2, the quarterly compliance data sets are relatively small (7 samples from the Southwest Alluvium and 5 samples from Zone 1). The relatively small compliance sample numbers would constrain the power of any statistical test to discriminate differences with the much larger background data sets. To overcome this limitation two consecutive quarters of compliance data are lumped for the tests. For example, fourth quarter 2004 data are lumped with first quarter 2005 data for the initial set of tests for 2005.

Southwest Alluvium

Example applications of the Two-Sample Test of Proportions to lumped quarterly compliance sample sets from 2004 and 2005 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 compliance data that exceeded the 95th percentile of background (5.2 pCi/L, see Table 4) was not significantly greater than the 5% that exceeded this value in the background data set. None of the 2005 compliance sample sets had a combined radium result higher than the 5.2 pCi/L. One sample from the 4th quarter of 2004 (5.8 pCi/L in Well 632) exceeded 5.2 pCi/L, but this was not found to be statistically significant in the pool of 14 compliance samples considered by the first quarter 2005 test (Appendix F).

The results of the Two-Sample Sample Test of Proportions with lumped data from 2005 are intuitively reasonable, given the demonstrated elevation of background concentrations over the historic pool of compliance samples (see Section 2). However, it is also reasonable to question: how many exceedances of 95th percentile

of background would be required in a pool of 14 compliance samples (two lumped quarters) for the test to indicate statistical significance at a 95% confidence level? To answer this question a series of trials were prepared using the same fixed background pool, but with varying numbers of compliance data that exceeded 5.2 pCi/L. These trials indicate that if a total of more than two samples from consecutive quarters exceed 5.2 pCi/L (a proportion of 14%) this will be found to be statistically significant at a 95% confidence level. This condition will remain applicable as long as the compliance sample pool is 14 samples and the background data set is fixed. The reason for this is that the test depends on relative proportions of sample results greater than the reference concentration.

Zone 1

Example applications of the Two-Sample Test of Proportions to compliance sample sets from 2004 and 2005 are provided in Appendix F. The example tests were made in the same manner as explained above for the Southwest Alluvium compliance data. As with the Southwest Alluvium examples, compliance data lumped from two consecutive quarters (10 samples) were used in the example applications of the Two-Sample Test of Proportions.

Example tests with the Two-Sample Test of Proportions indicate that the proportion of compliance data exceeding the 95th percentile of background (9.4 pCi/L) was significant at a 95% confidence level in one of the four tests (third quarter 2005). Of the five quarters of compliance data considered by the four tests (25 samples from 4th quarter 2004 through 4th quarter 2005) two samples had combined radium concentrations greater than 9.4 pCi/L. These samples came from well 604 in the second (9.9 pCi/L) and third quarters (9.6 pCi/L) of 2005. Therefore, the third quarter test included both of these results from well 604 and this was found to be a statistically significant exceedance. This result also answers the question posed in the previous section of how many sample results higher than the 95th percentile of background are required for the test to indicate statistical significance. If more than one compliance sample from any two consecutive quarters exceeds 9.4 pCi/L a finding will be made of a significant exceedance at the 95% confidence level.

It is reasonable to question what the overall or longer-term meaning is of a finding of statistically significant exceedance in one quarterly test from 2005, but not in the other three. One way of addressing this question is to run the test with compliance data lumped from all four quarters of 2005. This doubles the size of the compliance data set to 20 samples and increases the level of confidence (power) with which differences can be discriminated between the compliance and background data sets. This test was run and is included in Appendix F. It indicates that while two compliance results greater than the 95th percentile of background is statistically significant in a pool of 10 samples (as in the third quarter 2005 test), it is not statistically significant in the pool of 20 samples taken over the entire year. This

should be interpreted to mean that there probably *was* a significant exceedance in the third quarter of 2005. However, when viewed over the course of the entire year this probable exceedance does not appear to be an indicator of a persistent condition or a worsening trend. An examination of combined-radium concentration trends (see below) further substantiates this interpretation.

The trend of decreasing combined-radium concentrations can be illustrated by the numbers of compliance samples exceeding the current site standard of 5 pCi/L. The numbers of site standard exceedances in quarterly compliance data sets have significantly reduced over time since July 1989. 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 an important conclusion: the groundwater quality improved during active remediation and has continued to improve since the termination of active pumping in 1999. Moreover, with the exception of Well 604, the combined-radium water quality at the compliance locations appears to have improved to a quality similar to the background water.

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

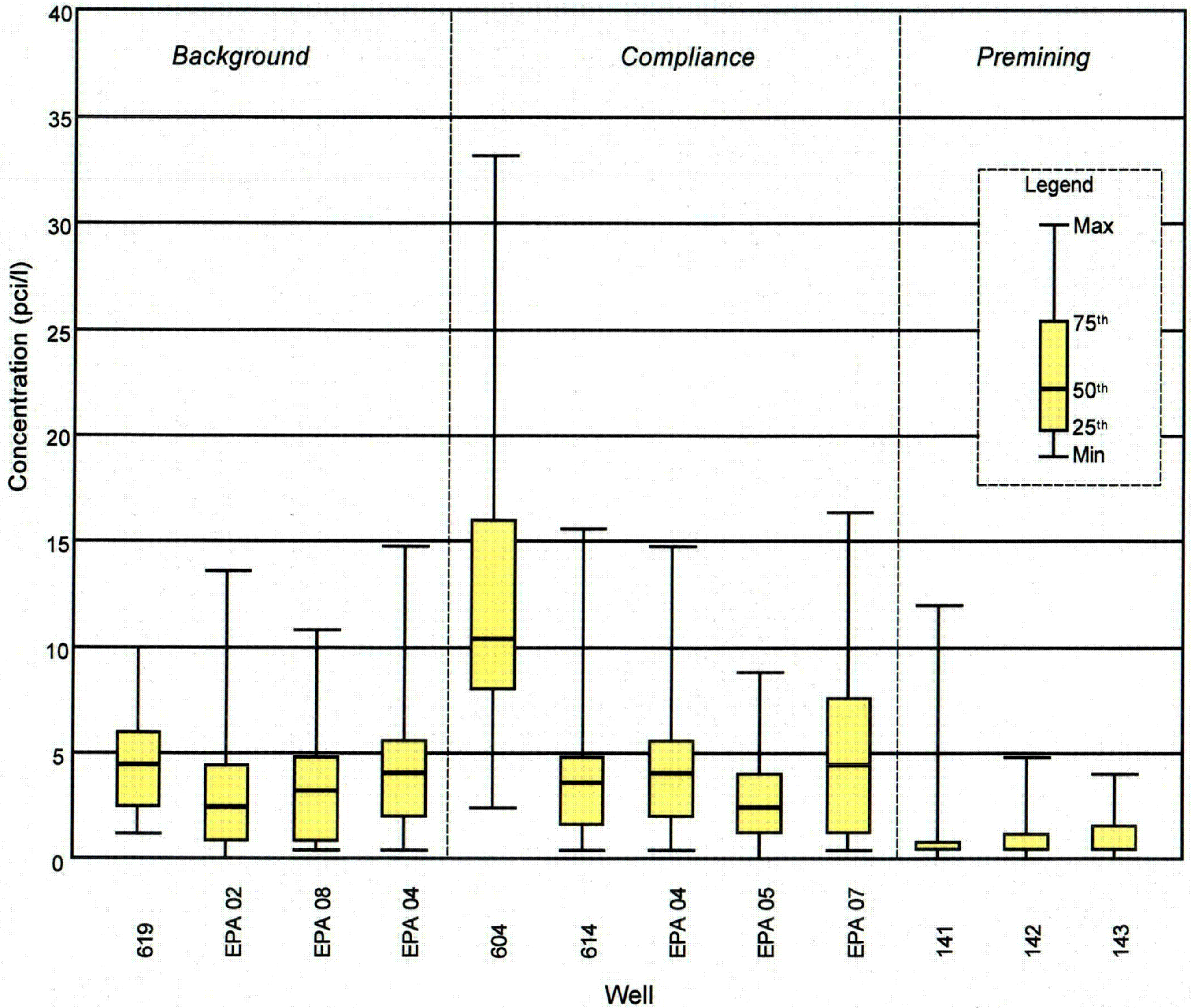
The Two-Sample Test of Proportions using new background-based standards (the 95th percentiles of the background concentration distributions in Zone 1 and the Southwest Alluvium) is proposed as a replacement for the current method of comparing combined radium concentrations in compliance well samples to the site standard. For continuity, the new standards for combined radium are recommended to be fixed, as they are presently based on the large pool of historic background samples, at 9.4 piC/L for Zone 1 and 5.2 piC/L for the Southwest Alluvium. The Two-Sample Test of Proportions will be applied quarterly to compliance data lumped from the current and previous quarter. If one or more of the quarterly applications of the Two-Sample Test of Proportions indicates a statistically significant exceedance in the course of a year, the test will be applied to data lumped from all four quarters in the fourth quarter of that year.

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. 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.

Figures

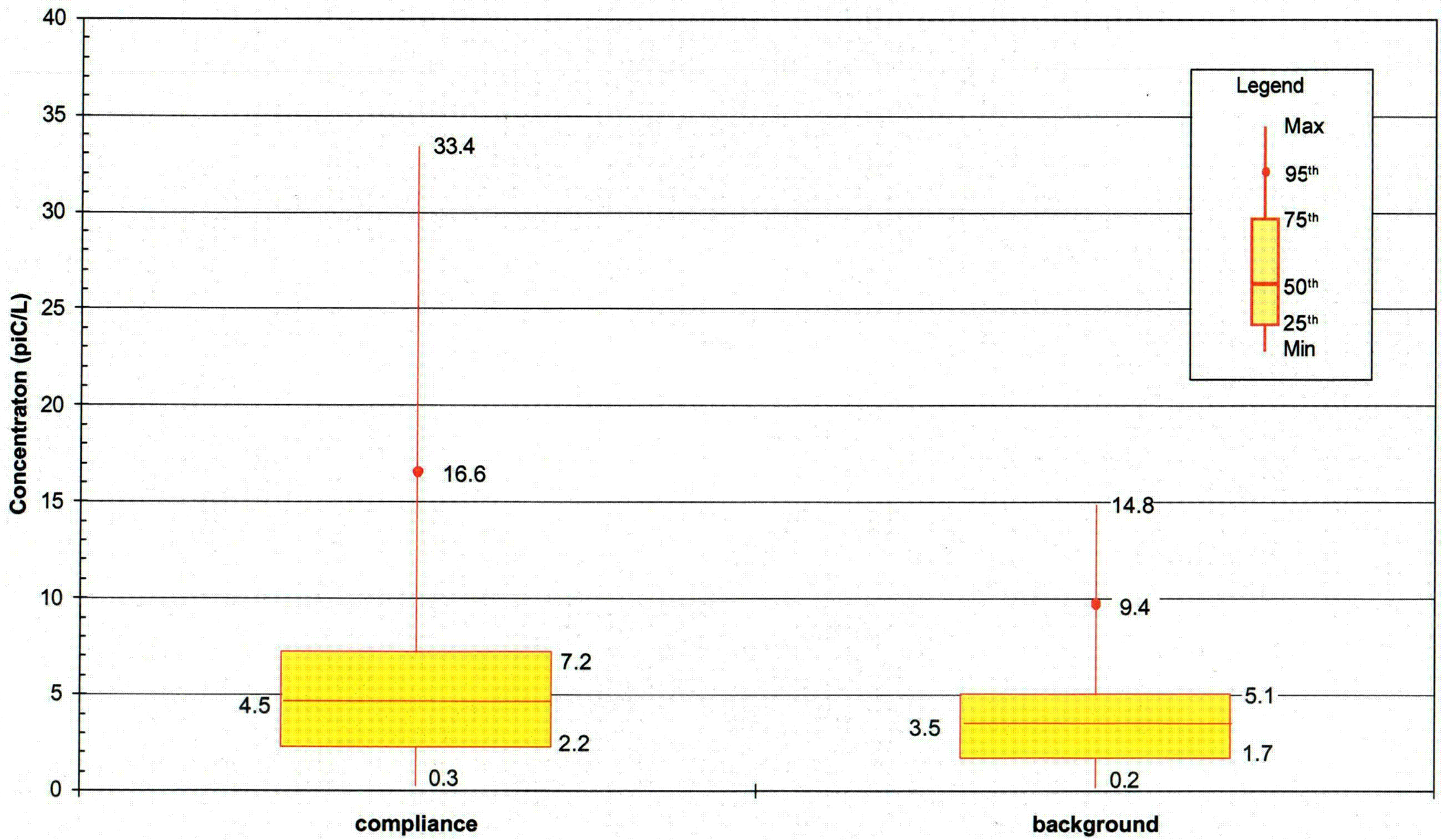
FIGURE 1

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



C01

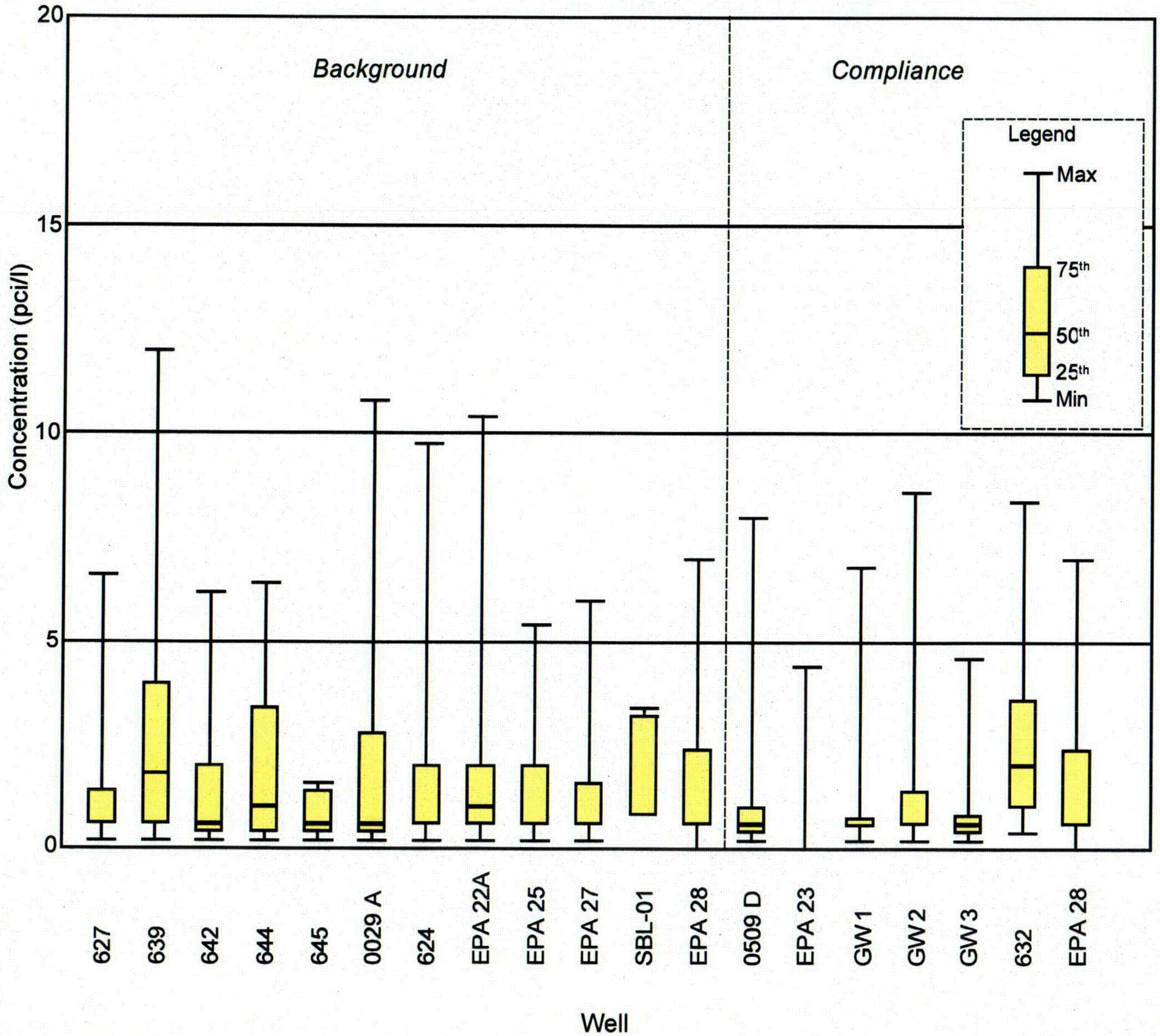
Figure 2
Box and whisker plot comparing the distrbutions of combined radium in historic background and compliance data sets from Zone 1



C02

FIGURE 3

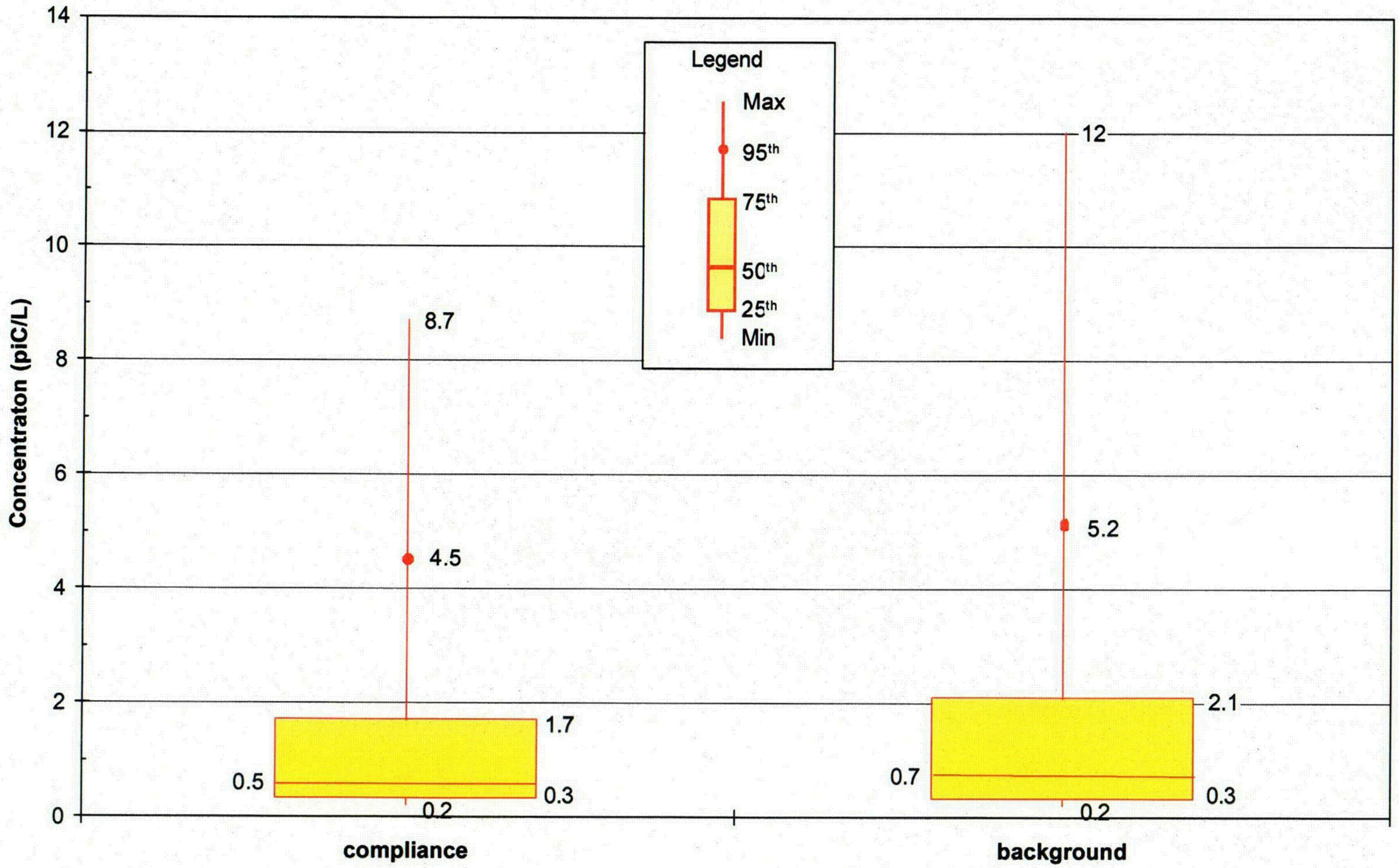
Box and whisker plot of combined radium in samples from Southwest Alluvium Wells



C03

FIGURE 4

Box and whisker plot comparing the distrbutions of combined radium in historic background and compliance data sets from the Southwest Alluvium

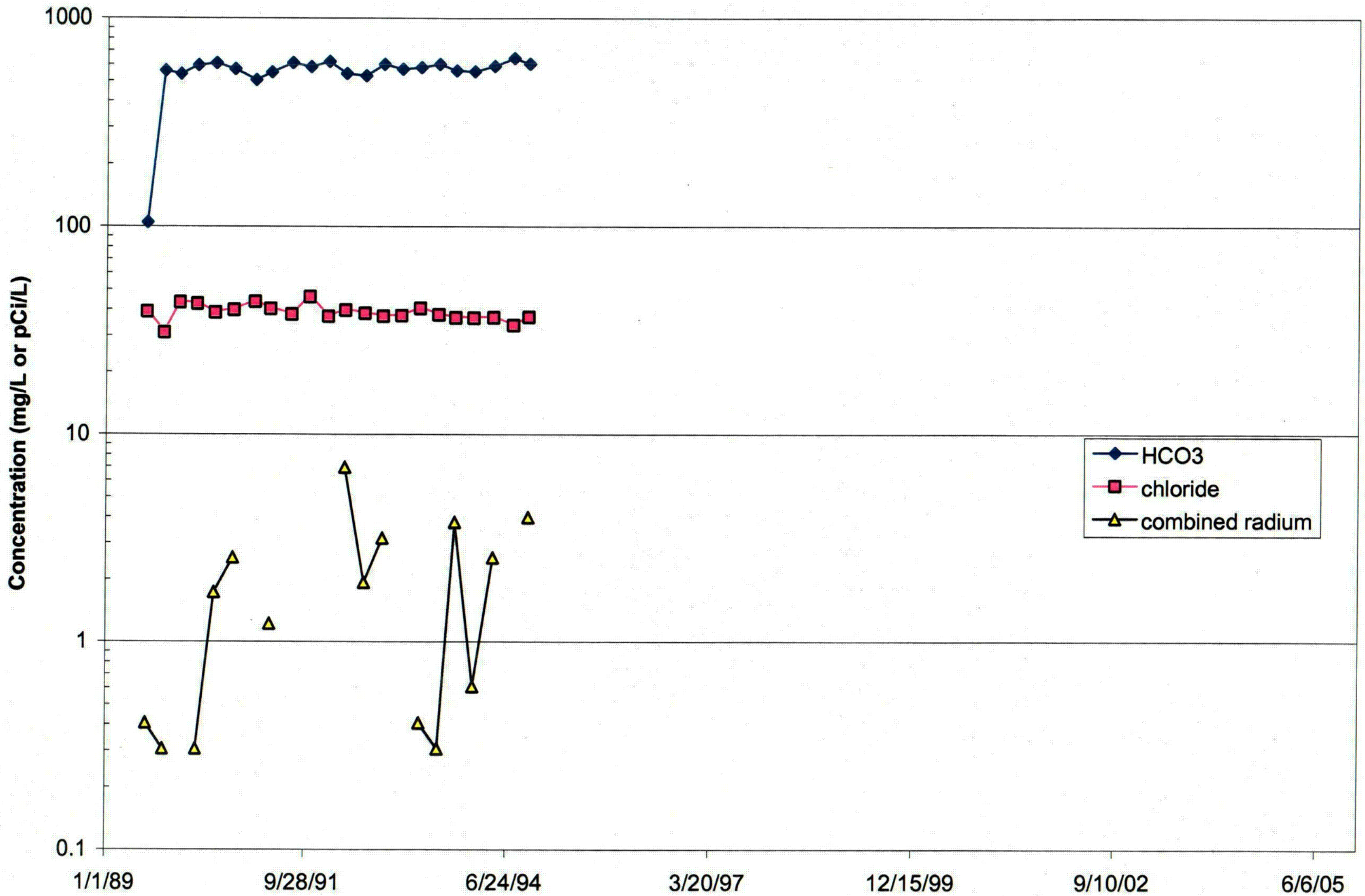


C04

Appendix A
Part 1

Time Series of Bicarbonate, Chloride, and Combined Radium for Wells in the Southwest Alluvium (July 1989 – October 2005)

0029 A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100
10
1
0.1
Concentration (mg/L or pCi/L)
1/1/89
9/28/91
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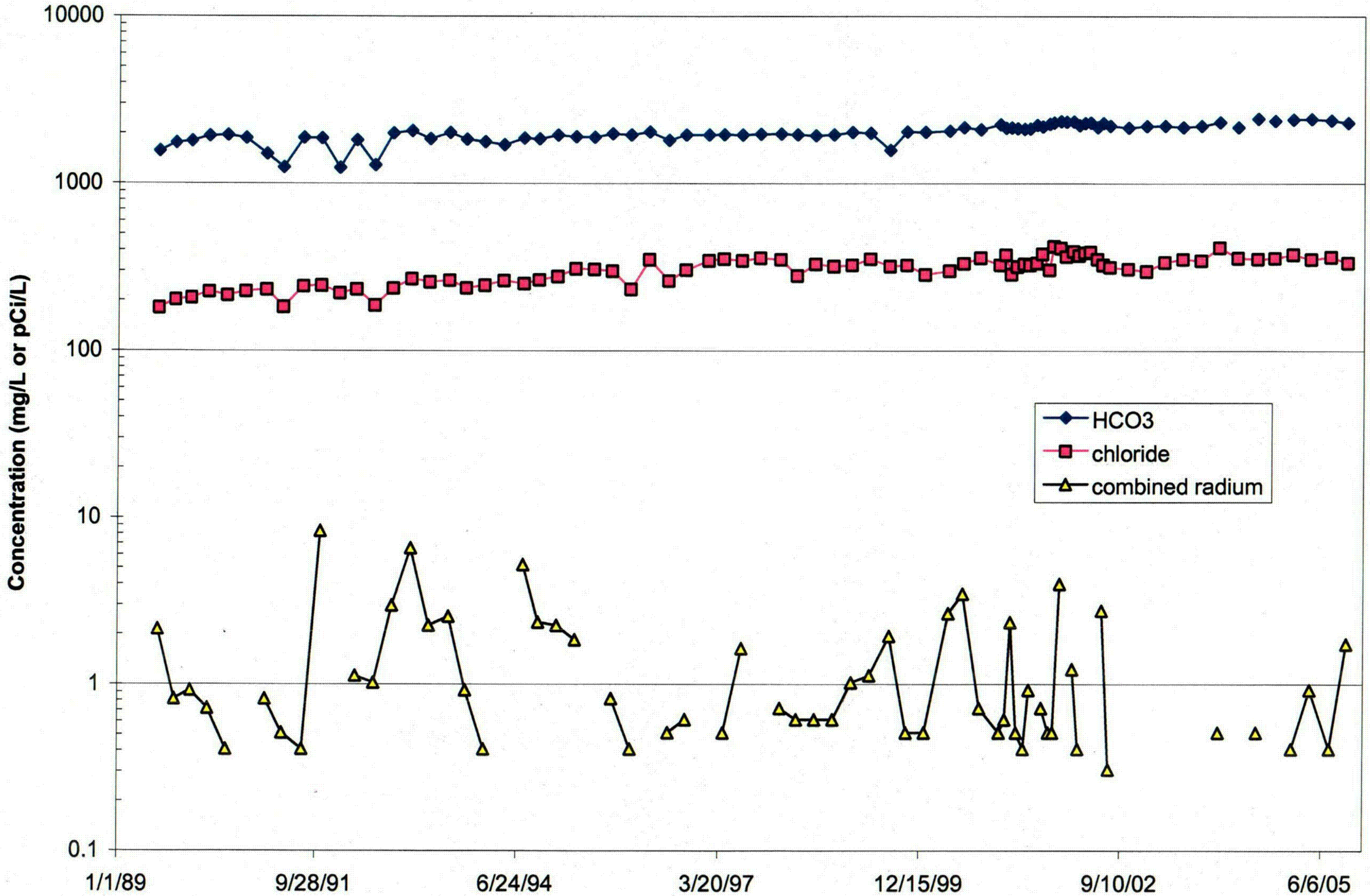
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

C05

509D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100
10
1
0.1
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HCO3
chloride
combined radium
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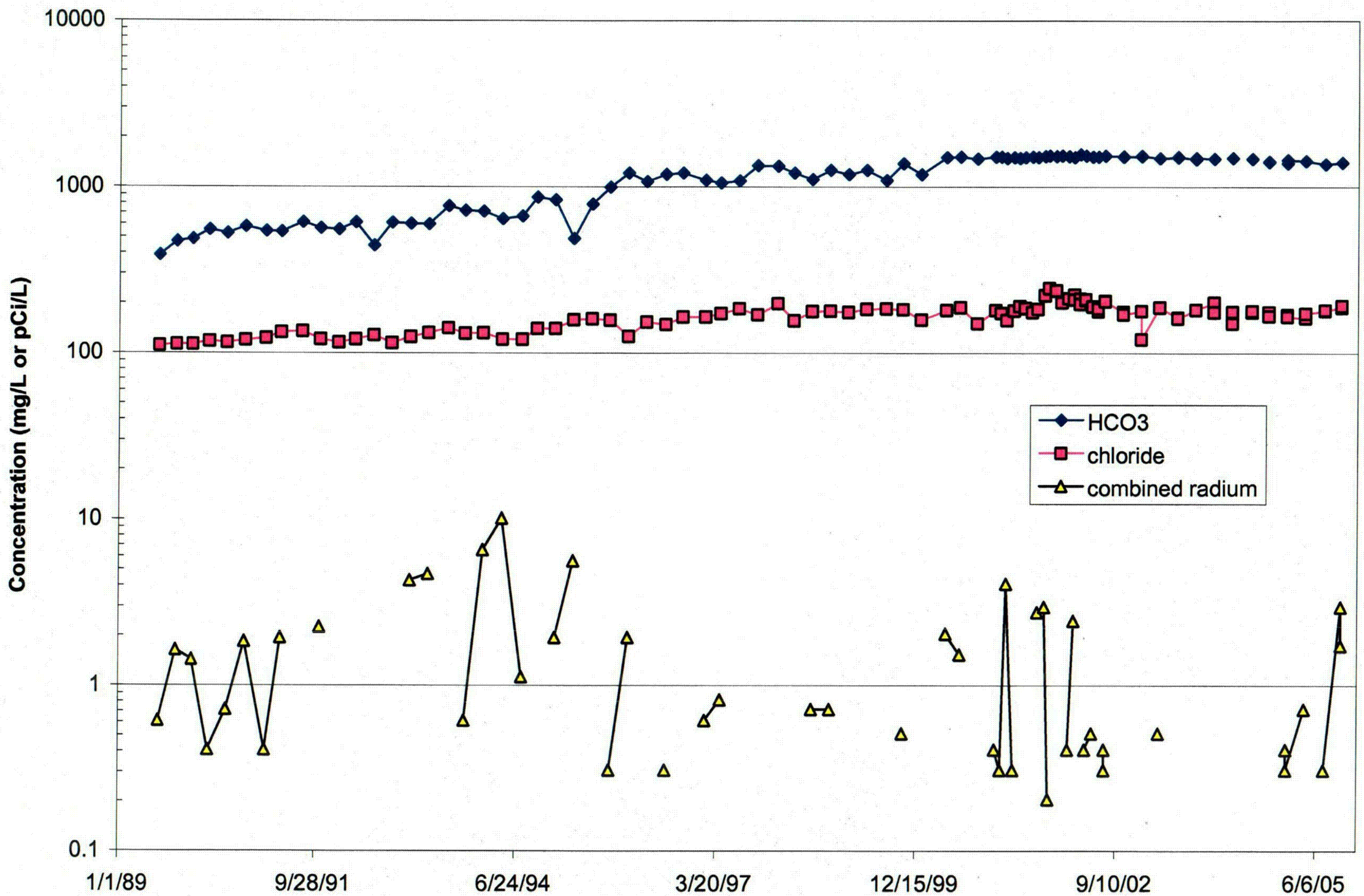
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05

C06

624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0.1
1/1/89
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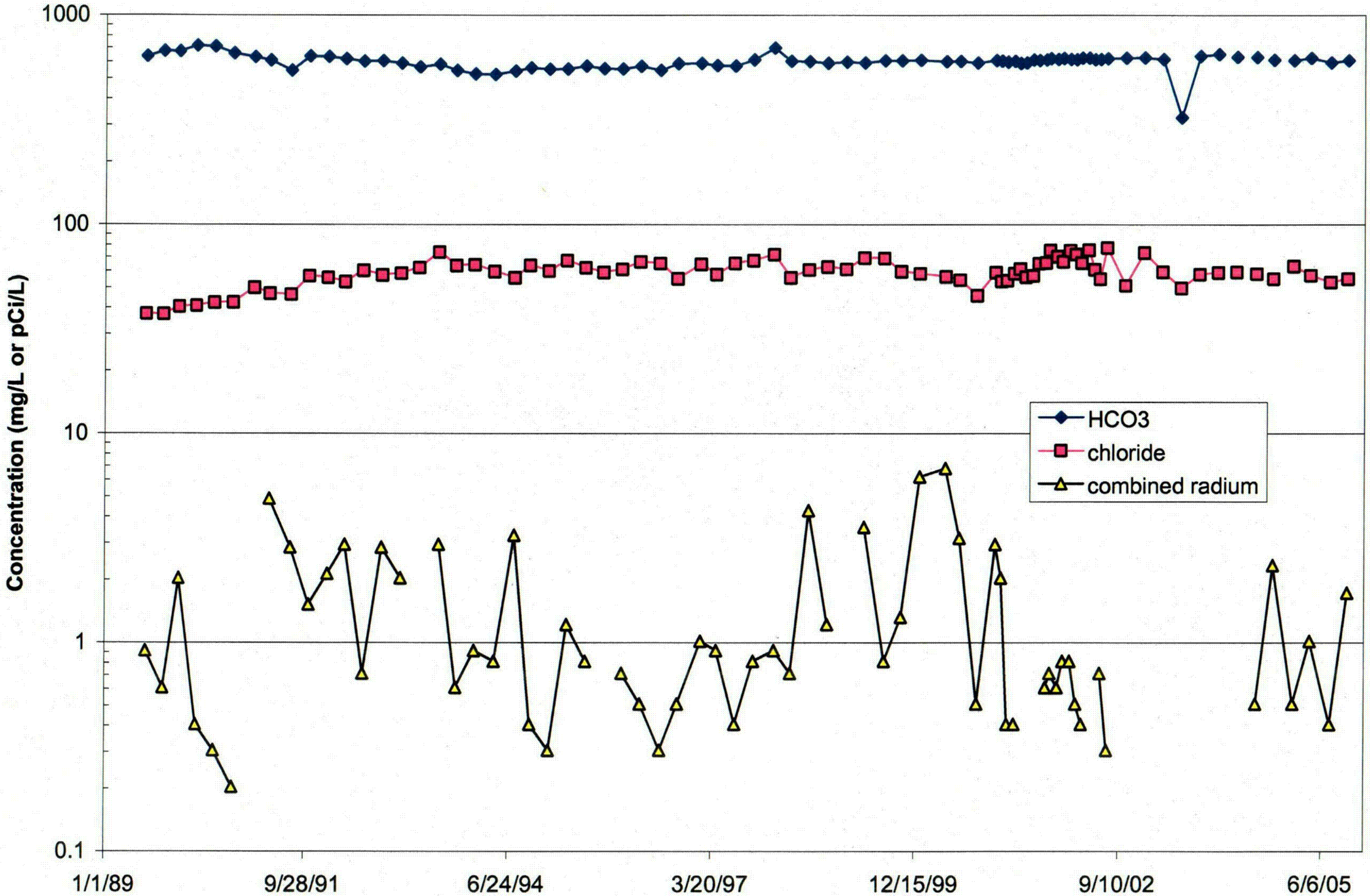
9/10/02
6/6/05
HCO3
chloride
combined radium

C07

627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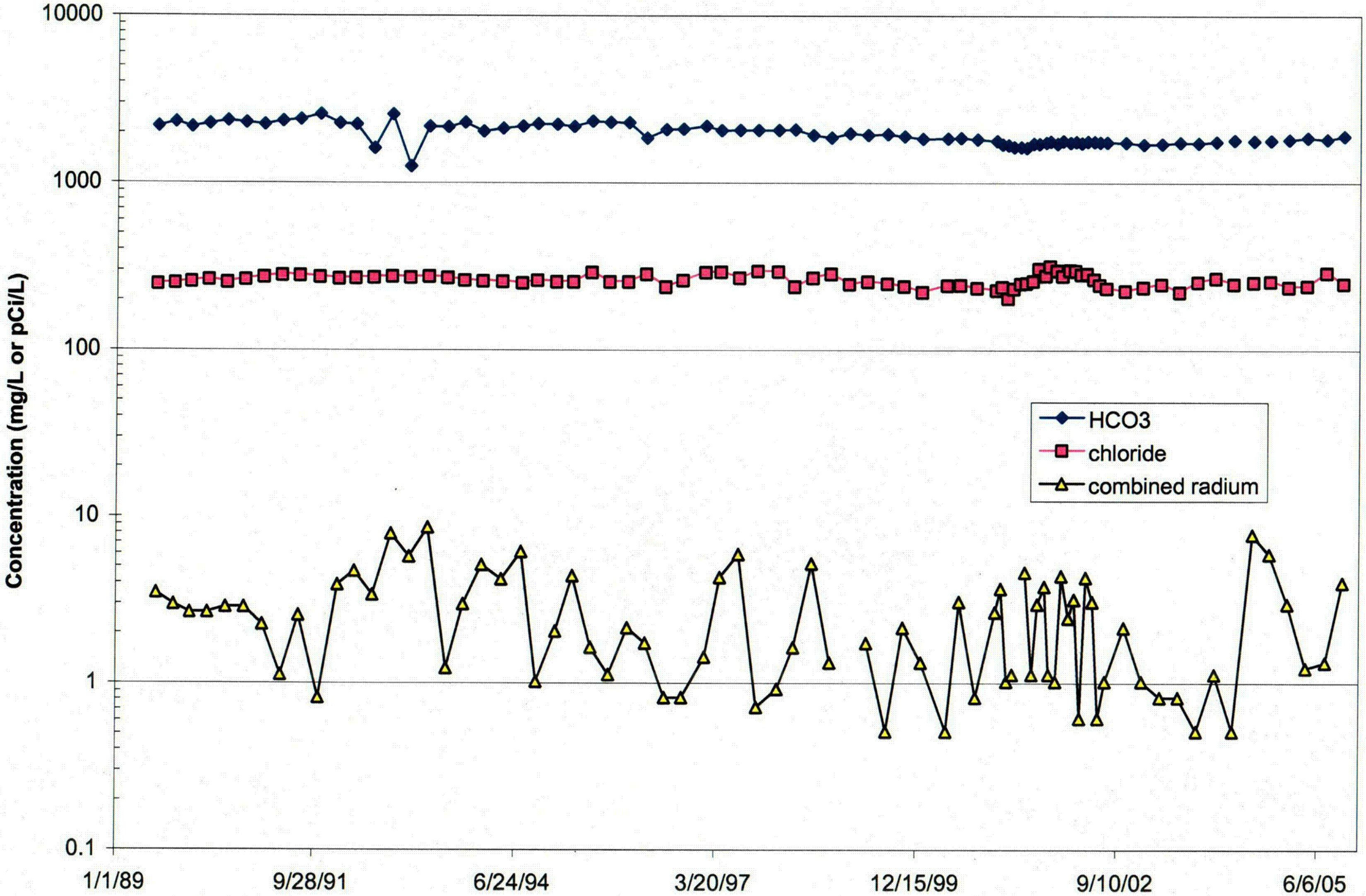
9/10/02
6/6/05
HCO3
chloride
combined radium

C08

632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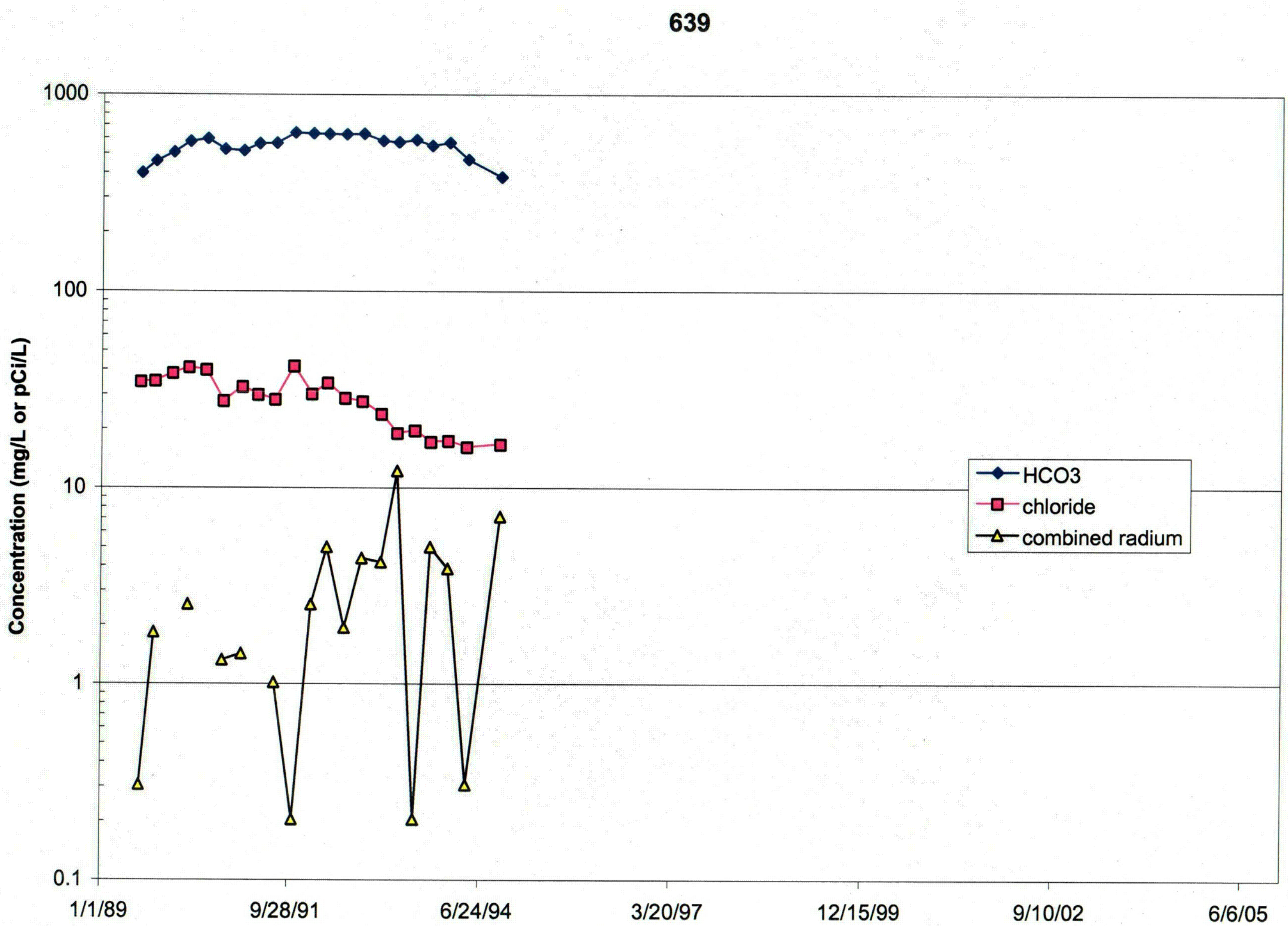
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

C09



639
1000
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0.1
Concentration (mg/L or pCi/L)
1/1/89
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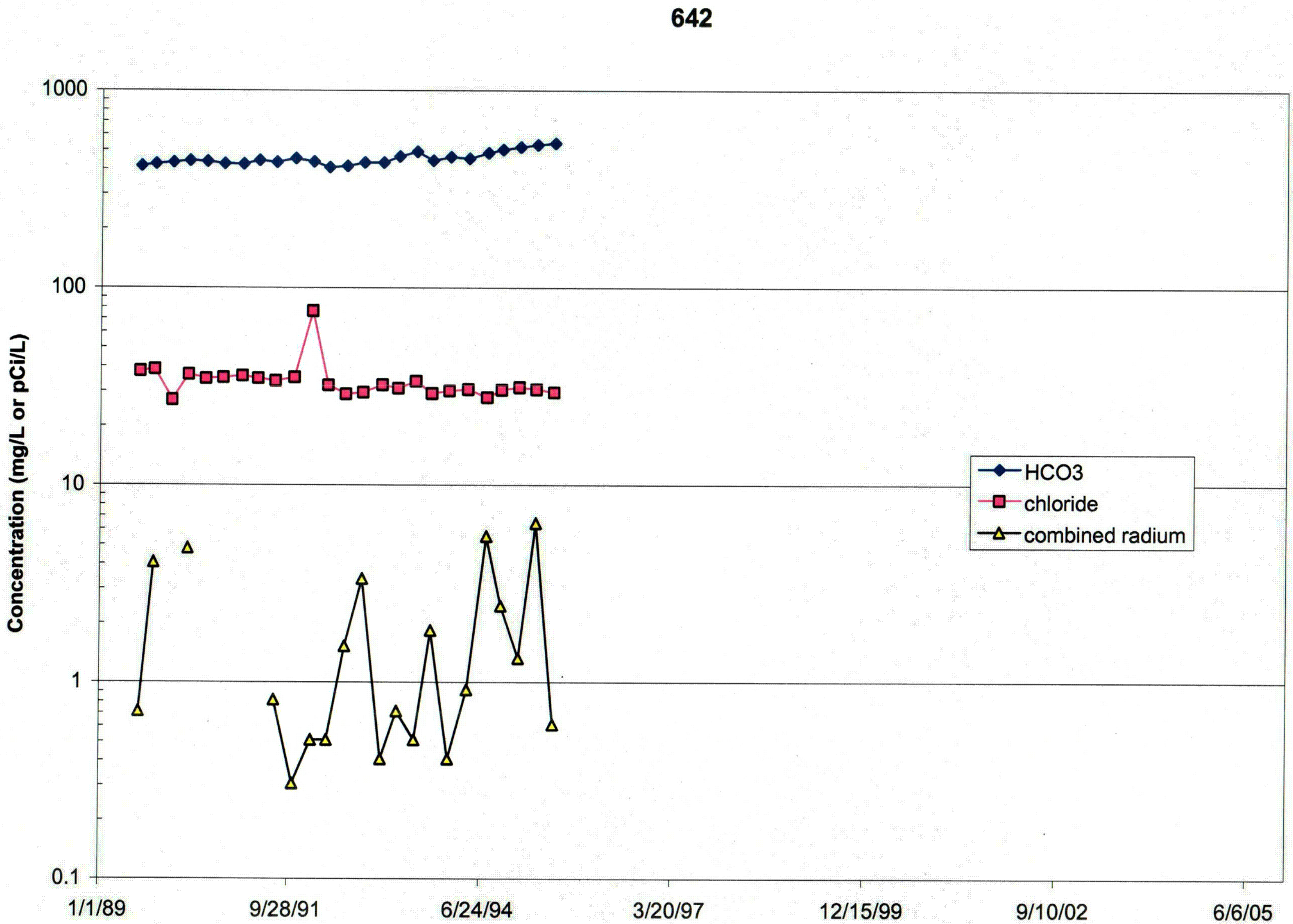
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

C10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1000
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10
1
0.1
Concentration (mg/L or pCi/L)
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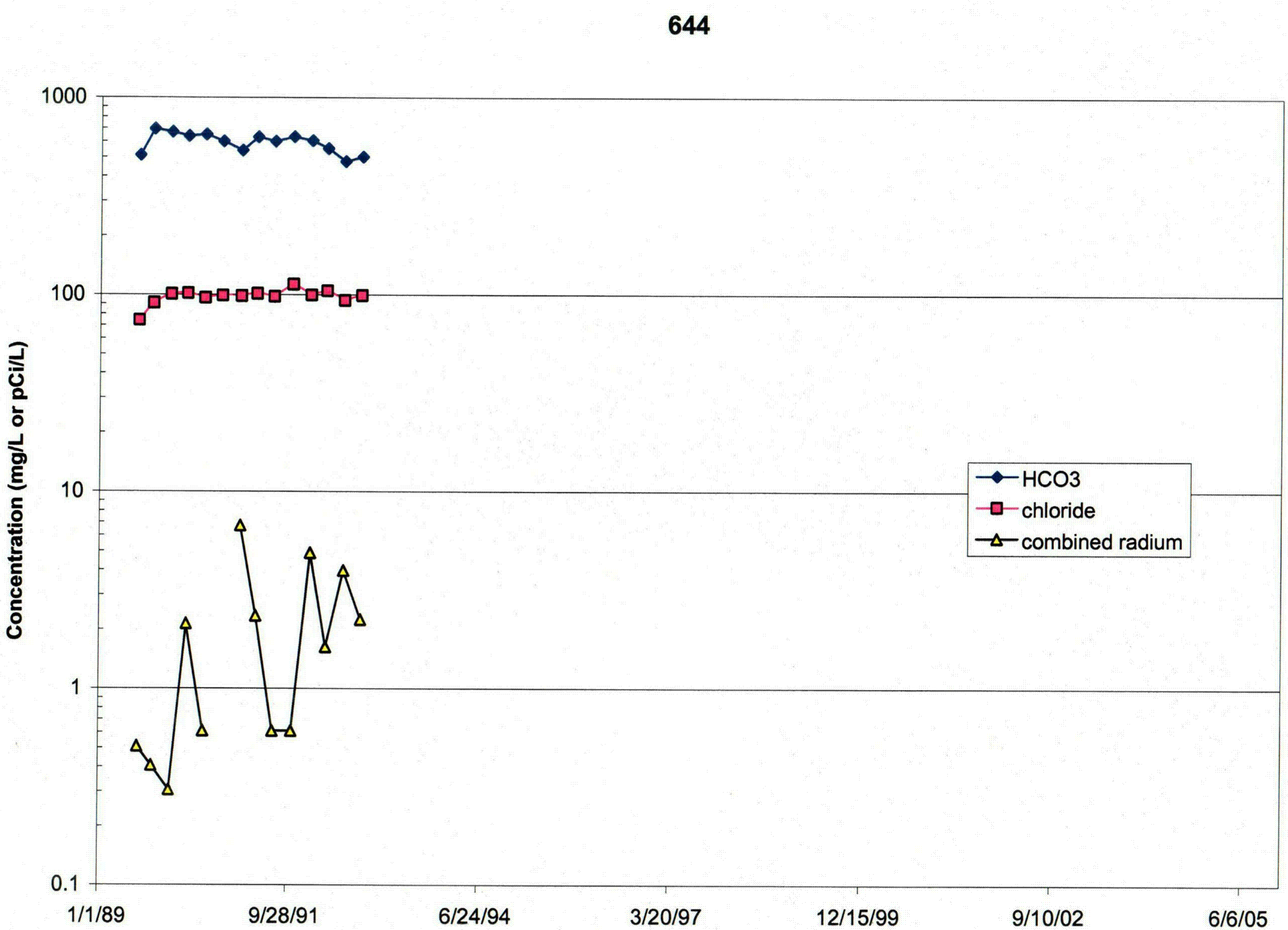
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

C11



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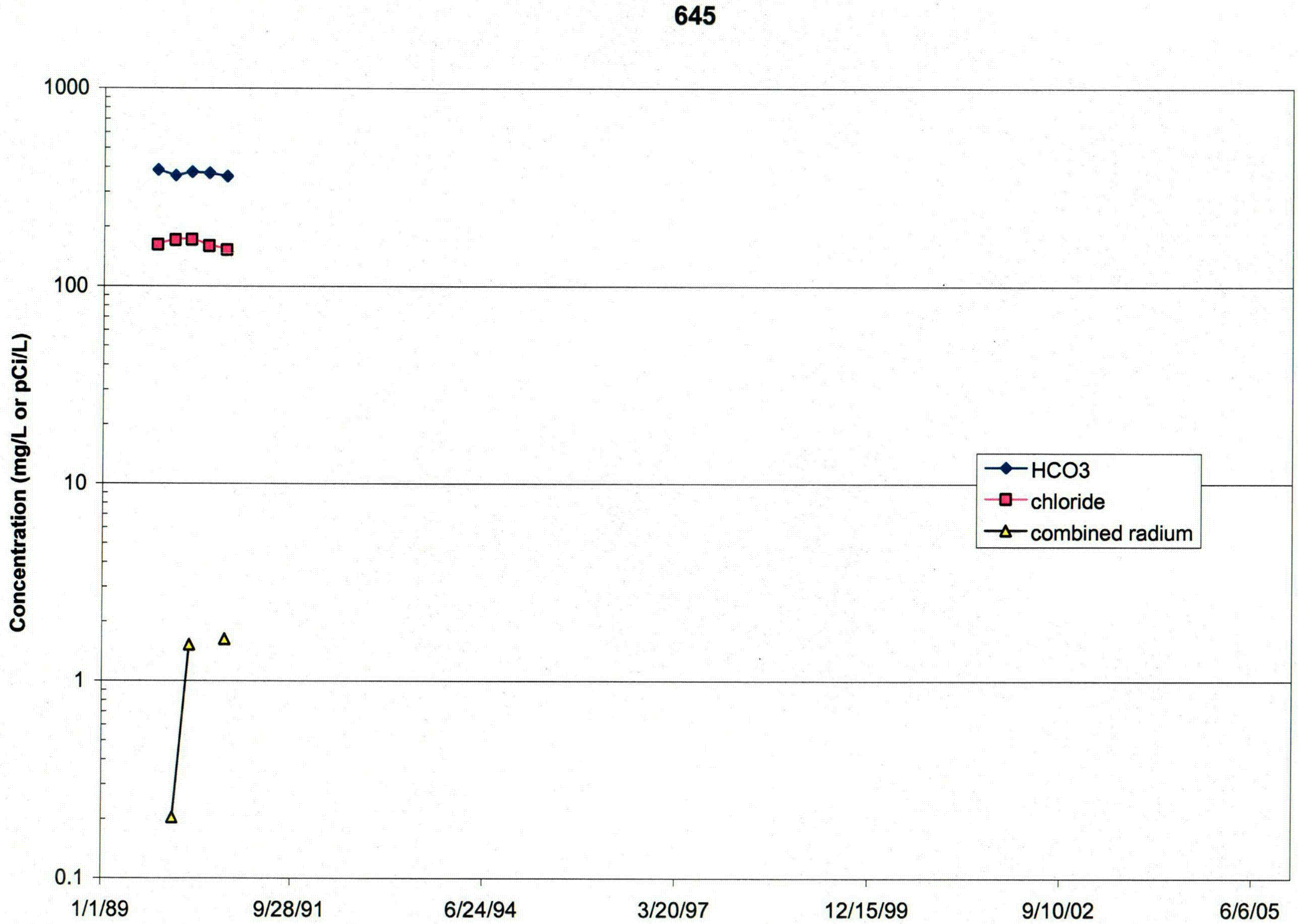
100
10
1
0.1
1/1/89
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

C12



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0.1
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9/28/91
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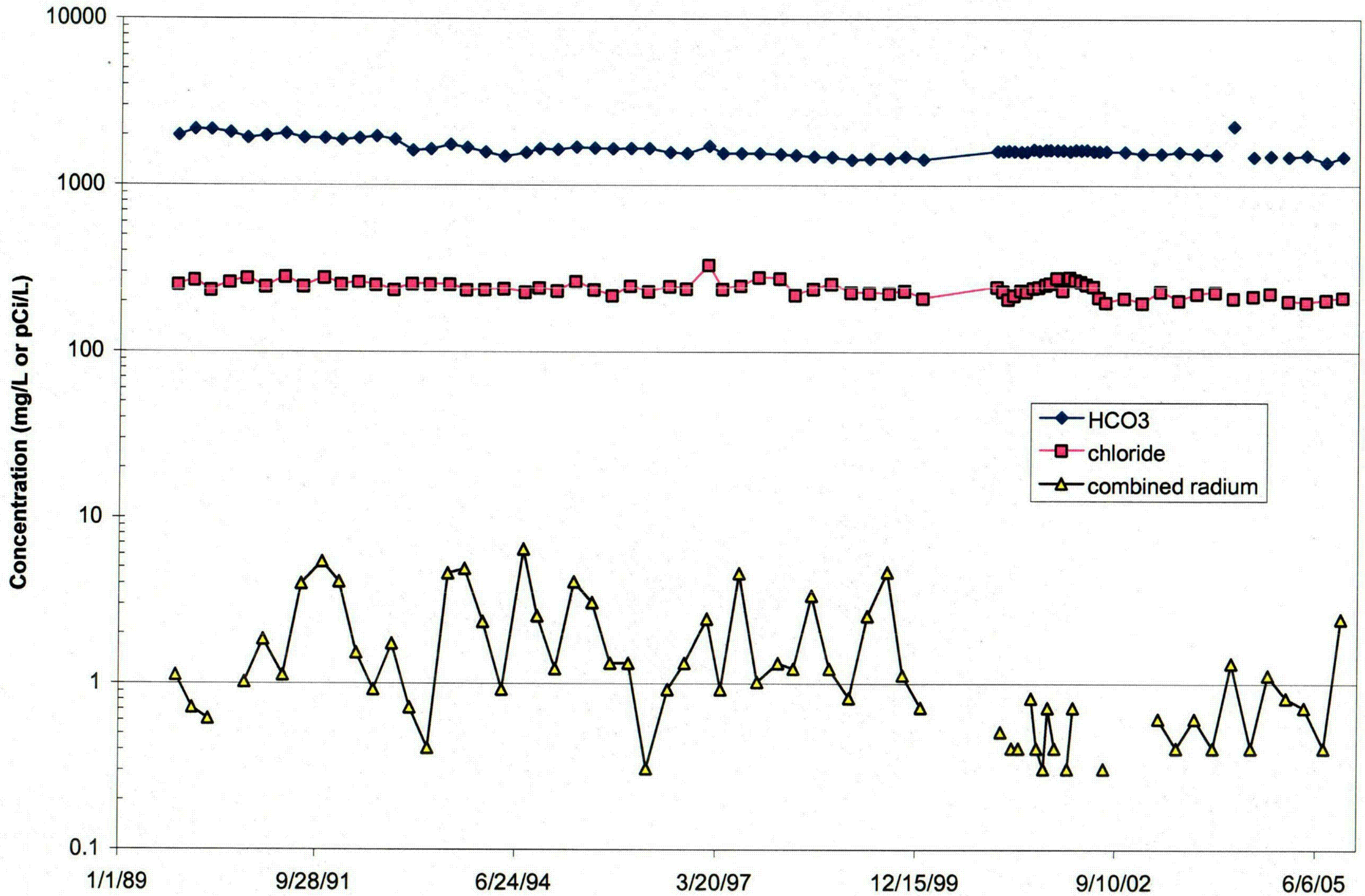
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

C13

801



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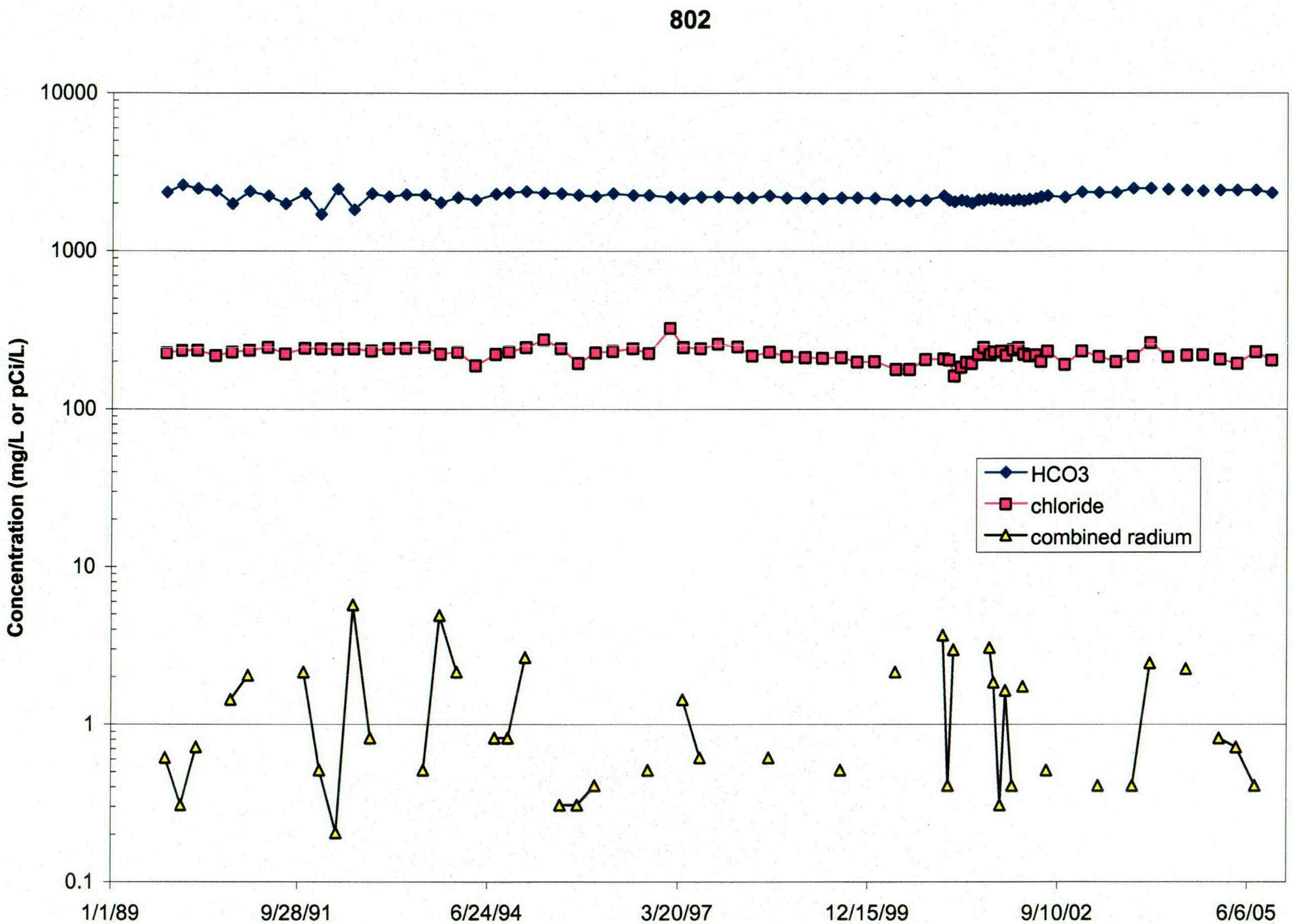
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

C14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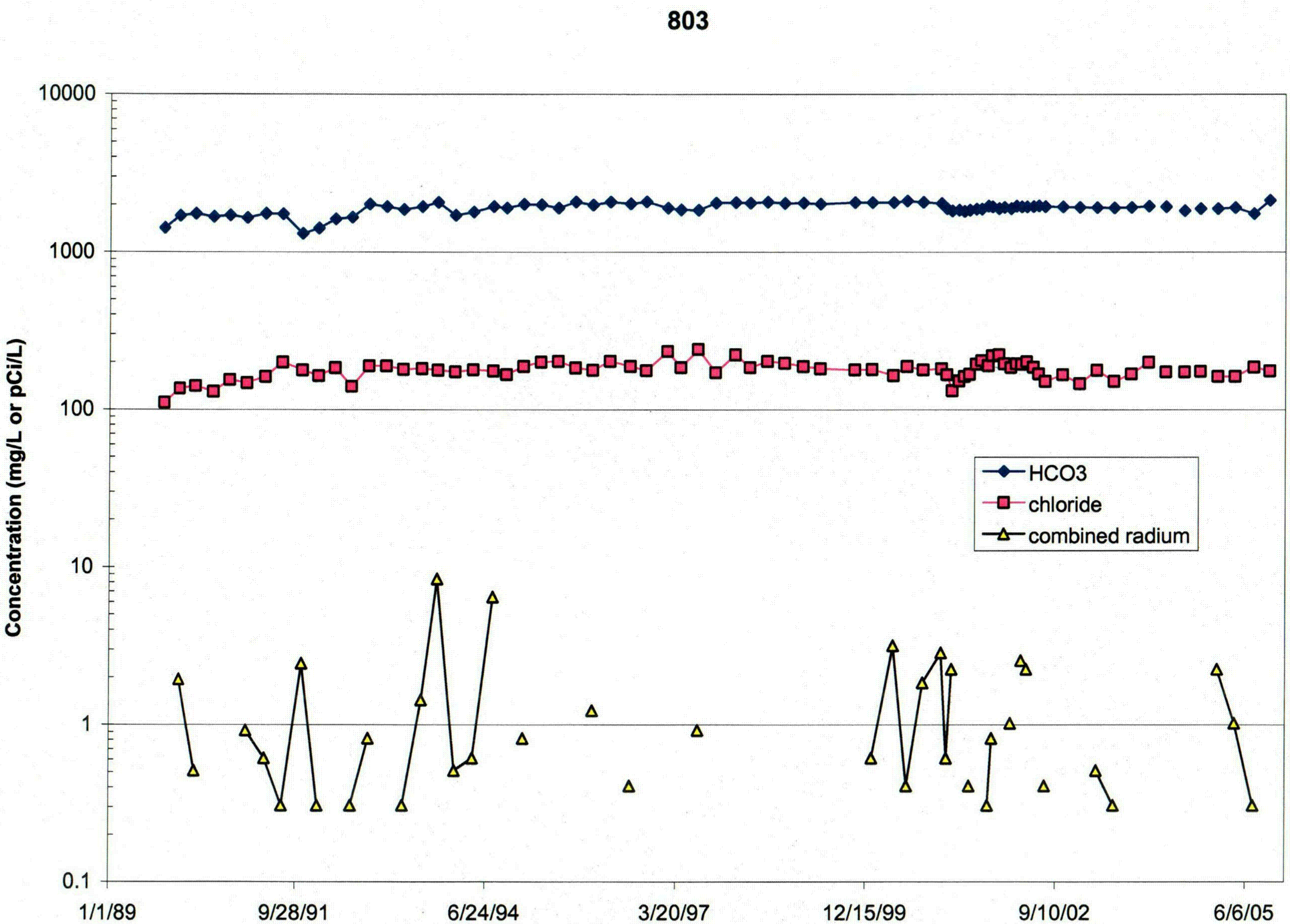
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

C15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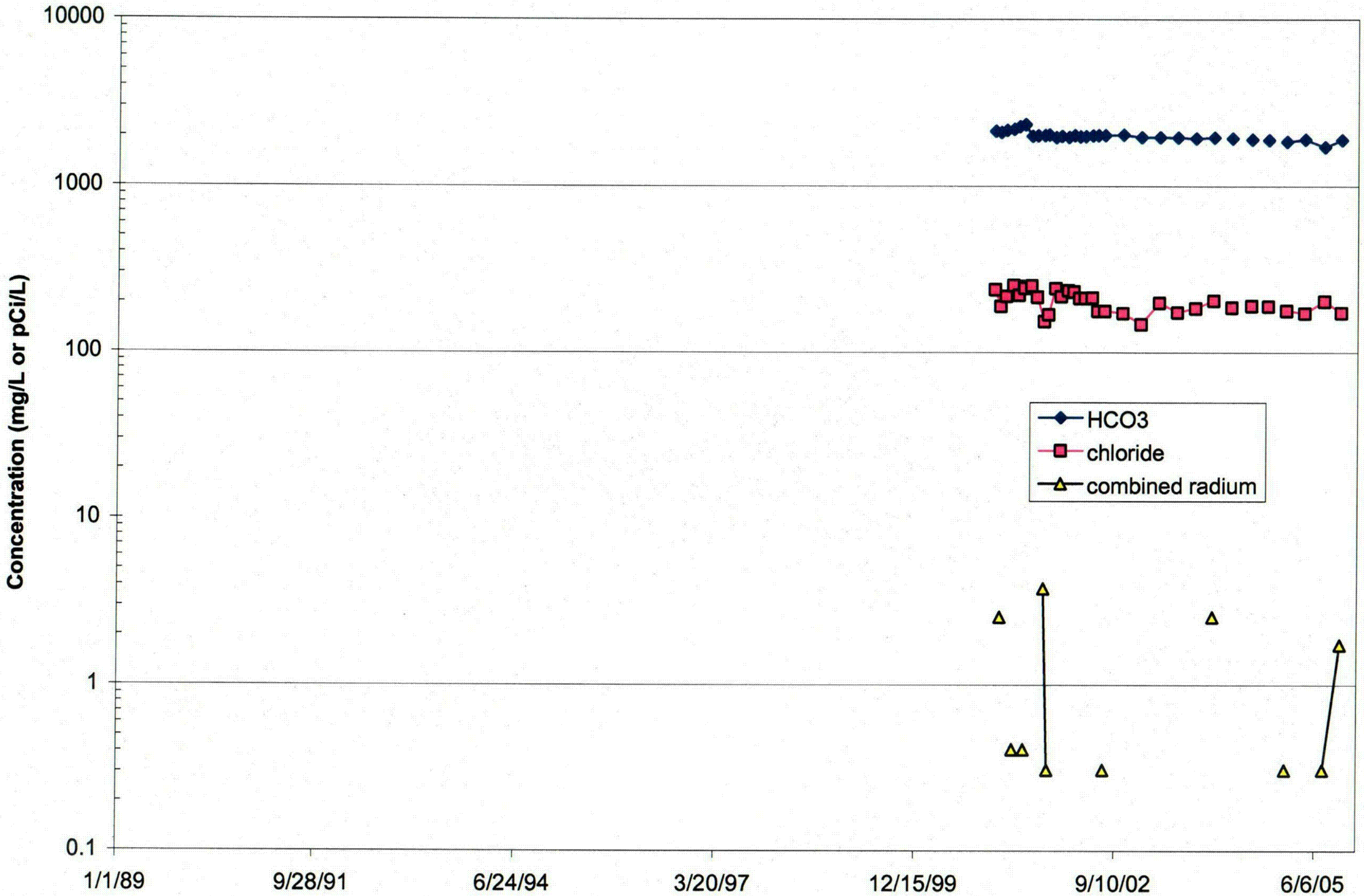
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

C16

808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10
1
0.1
Concentration (mg/L or pCi/L)
HCO3
chloride
combined radium
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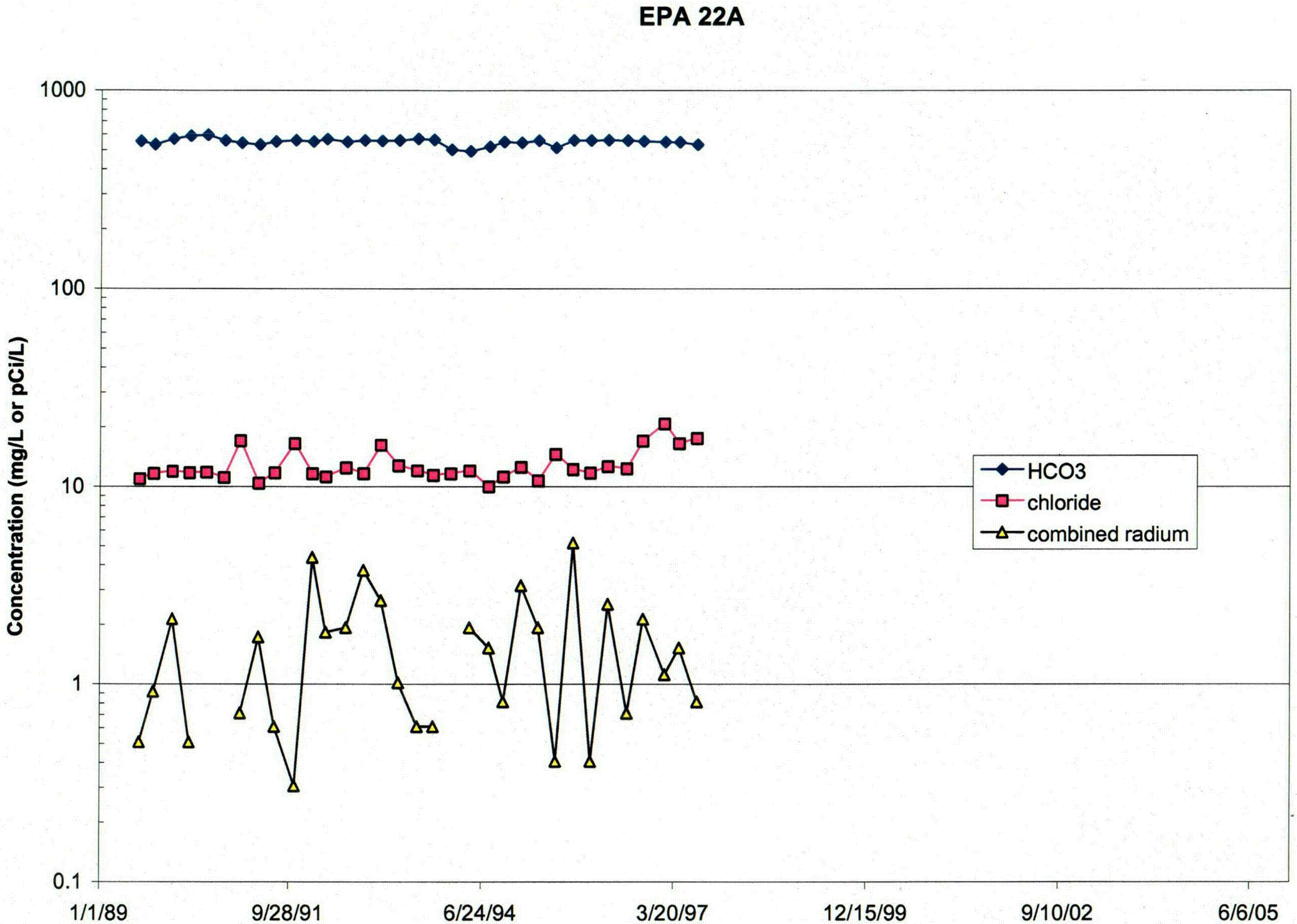
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05

C17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6/6/05
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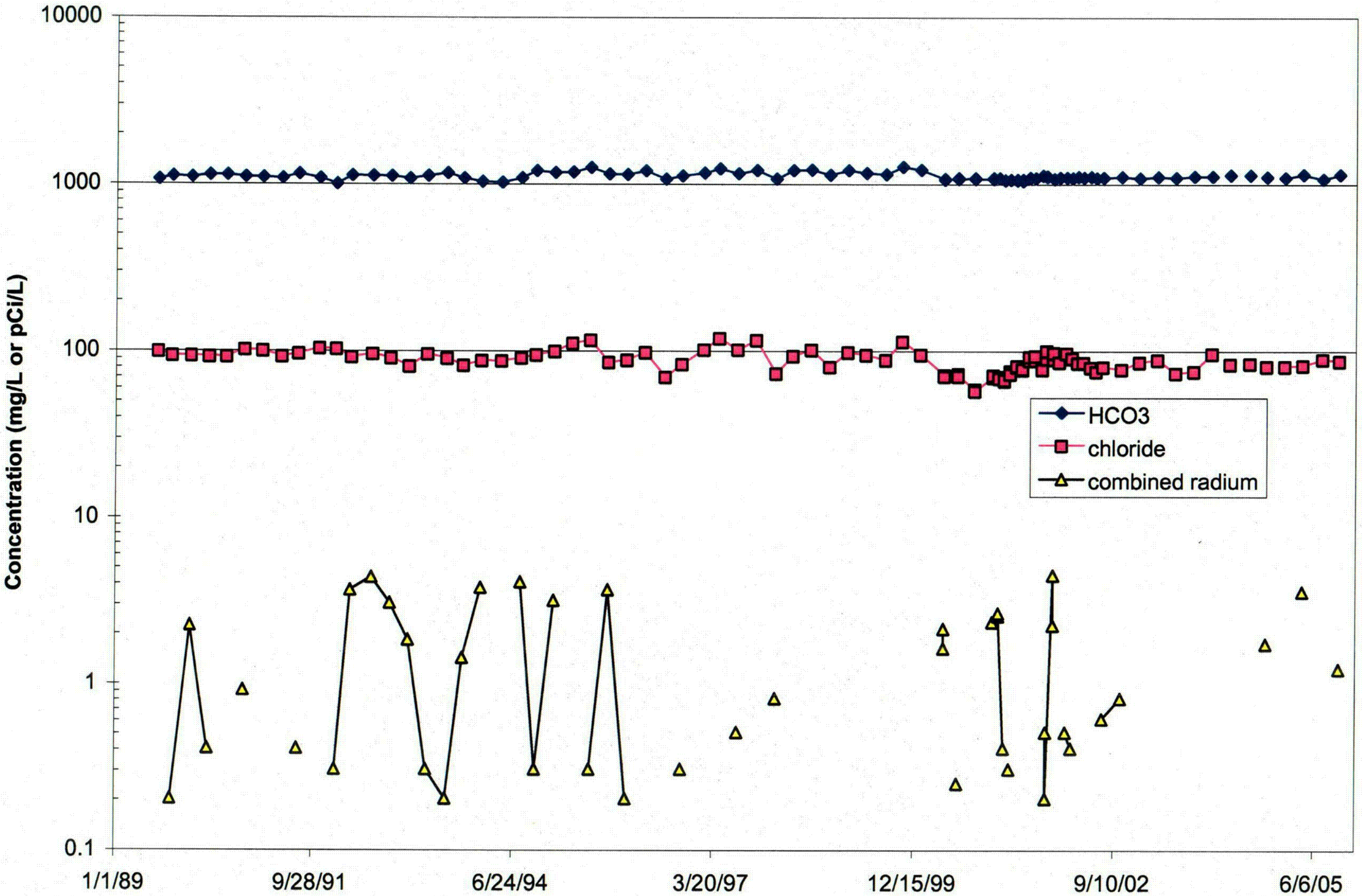
chloride
combined radium

C18

EPA 23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Concentration (mg/L or pCi/L)
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12/15/99
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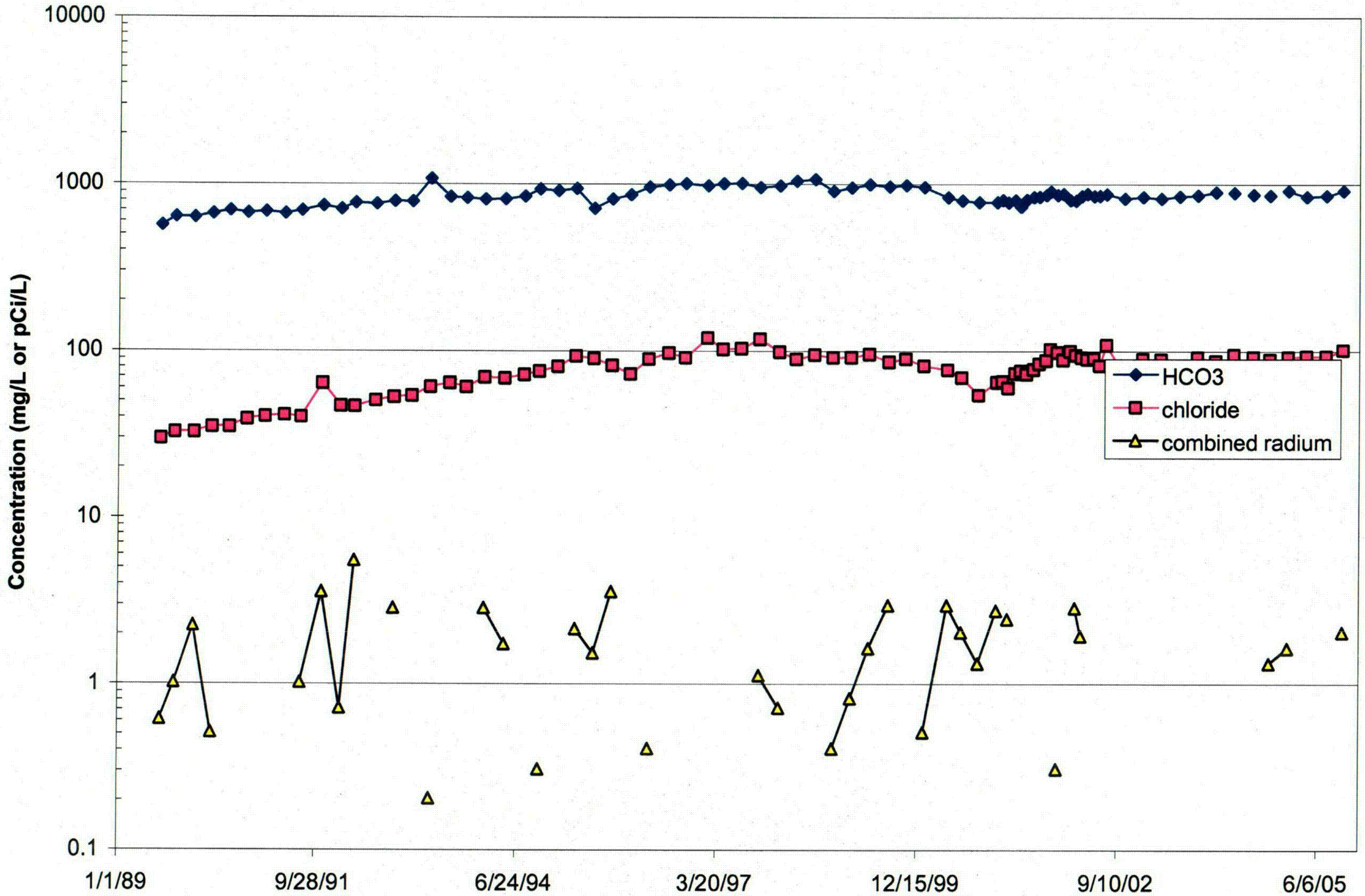
6/6/05
HCO3
chloride
combined radium

C19

EPA 25



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0.1
1/1/89
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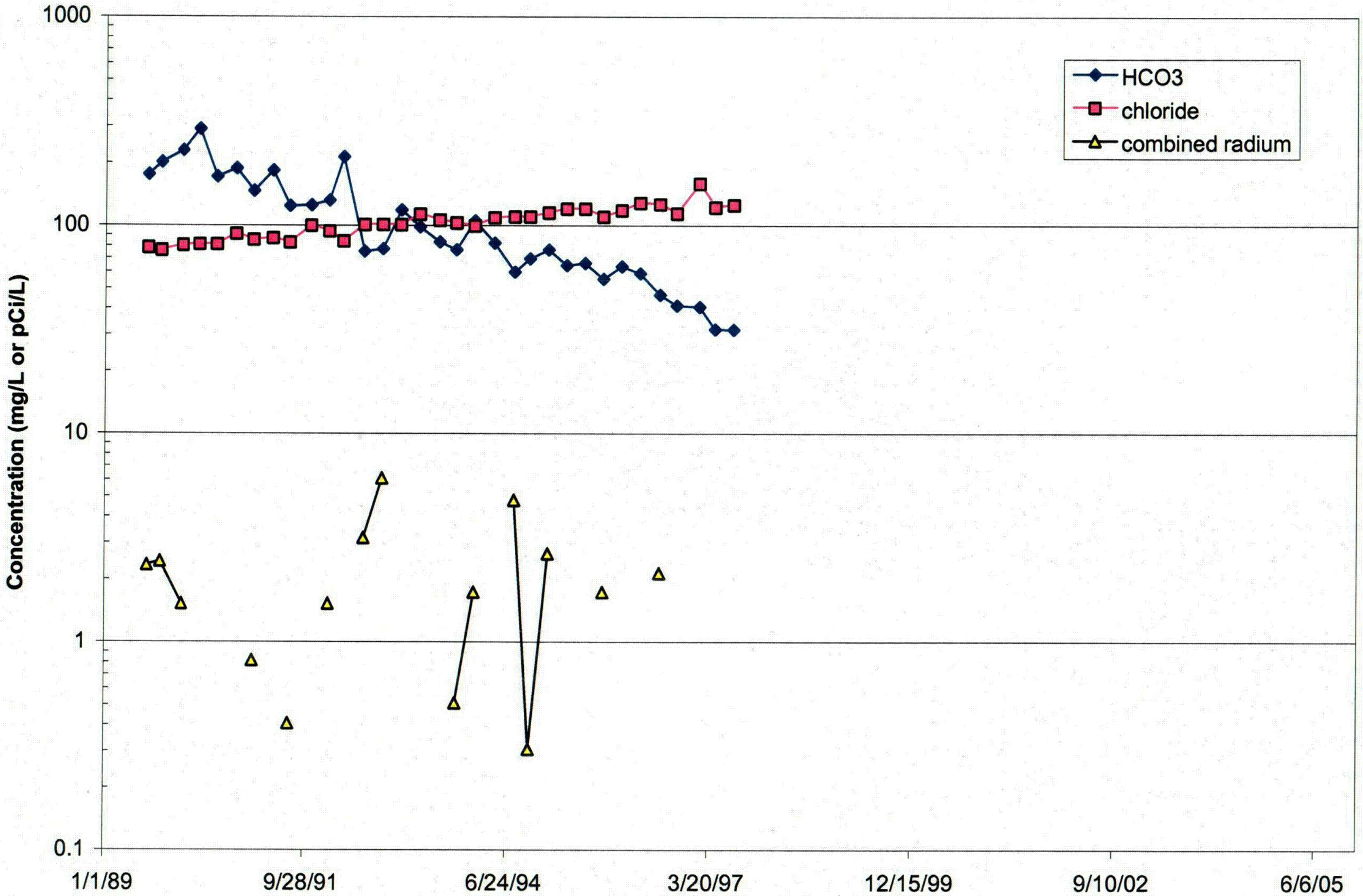
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

C20

EPA 27



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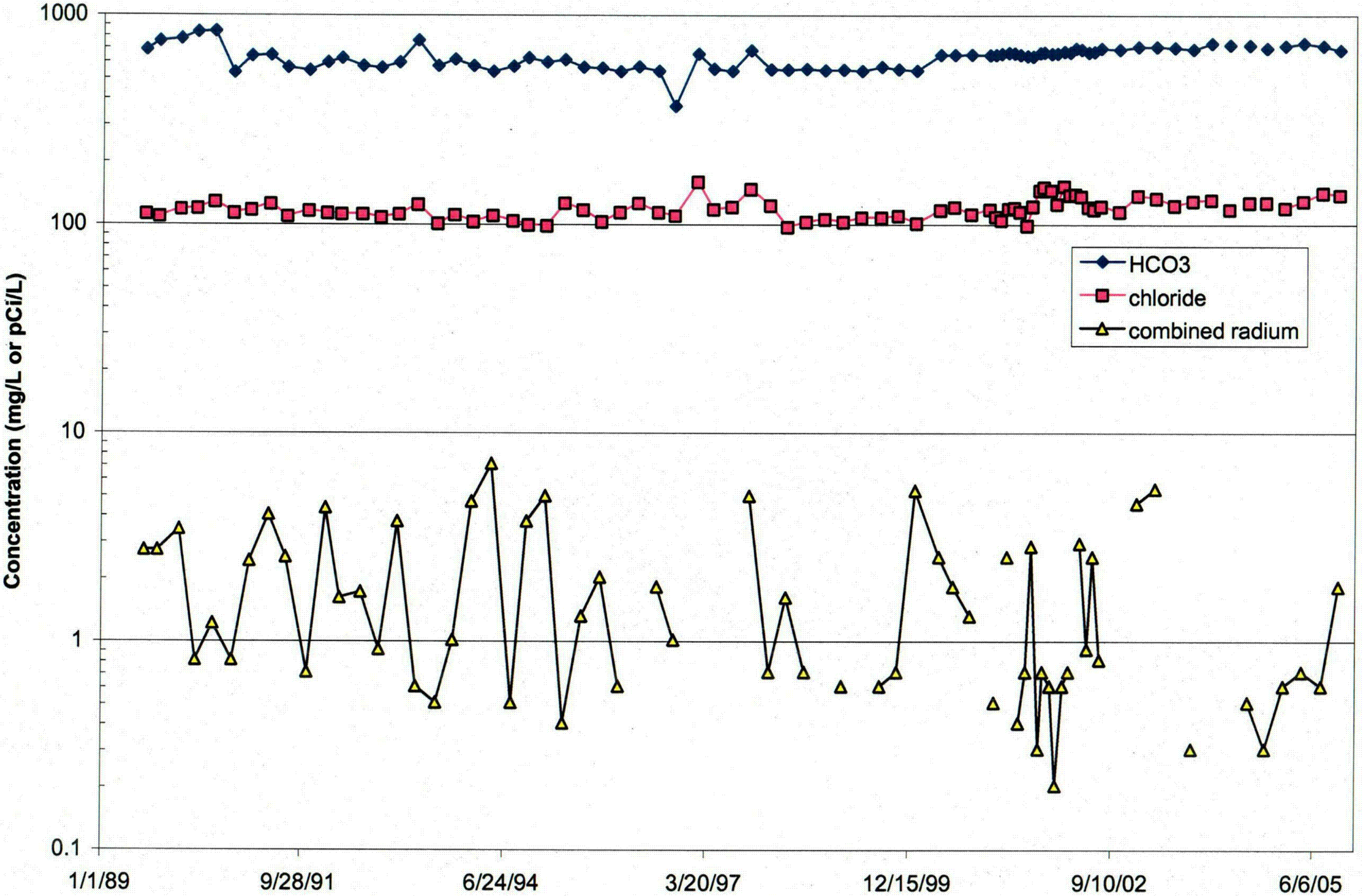
6/6/05
HCO3
chloride
combined radium

C21

EPA 28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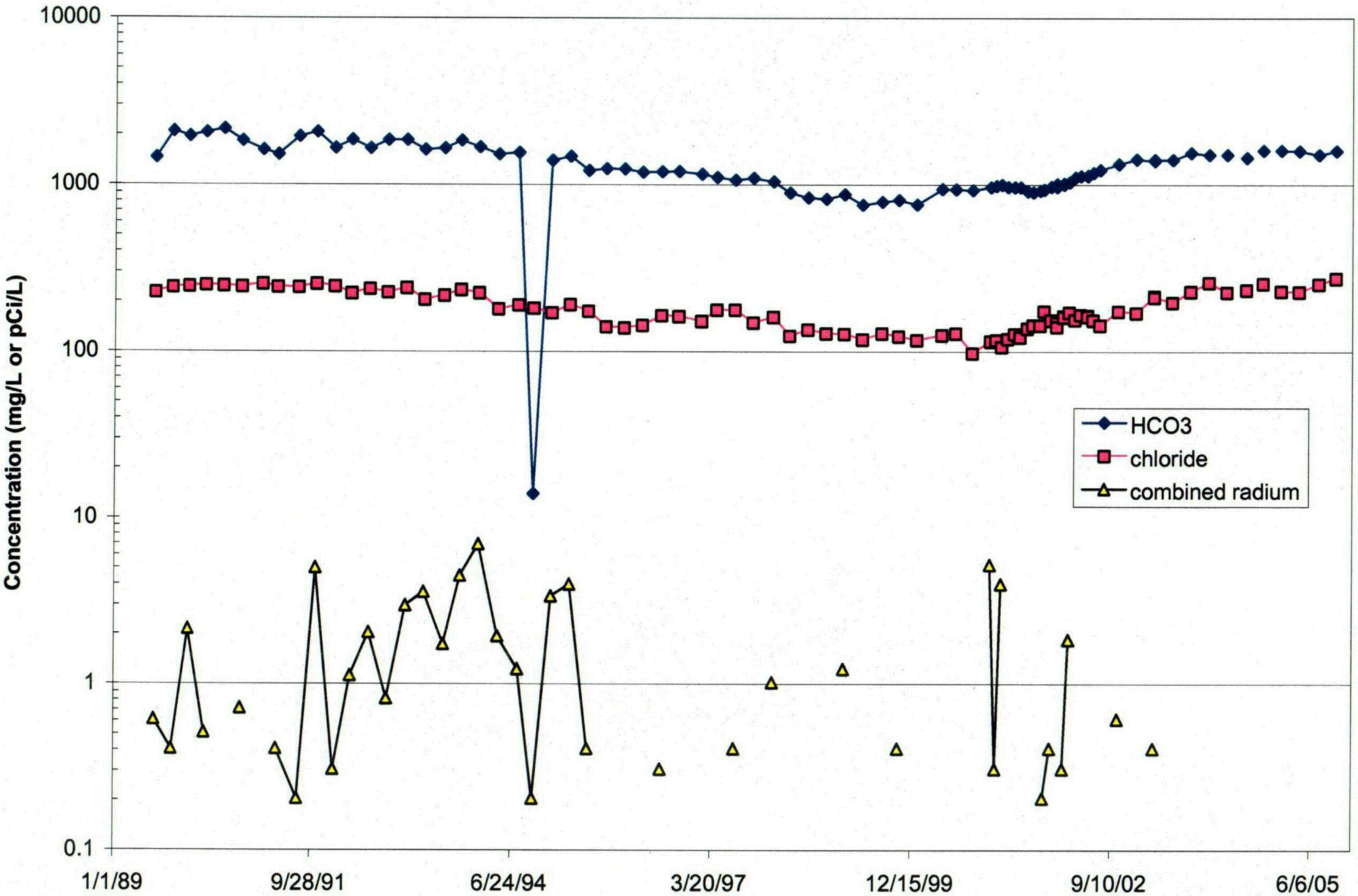
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

C22

GW 1



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10
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0.1
1/1/89
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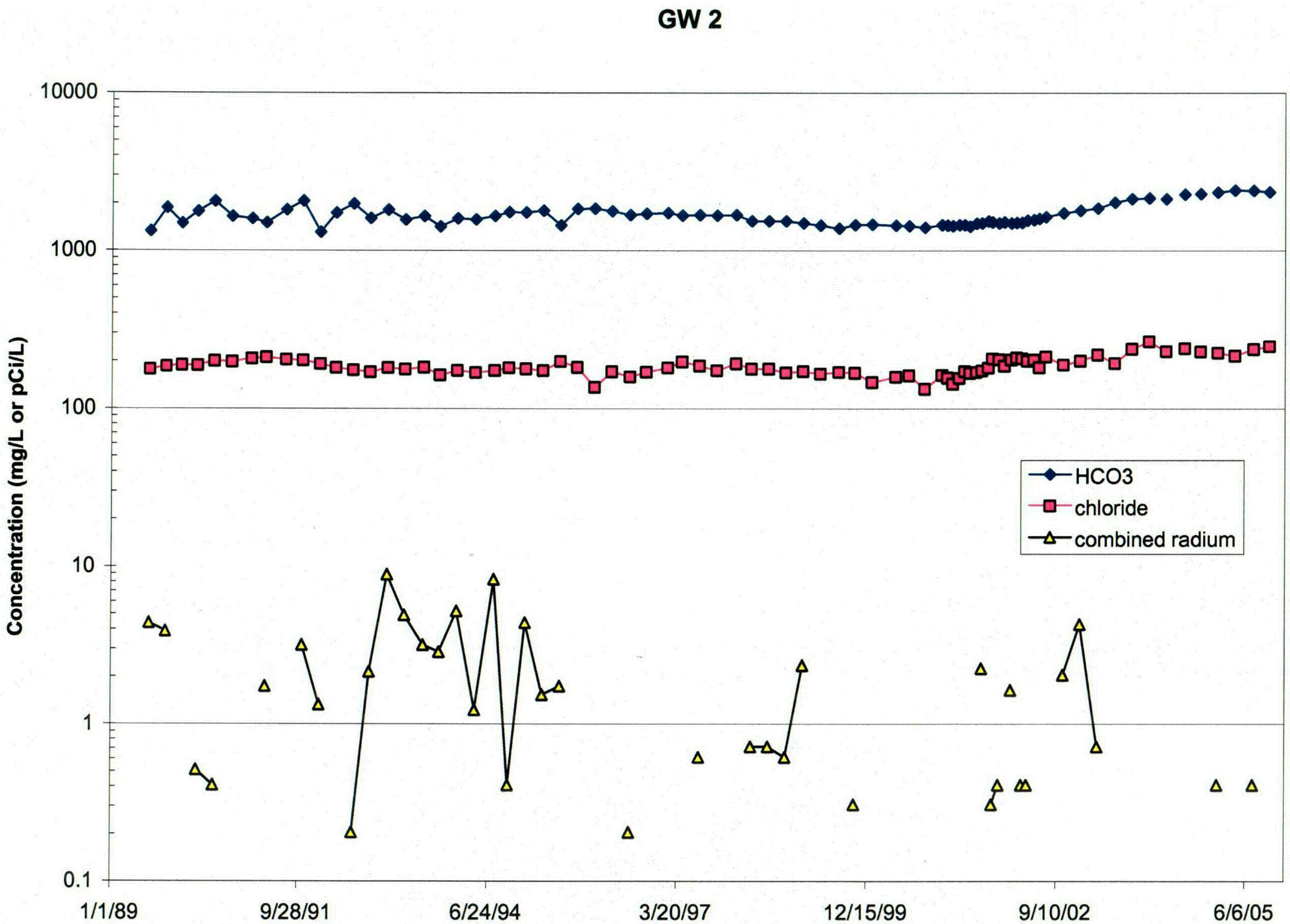
HCO3
chloride
combined radium

C23



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0.1
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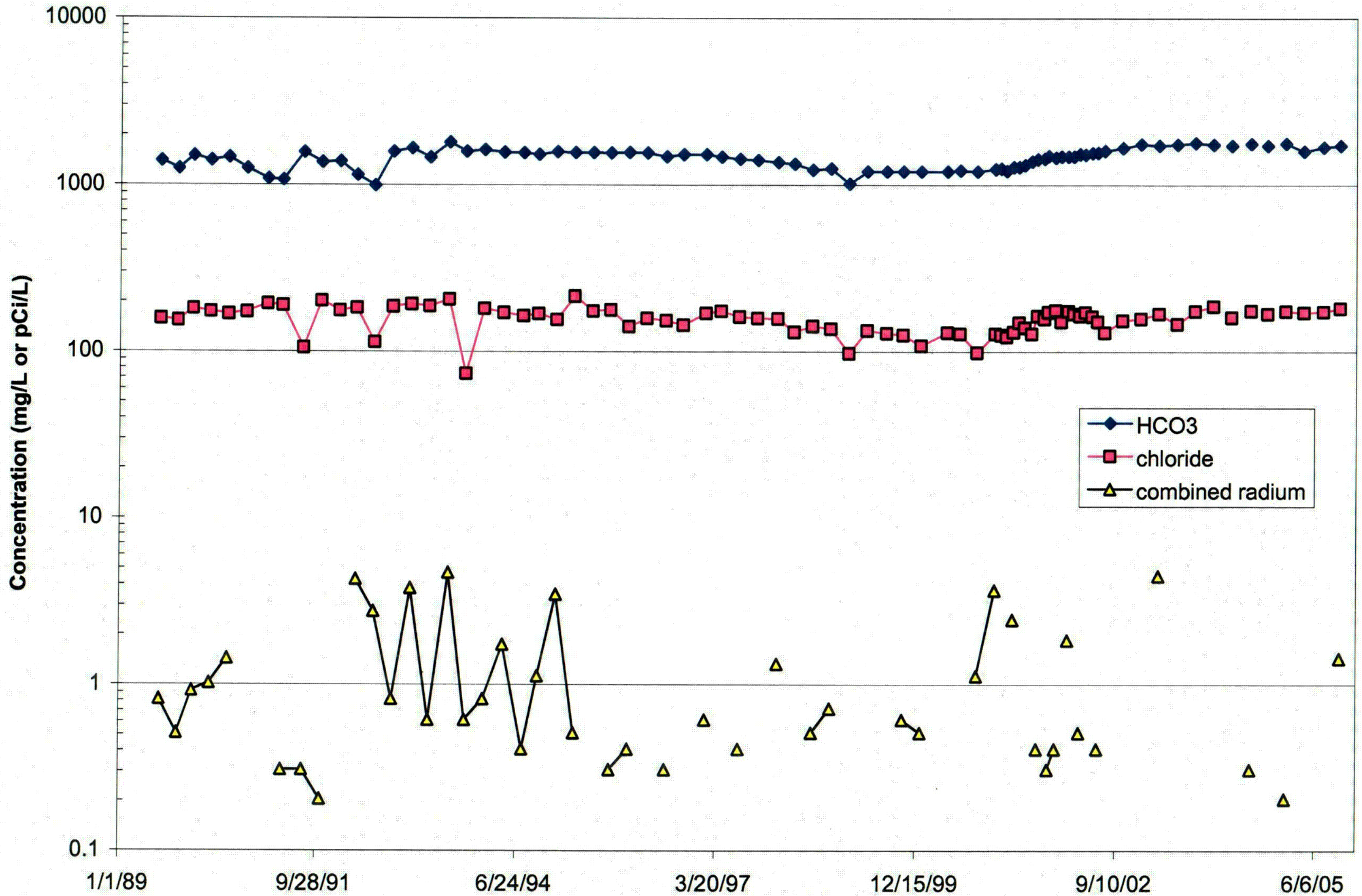
HCO3
chloride
combined radium

C24

GW 3



Concentration (mg/L or pCi/L)
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1000
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10
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0.1
1/1/89
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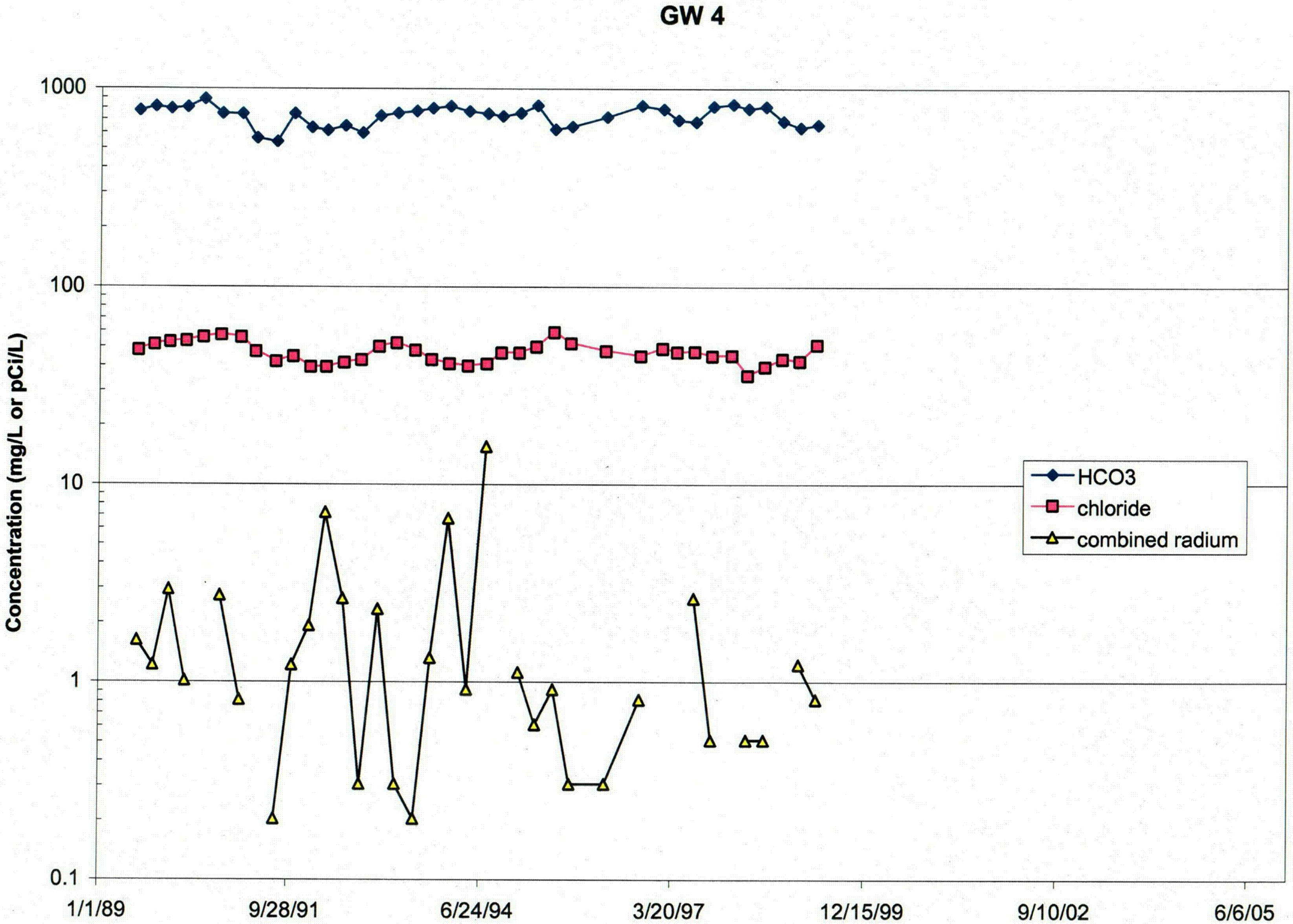
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

C25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Concentration (mg/L or pCi/L)
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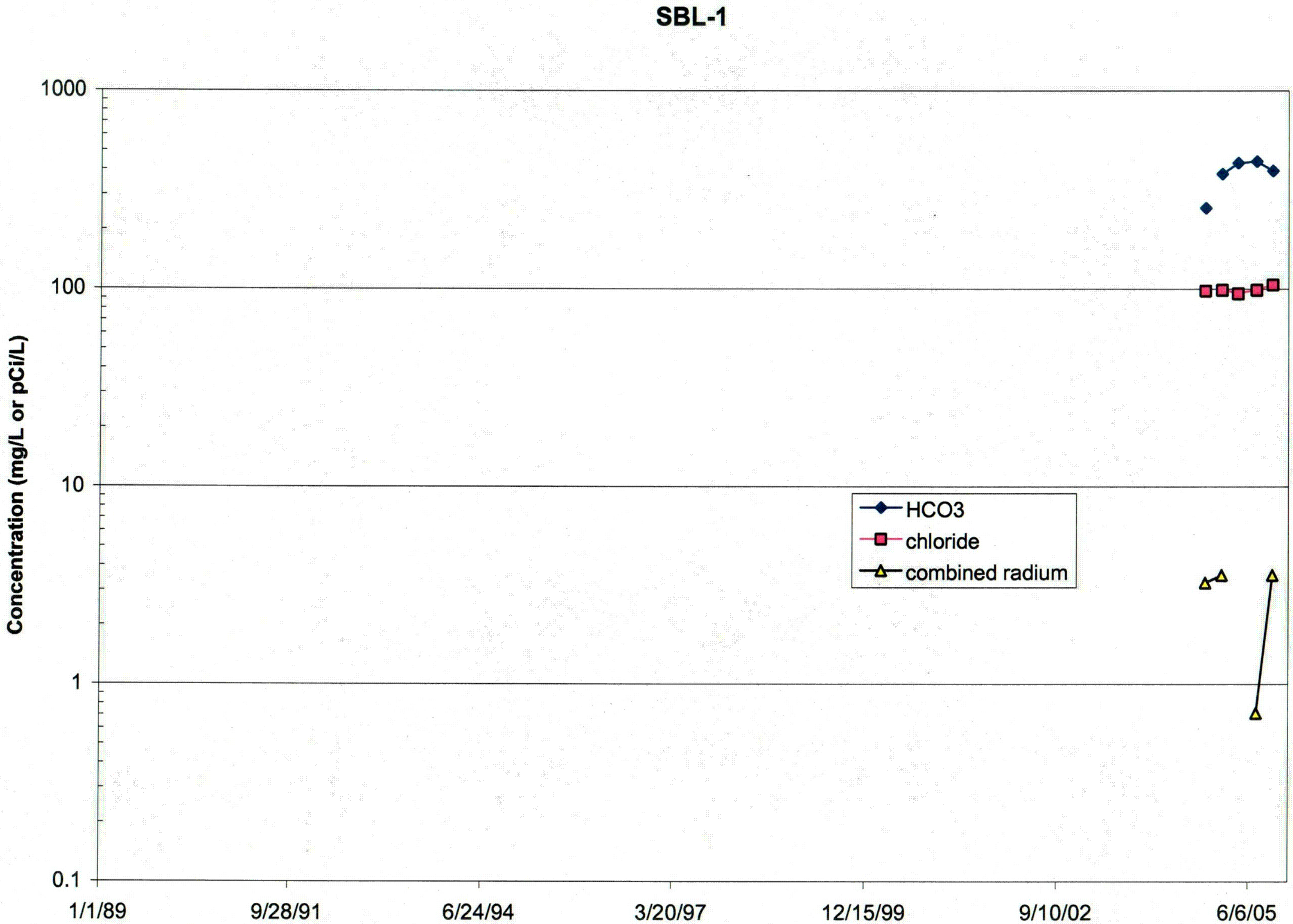
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium

C26


SBL-1
1000
100
10
1
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

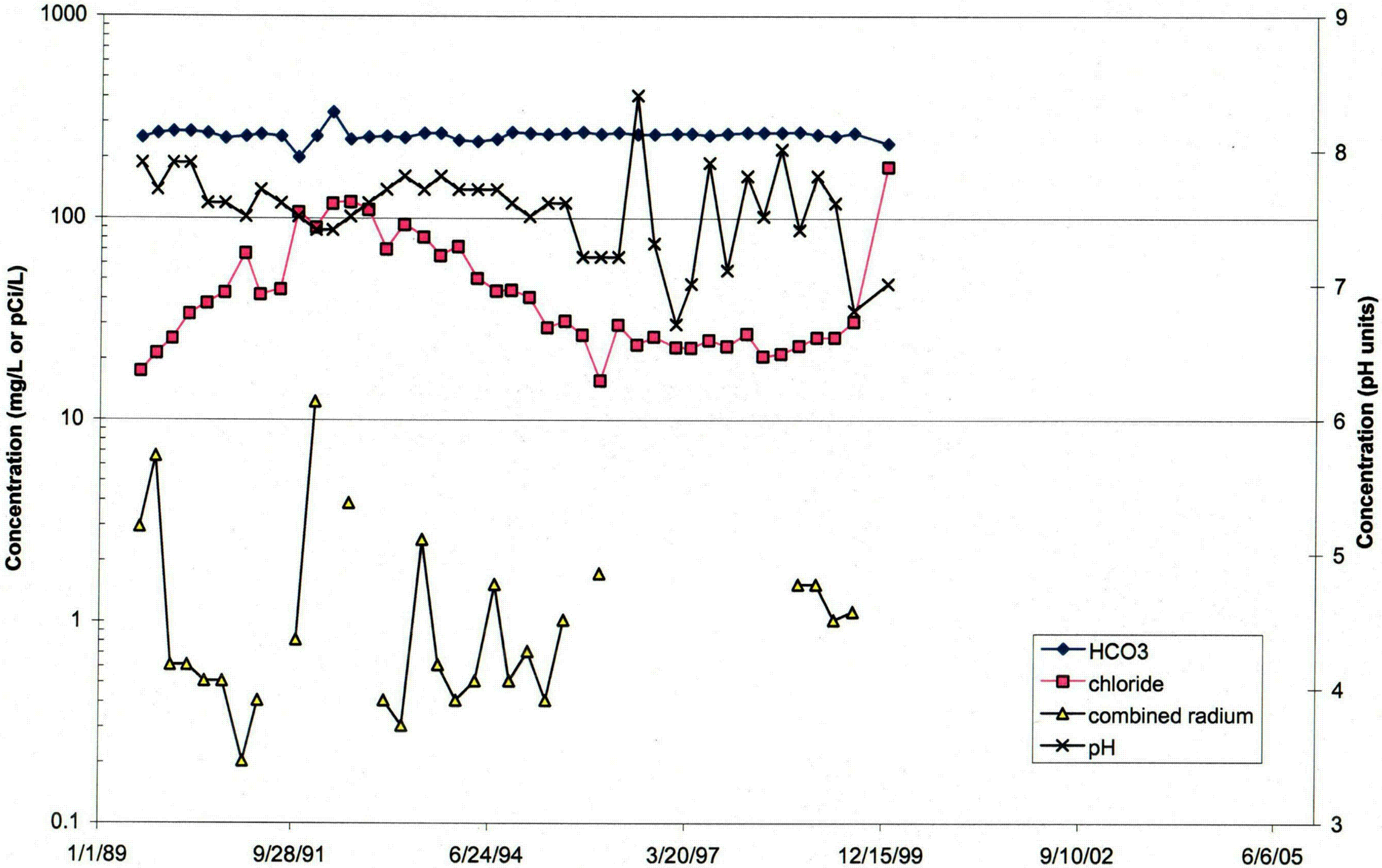
C27

NA WATERSYSTEMS

Appendix A
Part 2

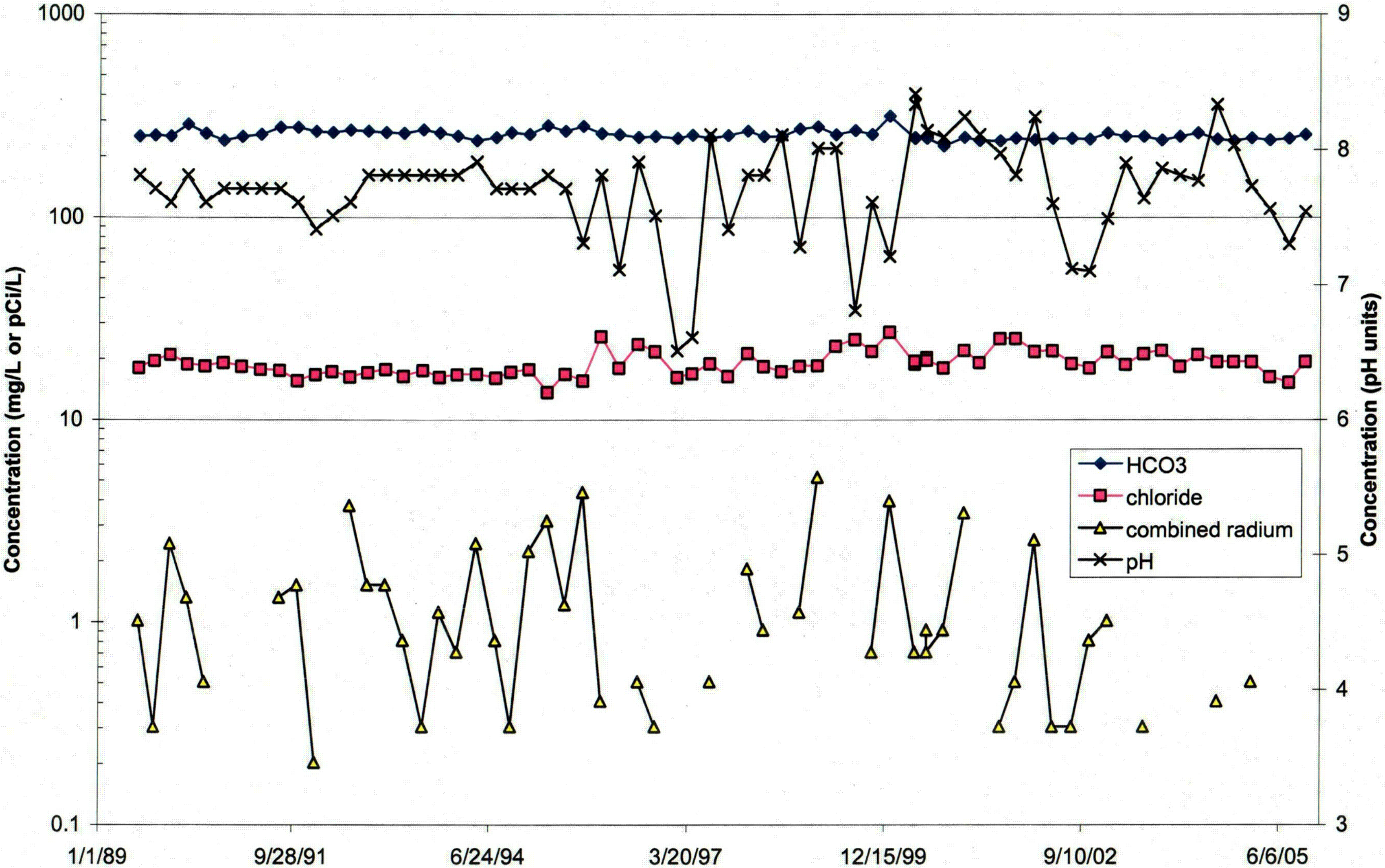
Time Series of Bicarbonate, Chloride, and Combined Radium for Wells in Zone 1
(July 1989 – October 2005)

0141


1000
100
10
1
0.1
9
8
7
6
5
4
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

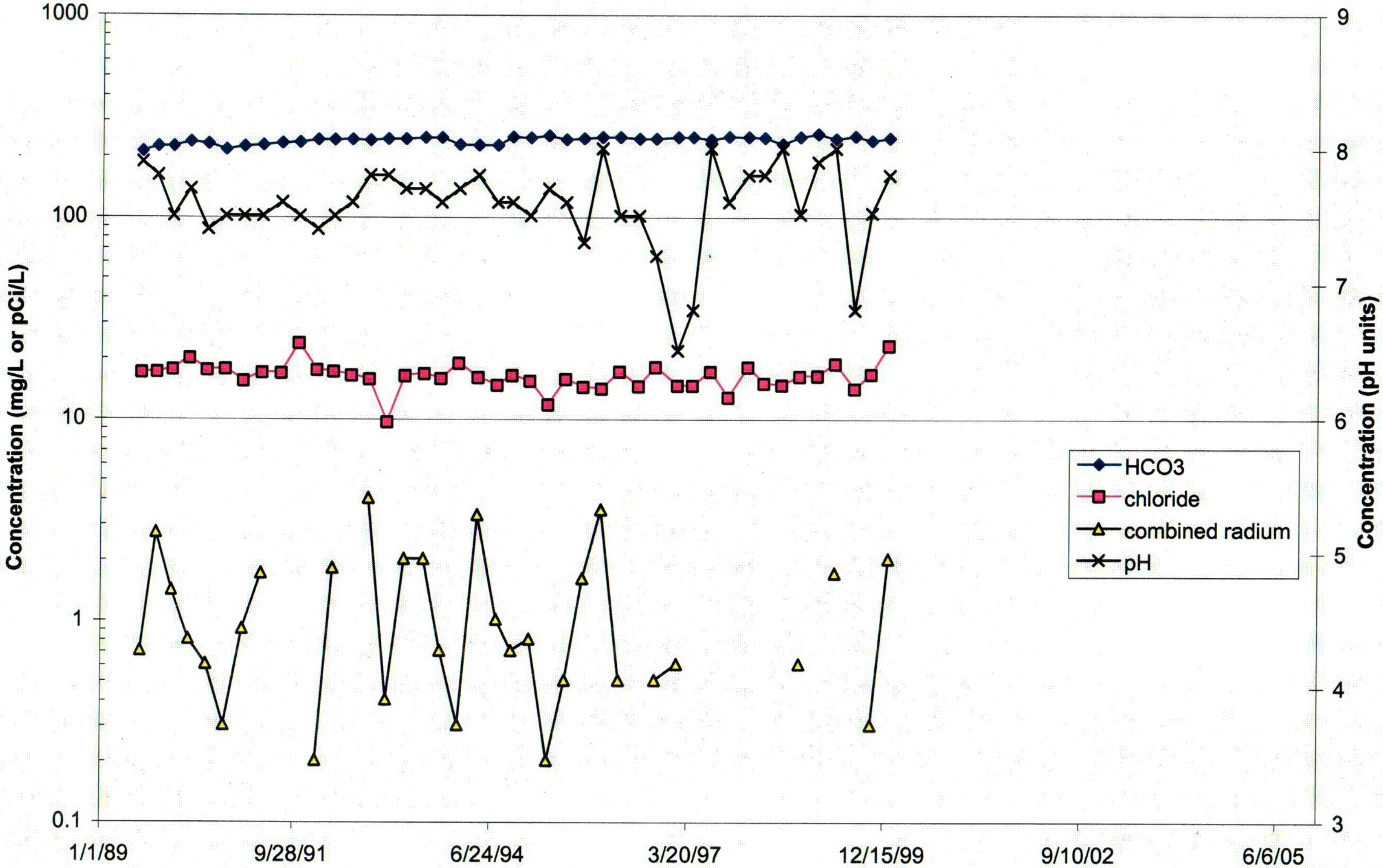
C28

0142


Concentration (mg/L or pCi/L)
Concentration (pH units)
1000
100
10
1
0.1
9
8
7
6
5
4
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

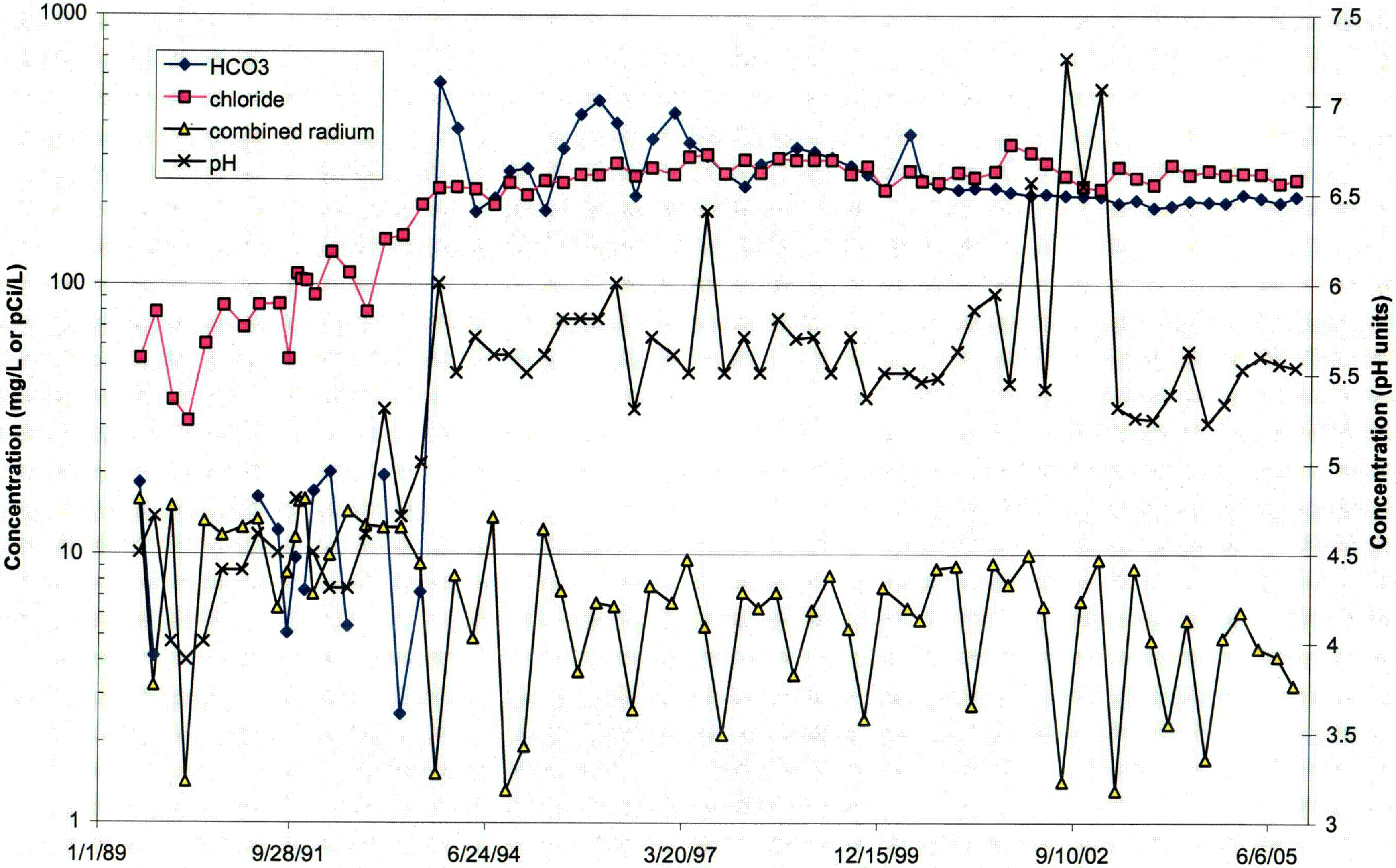
C29

0143

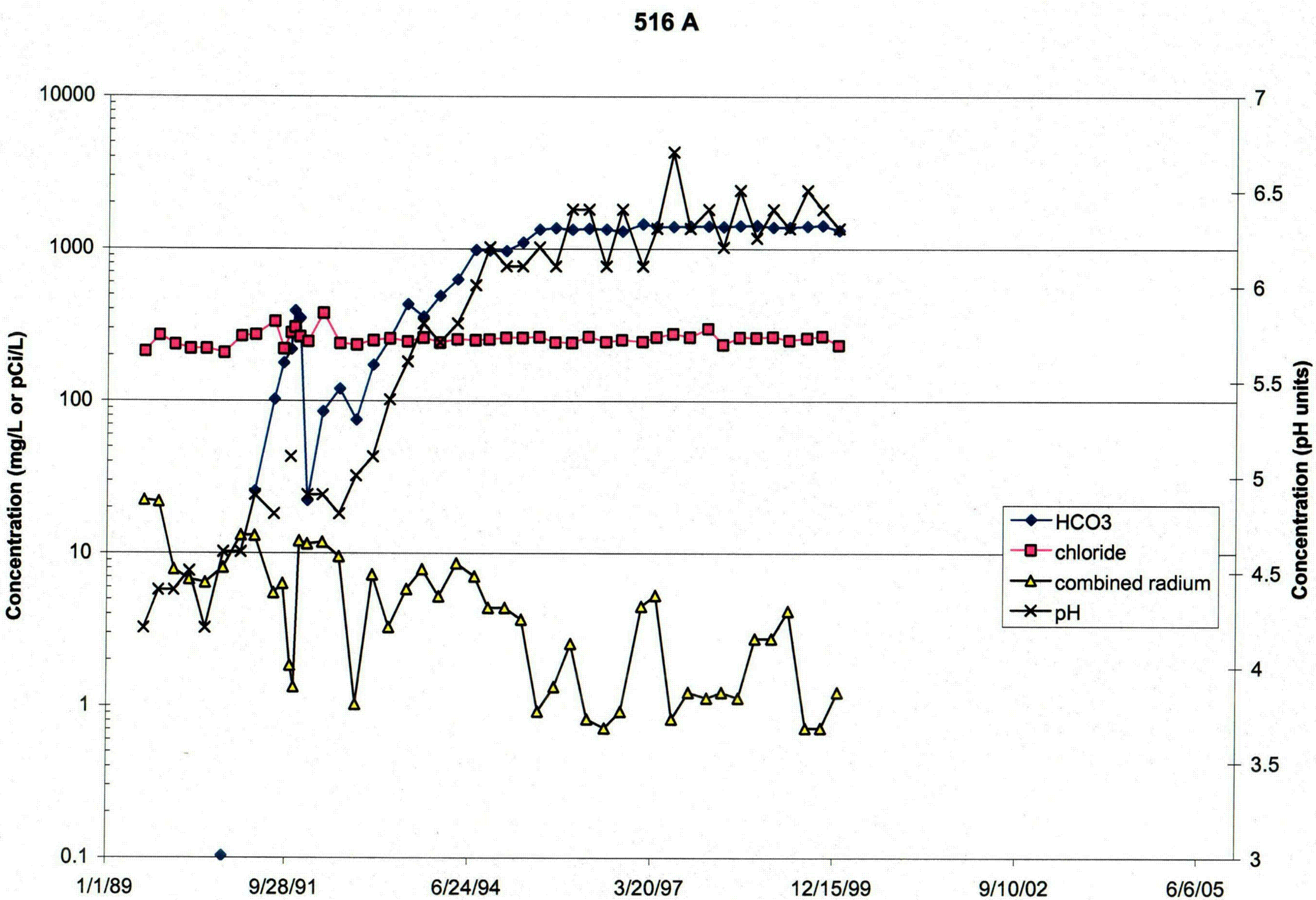

1000
100
10
1
0.1
9
8
7
6
5
4
3
Concentration (mg/L or pCi/L)
Concentration (pH units)
1/1/89
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium
pH

C30

515 A

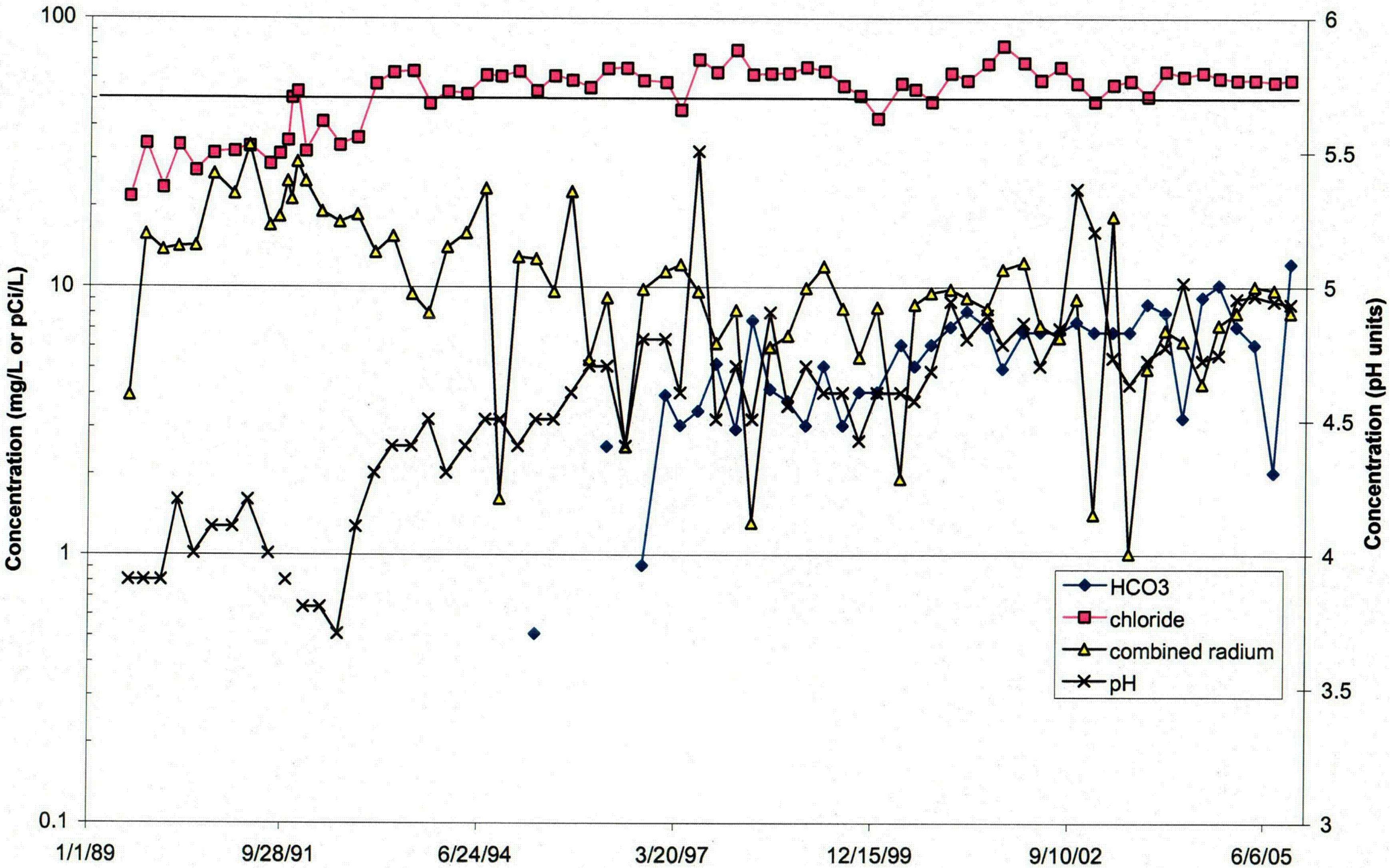

HCO3
chloride
combined radium
pH
Concentration (mg/L or pCi/L)
Concentration (pH units)
1000
100
10
1
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
1/1/89
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05

C31


516 A
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

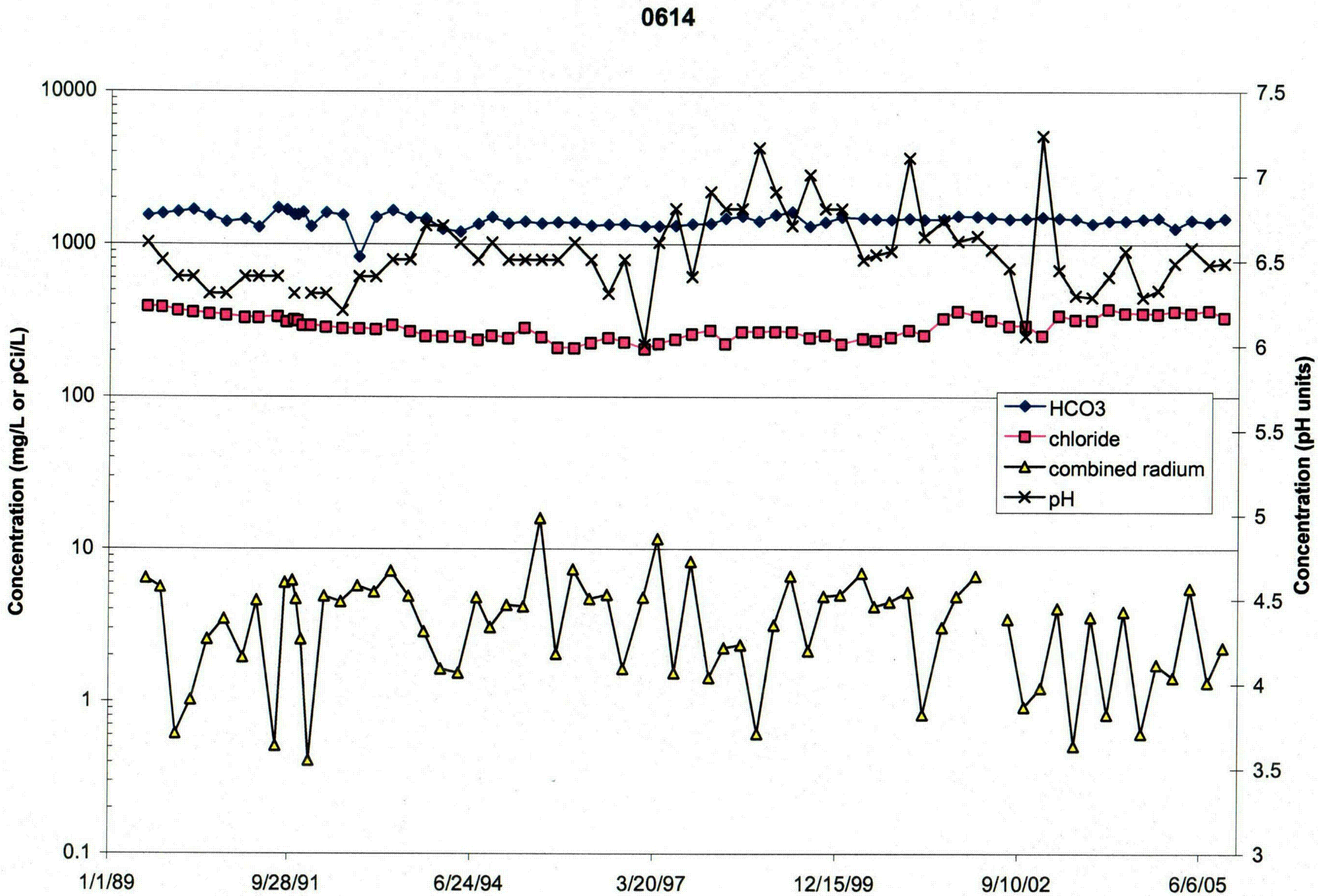
C32

0604

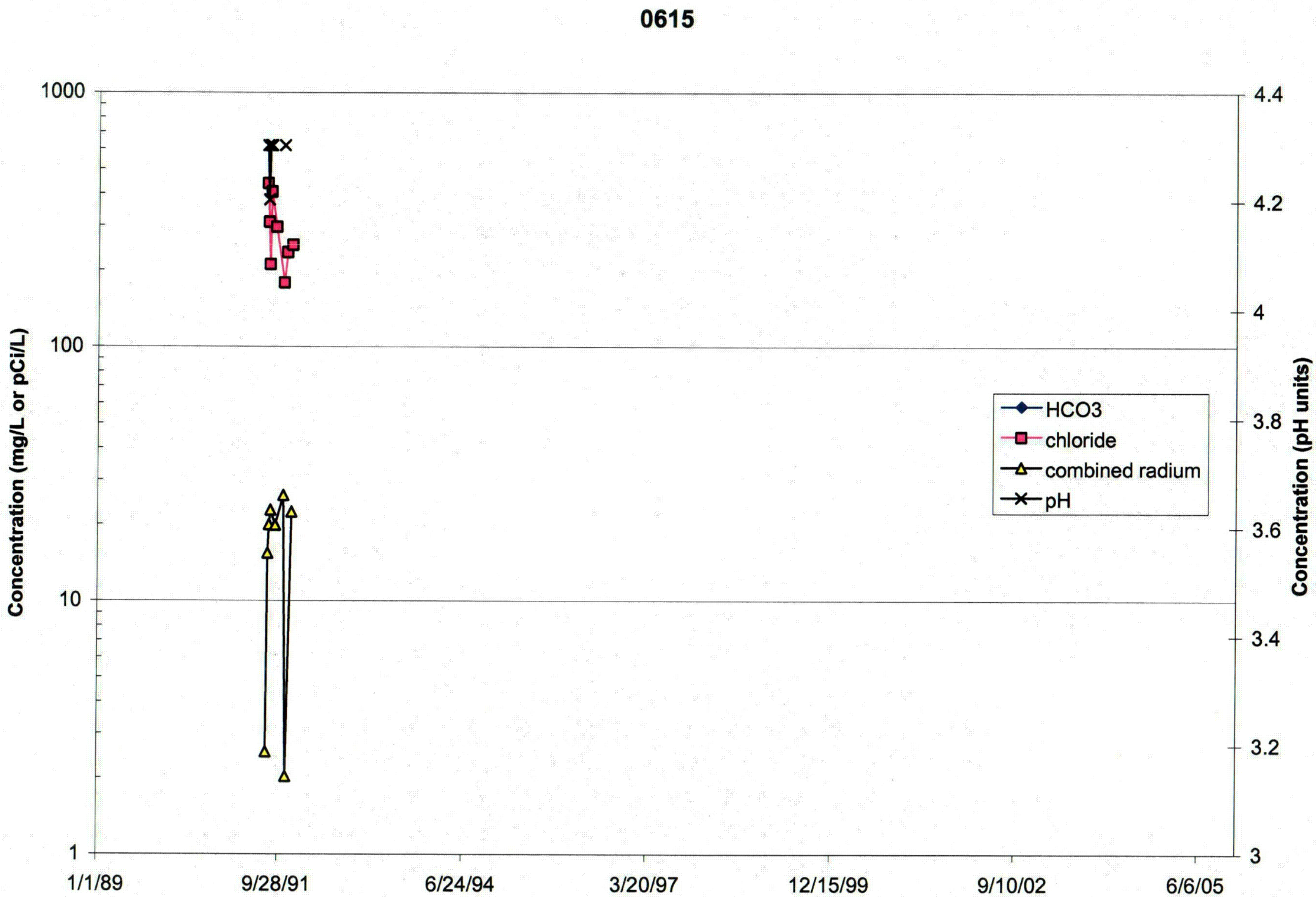


100
10
1
0.1
Concentration (mg/L or pCi/L)
6
5.5
5
4.5
4
3.5
3
Concentration (pH units)
1/1/89
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium
pH

C33


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)
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

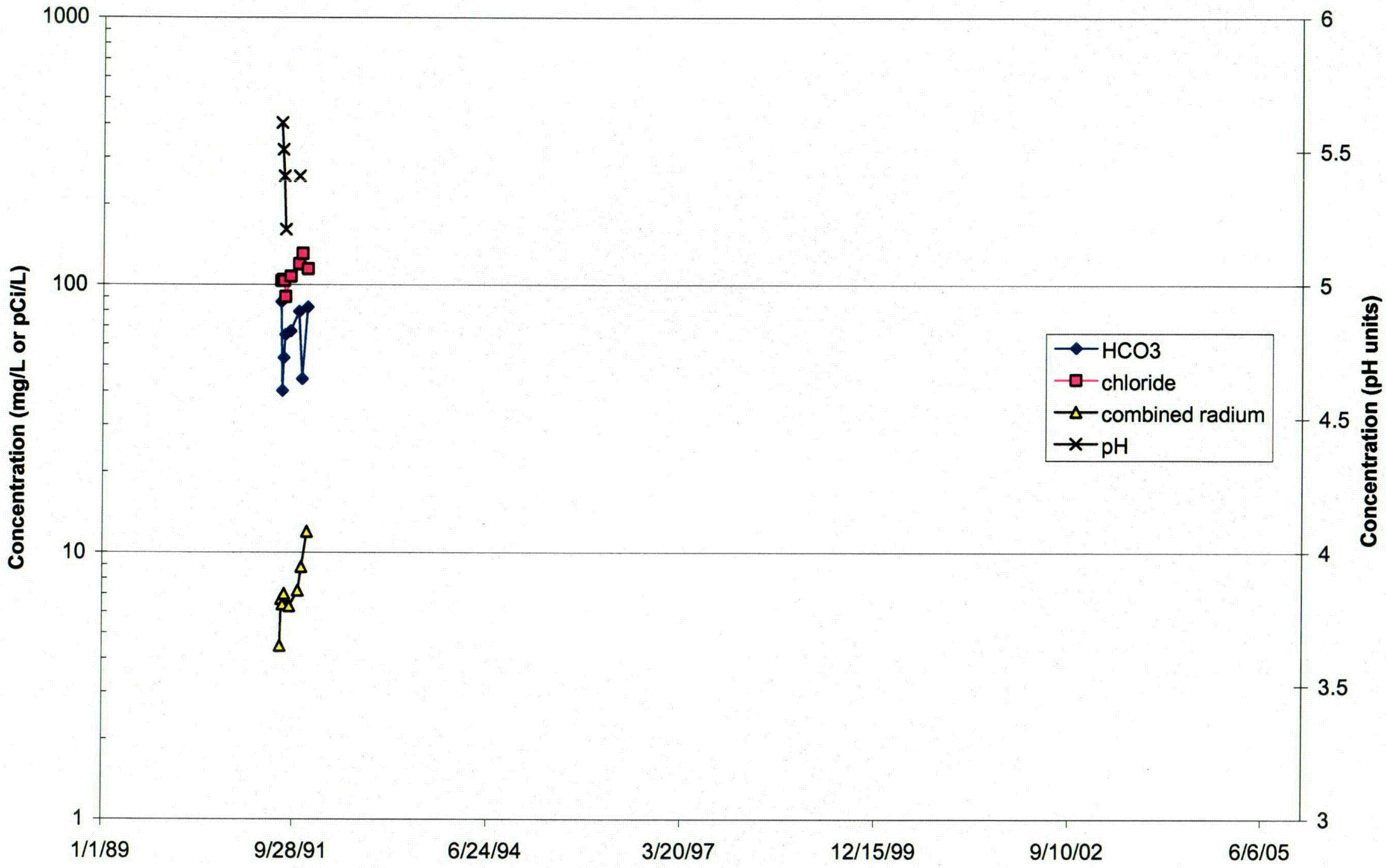
C34



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)
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

C35

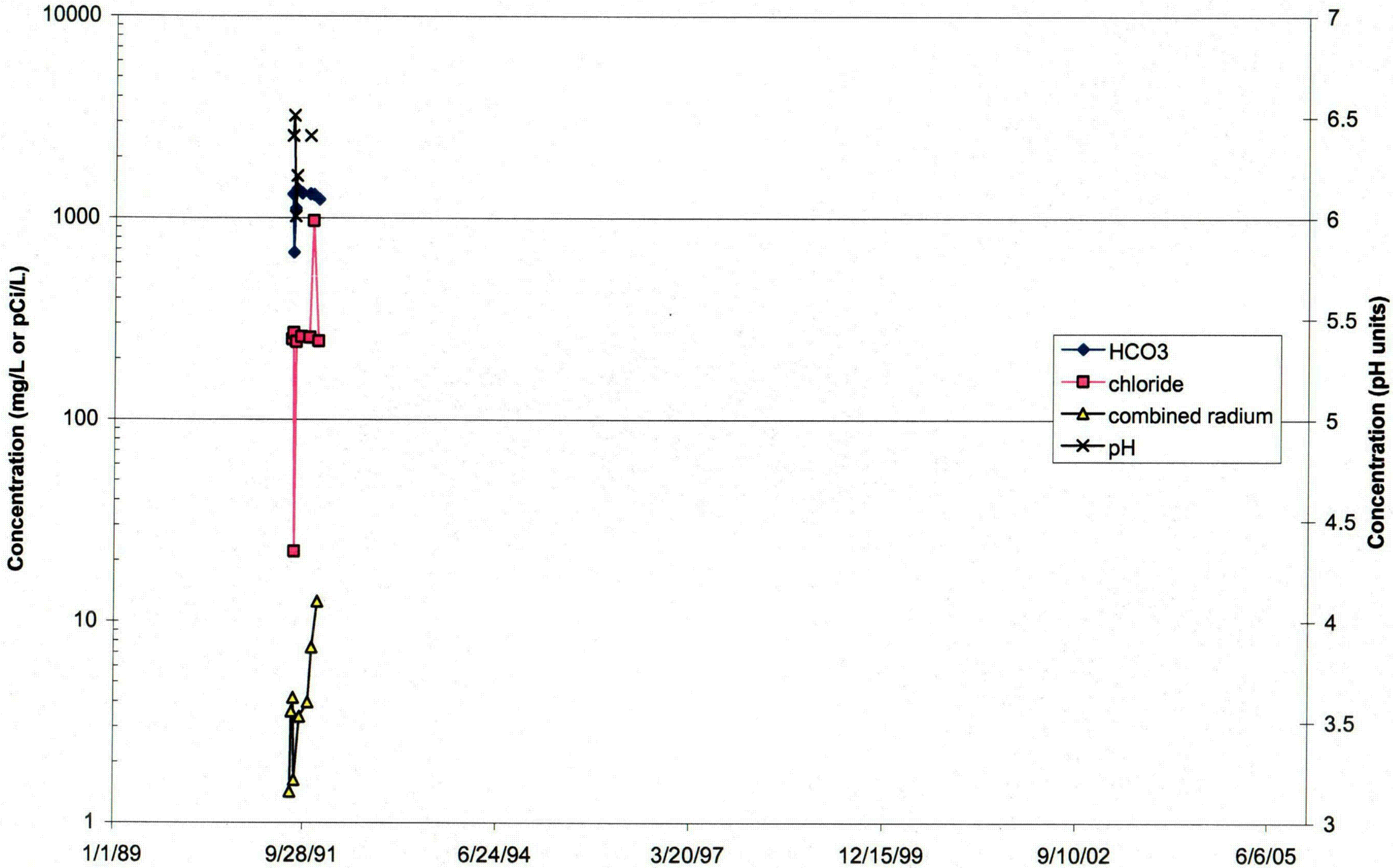
0615



1000
100
10
1
Concentration (mg/L or pCi/L)
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

C36

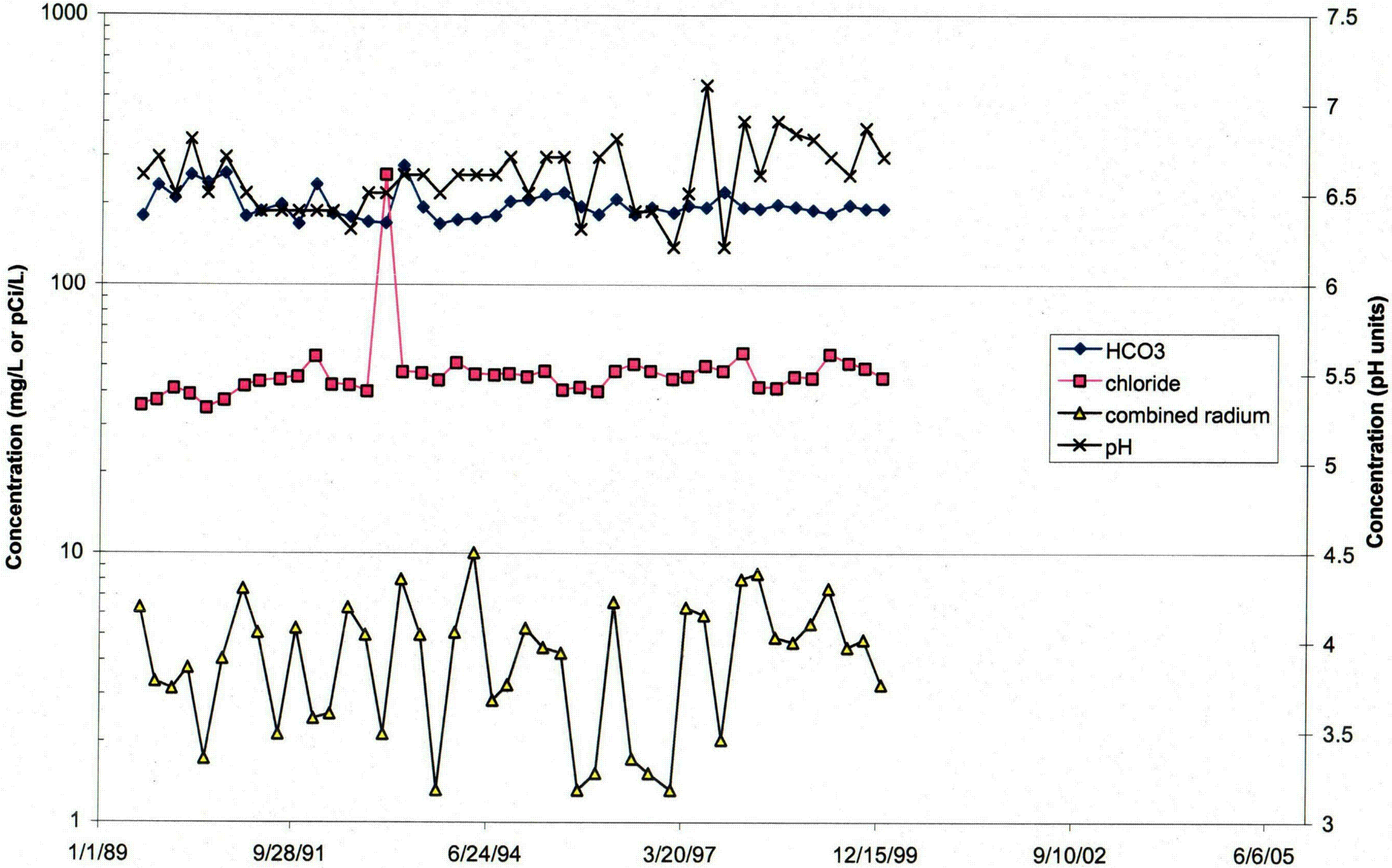
0617



10000
1000
100
10
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

C37

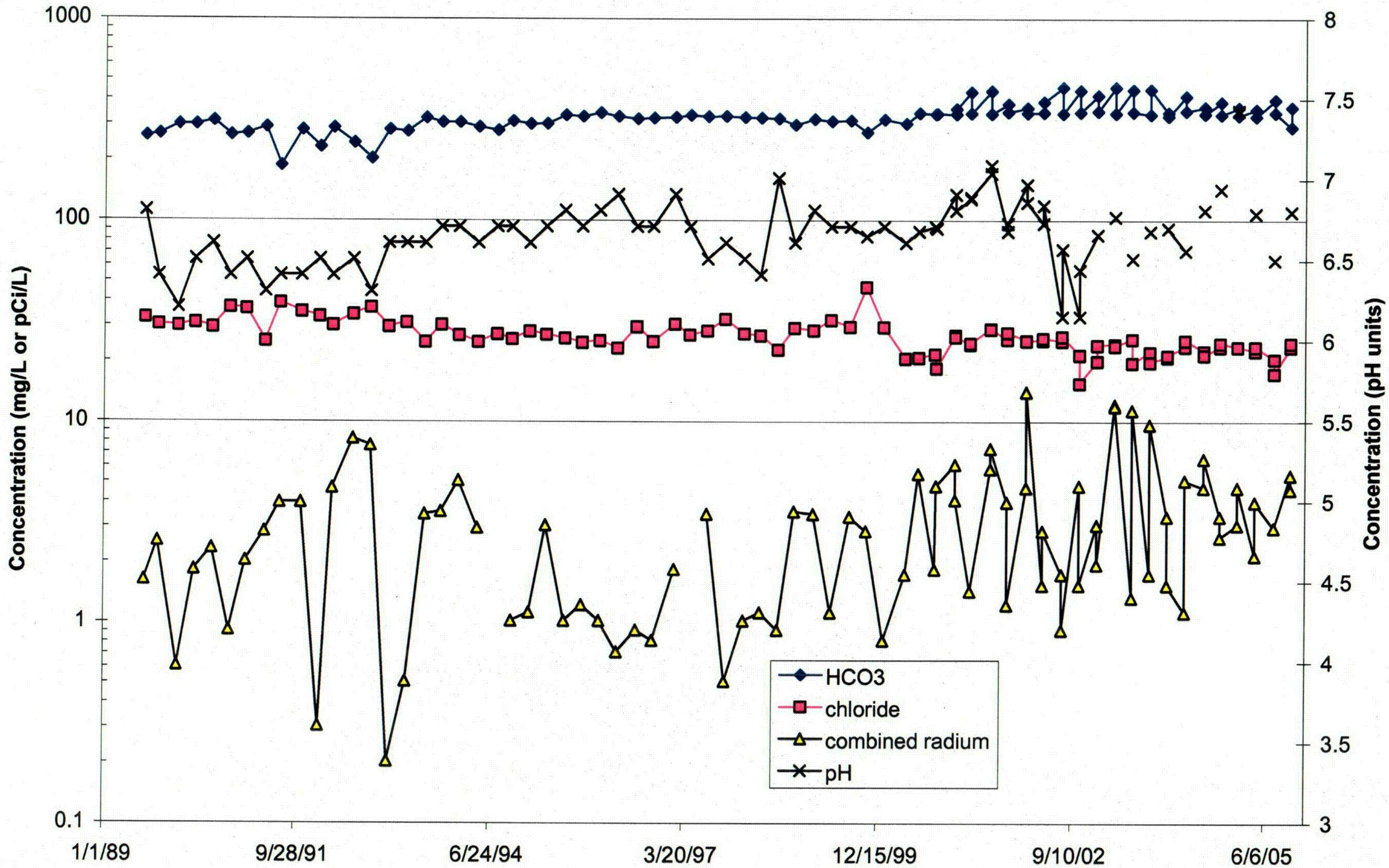
0619



1000
100
10
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

C38

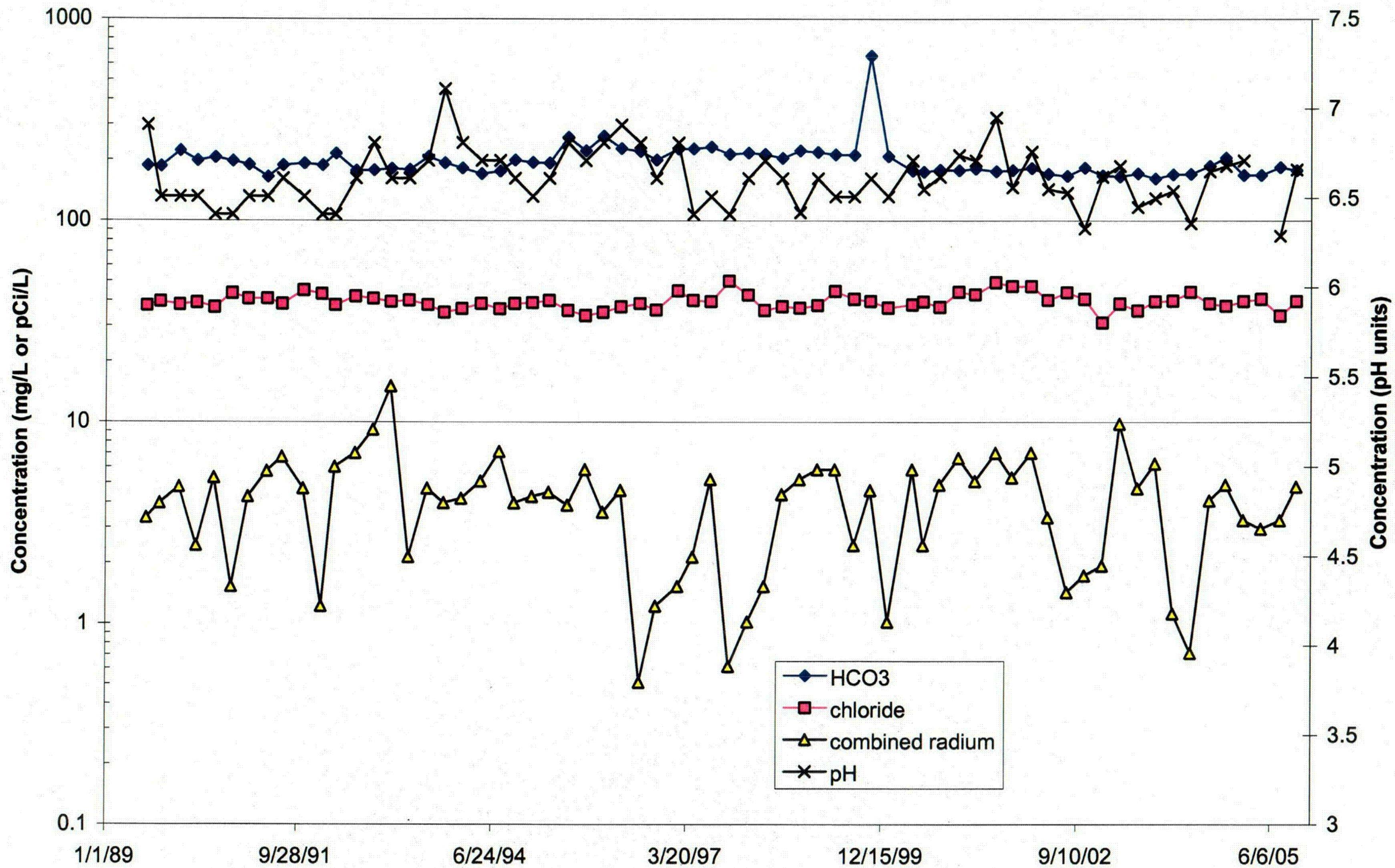
EPA-02



EPA-02
Concentration (mg/L or pCi/L)
Concentration (pH units)
1000
100
10
1
0.1
8
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

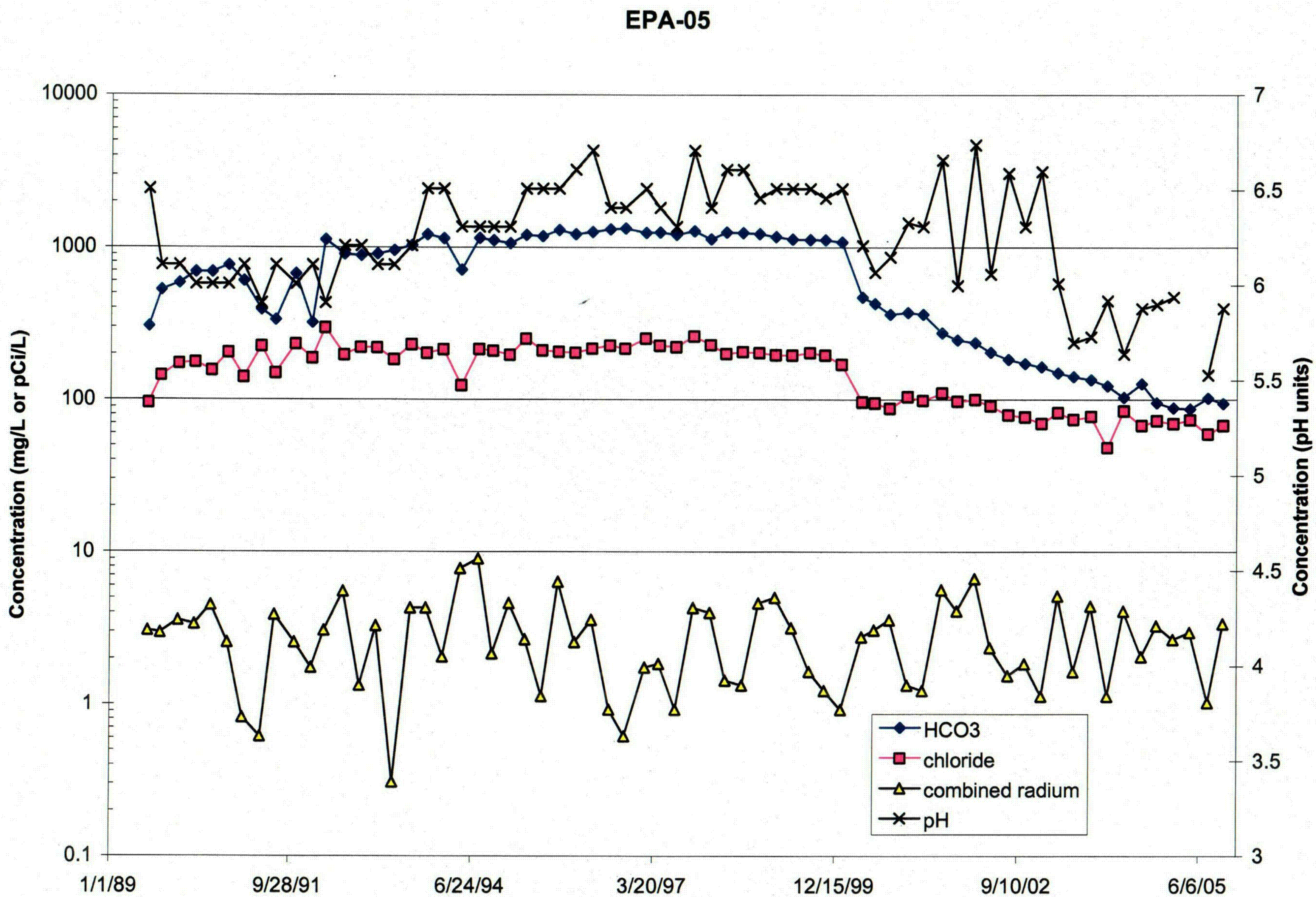
C39

EPA-04



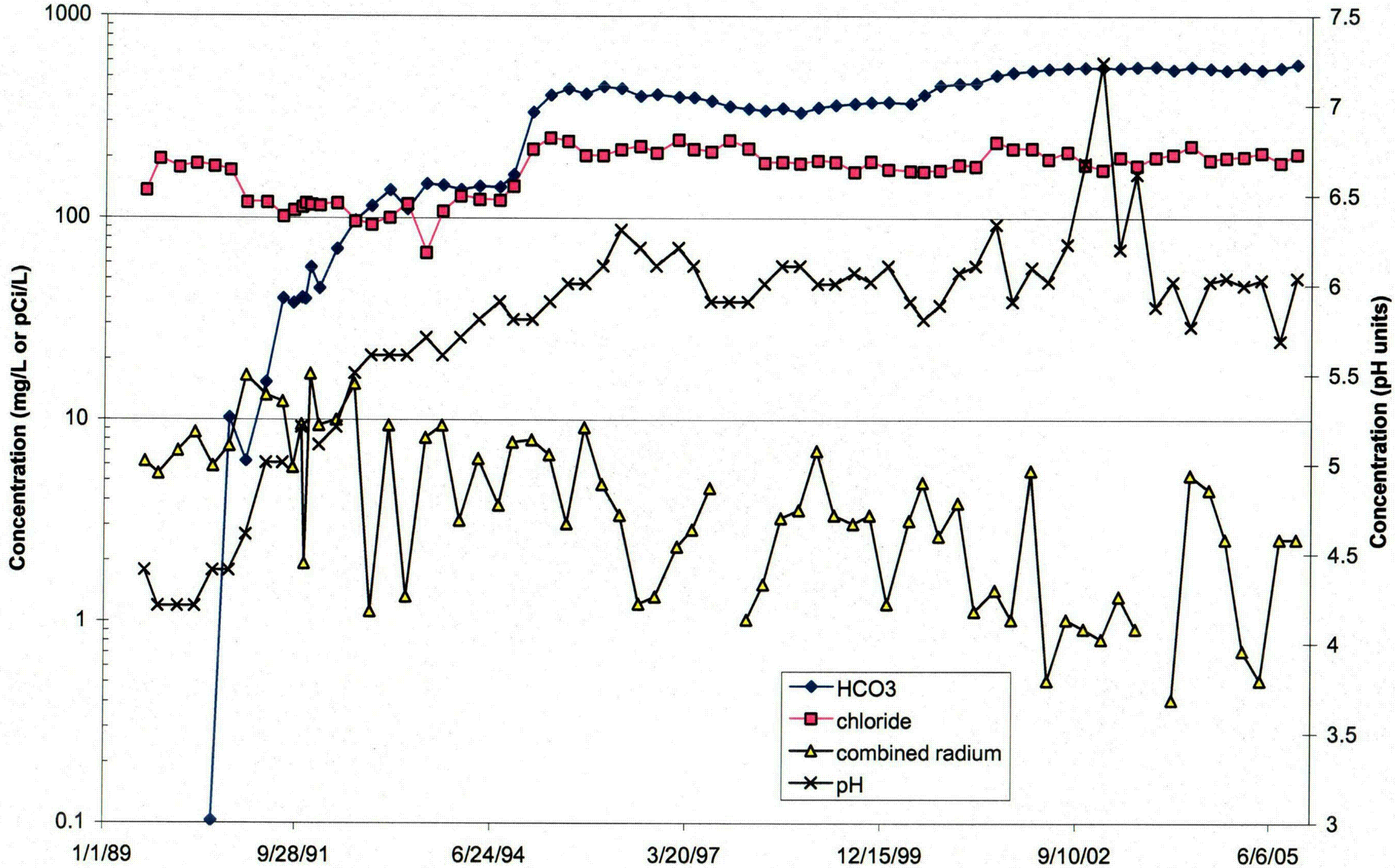
1000
100
10
1
0.1
Concentration (mg/L or pCi/L)
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
Concentration (pH units)
1/1/89
9/28/91
6/24/94
3/20/97
12/15/99
9/10/02
6/6/05
HCO3
chloride
combined radium
pH

C40


EPA-05
10000
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

C41

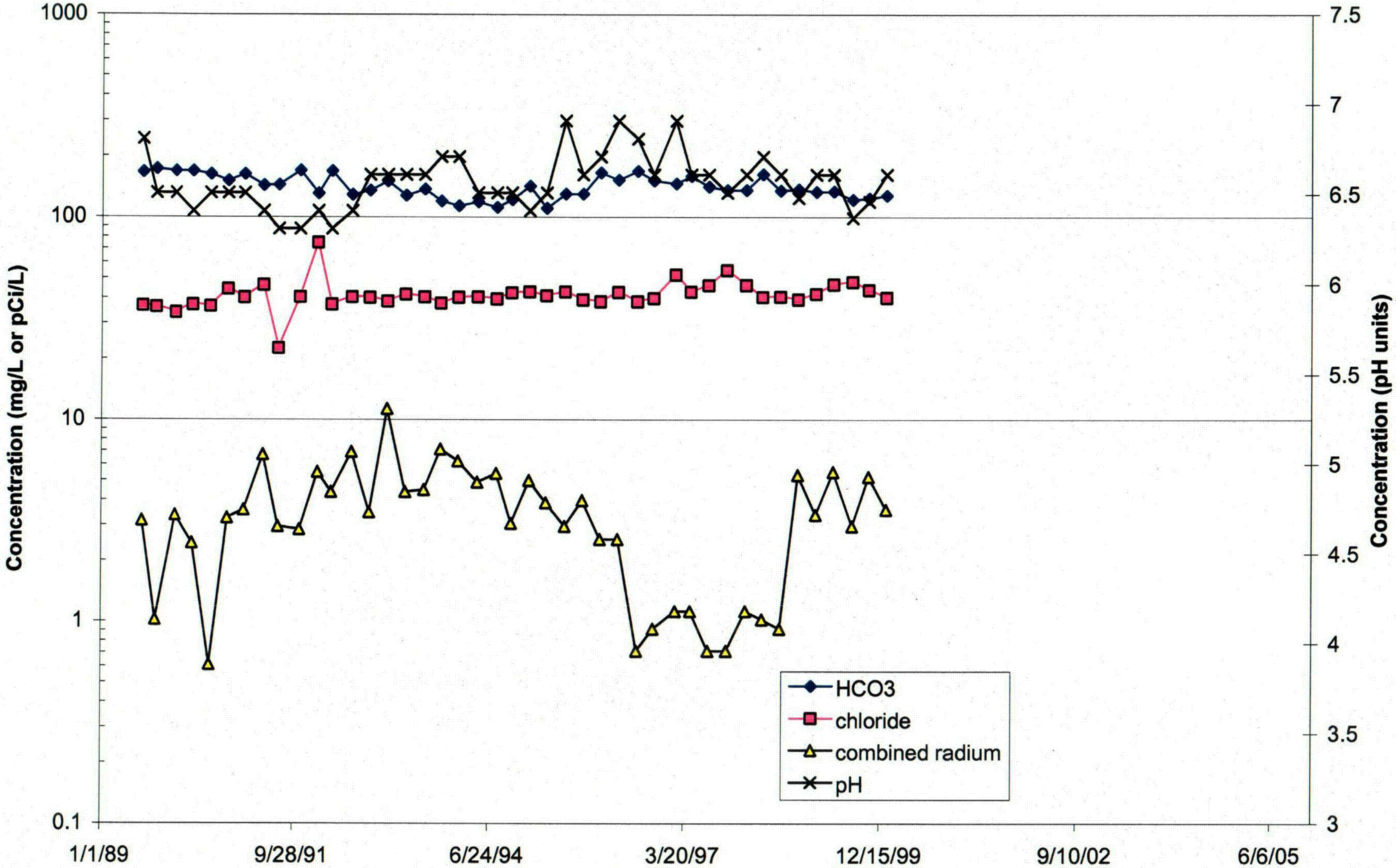
EPA-07



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

C42

EPA-08


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

C43

NA WATERSYSTEMS

Appendix B
Basic Statistics Output from Chemstat

NA WATERSYSTEMS

Basic Statistics for Combined Radium

Southwest Alluvium

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

Total Measurements890
Total Non-Detects281 (31.573%)
Pooled Mean1.4816
Pooled Std Dev1.63417

Compliance Meas.536
Compliance Mean1.3783
Compliance Std Dev1.49725

Background Meas.354
Background Mean1.63799
Background Std Dev1.81306

===

Background Locations

There are 12 background locations

Location	Meas.	Non-Detects	% ND	Total
627	74	16	21.6	99.3
639	21	3	14.2	56.2
642	25	5	20	40
644	14	1	7.1	27.1
645	5	2	40	4.5
0029 A	22	7	31.8	42.8
624 B	26	8	30.7	50.3
EPA 22A	33	3	9.0	58.4
EPA 25 B	26	10	38.4	35.8
EPA 27	33	18	54.5	42.4
EPA 28(B)	74	14	18.9	119.8
SBL-01	1	0	0	3.2

Location	Mean	Std Dev	Std Err	Rank Sum	Rank Mean
627	1.34	1.45	0	33861	457.5
639	2.67	2.87	0	12006	571.7
642	1.6	1.73	0	12094	483.7
644	1.93	1.92	0	7731	552.2
645	0.9	0.61	0	1813	362.6
0029 A	1.94	2.58	0	9847	447.5
624 B	1.93	2.33	0	12274	472.0
EPA 22A	1.76	1.96	0	18113	548.8
EPA 25 B	1.37	1.28	0	11026	424.0
EPA 27	1.28	1.29	0	11953	362.2
EPA 28(B)	1.61	1.54	0	37556	507.5
SBL-01	3.2	0	0	773	773

===

NA WATERSYSTEMS

Compliance Locations
There are 7 compliance locations

Location	Obs.	Non-Detects	% ND	Total
632	74	2	2.7	185.8
0509 D	74	19	25.6	89.9
EPA 23	88	48	54.5	87.7
EPA 28	74	14	18.9	119.8
GW 1	78	41	52.5	85.1
GW 2	74	38	51.3	99.5
GW 3	74	32	43.2	70.9

Location	Mean	Std Dev	Dif From Bkg	Std Err	Rank Sum	Rank Mean
632	2.51	1.89	0.87	0.20	48934	661.2
0509 D	1.21	1.37	-0.42	0.20	32773	442.8
EPA 23	0.99	1.01	-0.64	0.18	28140	319.7
EPA 28	1.61	1.54	-0.01	0.20	38030	513.9
GW 1	1.09	1.28	-0.54	0.19	26075	334.2
GW 2	1.34	1.66	-0.29	0.20	26993	364.7
GW 3	0.95	1.00	-0.67	0.20	26503	358.1

NA WATERSYSTEMS

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

NA WATERSYSTEMS

Appendix C
Normal Probability Plots and Tests of Normality

VEOLIA Water

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

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

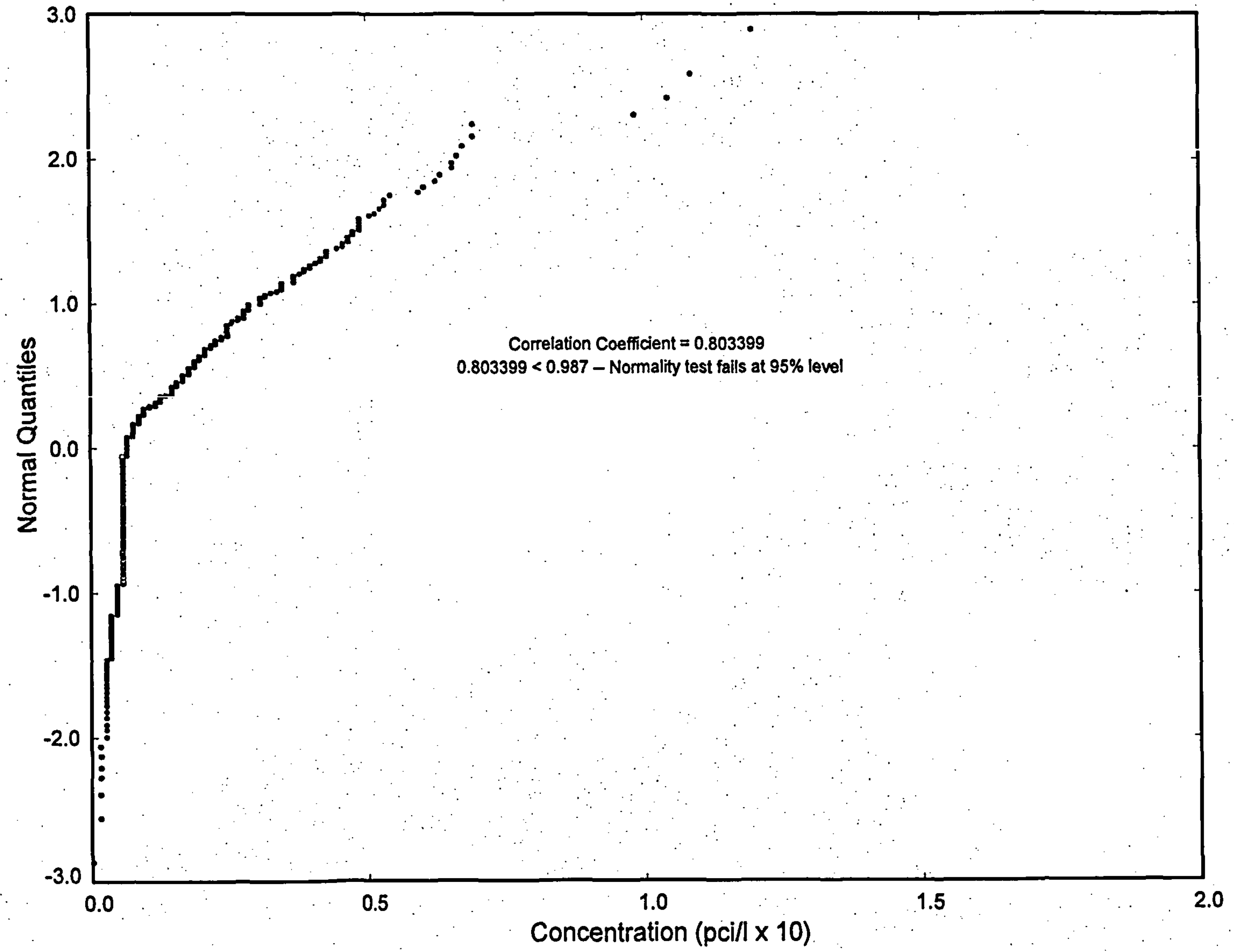


FIGURE C-2
Probability Plot of Combined Radium Values for Compliance Wells in the Southwest Alluvium

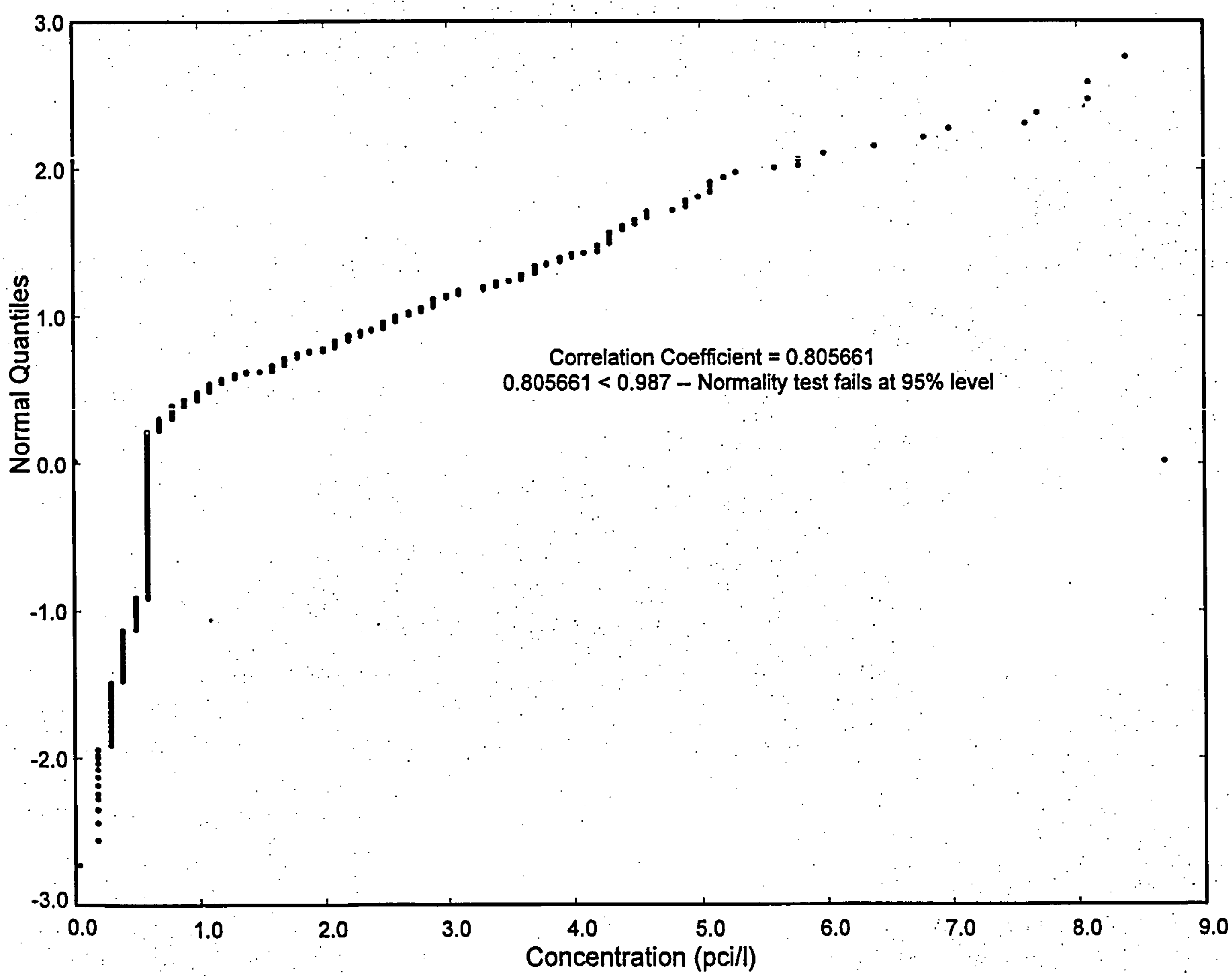


FIGURE C-3
Probability Plot of Combined Radium Values for Background Wells in Zone 1

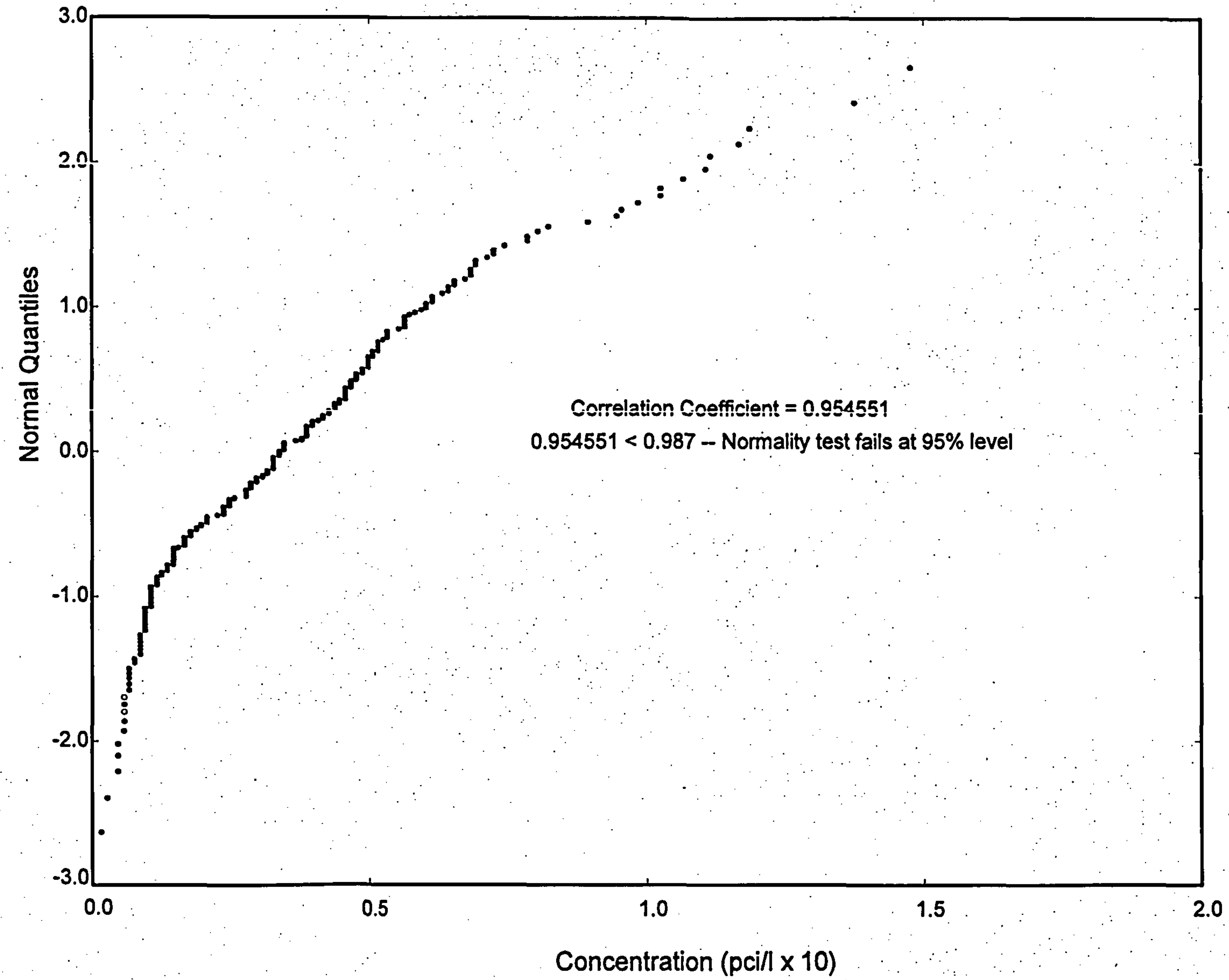
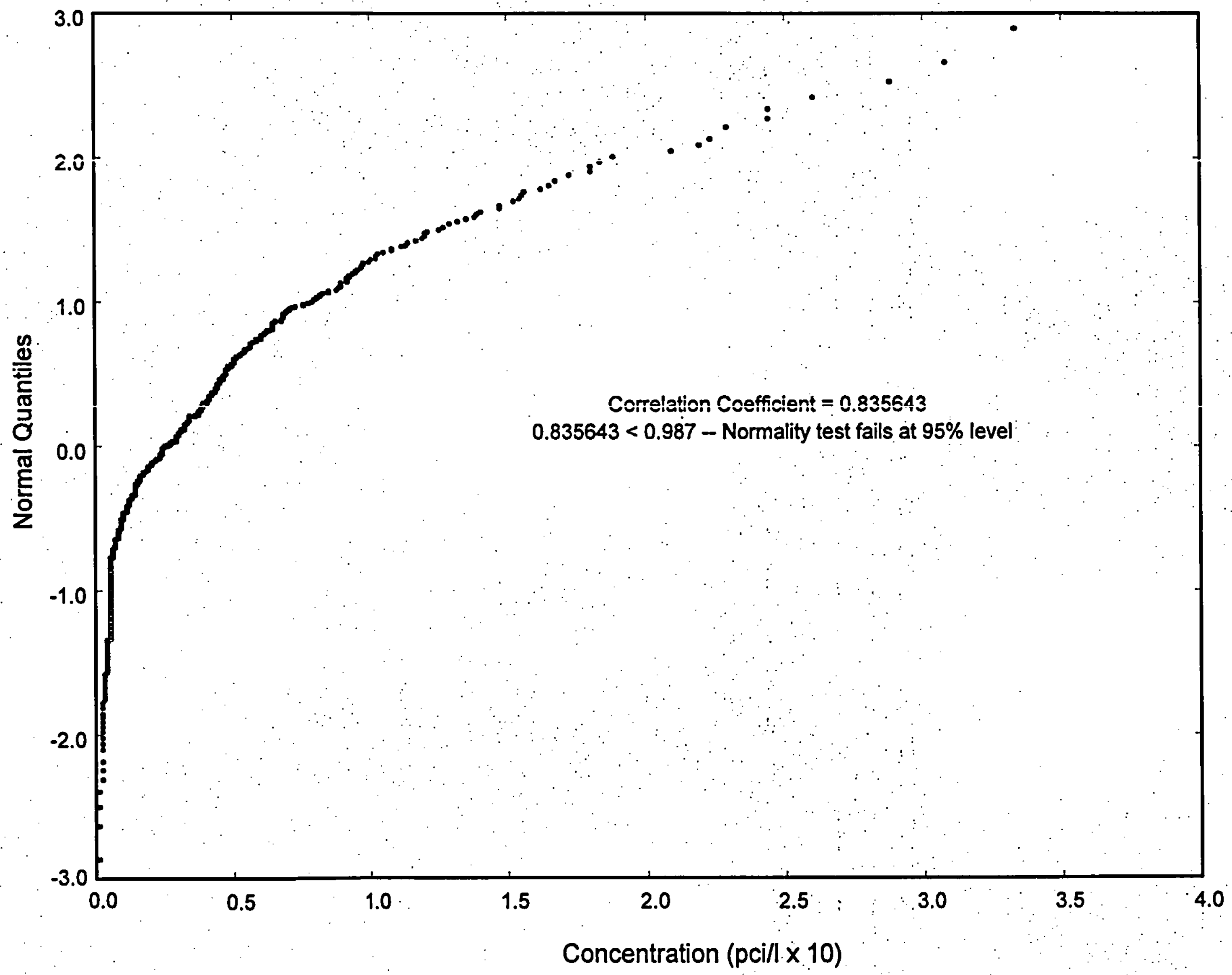


FIGURE C-4
Probability Plot of Combined Radium Values for Compliance Wells in Zone 1



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 = 114.371
Kruskal-Wallis H Statistic (adjusted for tied non-detects) = 118.088
95% Confidence comparison value is 14.0671 at 7 degrees of freedom
114.371 > 14.0671 indicating a significant group difference at 5% significance level
118.088 > 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 196.838

Well	Mean Rank	Dif from Bkg	Critical Value
632	661.27	183.736	76.4401
0509 D	442.878	-34.6555	76.4401
EPA 23	319.773	-157.761	71.2336
EPA 28	513.919	36.385	76.4401
GW 1	334.295	-143.239	74.8014
GW 2	364.77	-112.764	76.4401
GW 3	358.149	-119.385	76.4401

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 477.534

Well	Mean Rank	Dif from Bkg	Critical Value
632	661.27	183.736	80.7423
0509 D	442.878	-34.6555	80.7423
EPA 23	319.773	-157.761	75.2428
EPA 28	513.919	36.385	80.7423
GW 1	334.295	-143.239	79.0114
GW 2	364.77	-112.764	80.7423
GW 3	358.149	-119.385	80.7423

NA WATERSYSTEMS

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

VEOLIA Water

N.A. WaterSystems

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

Two-Sample Test of Proportions Using the Site Standard

Southwest Alluvium

Parameter: radium-combined
Original Data (Not Transformed)
Non-Detects Replaced with Detection Limit
Background measurements = 354
Compliance measurements = 536
Comparison Level = 5

20 background measurements exceed 5

19 compliance measurements exceed 5

p background = 0.0564972 = 20 / 354
p compliance = 0.0354478 = 19 / 536
p total = 0.0438202 = 39 / 890

nPs = 19
mPb = 20
n(1-Ps) = 517
m(1-Pb = 334

Zp = -1.50149 = -0.0210494 / 0.014019
Z critical = 1.64485 at 95% confidence level

-1.50149 < 1.64485
No Statistical Significance at 95% Confidence Level
When Compared to Compliance Limit = 5

NA WATERSYSTEMS

Two-Sample Test of Proportions Using the 95th Percentile of Background

Southwest Alluvium

Parameter: radium-combined
Original Data (Not Transformed)
Non-Detects Replaced with Detection Limit
Background measurements = 354
Compliance measurements = 536
Comparison Level = 5.2

18 background measurements exceed 5.2

14 compliance measurements exceed 5.2

p background = 0.0508475 = 18 / 354
p compliance = 0.0261194 = 14 / 536
p total = 0.0359551 = 32 / 890

nPs = 14
mPb = 18
n(1-Ps) = 522
m(1-Pb = 336

Zp = -1.93932 = -0.0247281 / 0.0127509
Z critical = 1.64485 at 95% confidence level

-1.93932 < 1.64485
No Statistical Significance at 95% Confidence Level
When Compared to Compliance Limit = 5.2

Two-Sample Test of Proportions Using the Site Standard

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

Two-Sample Test of Proportions Using the 95th Percentile of Background

Zone 1

Parameter: radium-combined
Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL
Background measurements = 227
Compliance measurements = 319
Comparison Level = 9.4

12 background measurements exceed 9.4

54 compliance measurements exceed 9.4

p background = 0.0528634 = 12 / 227
p compliance = 0.169279 = 54 / 319
p total = 0.120879 = 66 / 546

nPs = 54
mPb = 12
n(1-Ps) = 265
m(1-Pb = 215

Zp = 4.11266 = 0.116416 / 0.0283066
Z critical = 1.64485 at 95% confidence level

4.11266 > 1.64485
Significance is Indicated at 95% Confidence Level
When Compared to Compliance Limit = 9.4

UNA WATERSYSTEMS

Appendix F

Example Applications of the Two-Sample Test of Proportions with 2004 and 2005 Quarterly Compliance Sample Data Sets from the Southwest Alluvium and Zone 1

VEOLIA Water

First Quarter 2005

Southwest Alluvium

Two-Sample Test of Proportions

Parameter: radium-combined

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL
Background measurements = 354
Compliance measurements = 14
Comparison Level = 5.2

18 background measurements exceed 5.2

1 compliance measurements exceed 5.2

p background = 0.0508475 = 18 / 354
p compliance = 0.0714286 = 1 / 14
p total = 0.0516304 = 19 / 368

nPs = 1 < 5.0
mPb = 18
n(1-Ps) = 13
m(1-Pb = 336

Zp = 0.341326 = 0.0205811 / 0.0602976
Z critical = 1.64485 at 95% confidence level

0.341326 < 1.64485
No Statistical Significance at 95% Confidence Level
When Compared to Compliance Limit = 5.2

First Quarter 2005

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 = 10
Comparison Level = 9.4

12 background measurements exceed 9.4

0 compliance measurements exceed 9.4

p background = 0.0528634 = 12 / 227
p compliance = 0 = 0 / 10
p total = 0.0506329 = 12 / 237

nPs = 0 < 5.0
mPb = 12
n(1-Ps) = 10
m(1-Pb = 215

Zp = -0.746209 = -0.0528634 / 0.0708426
Z critical = 1.64485 at 95% confidence level

-0.746209 < 1.64485
No Statistical Significance at 95% Confidence Level
When Compared to Compliance Limit = 9.4

Second Quarter 2005

Southwest Alluvium

Two-Sample Test of Proportions

Parameter: radium-combined
Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL
Background measurements = 354
Compliance measurements = 14
Comparison Level = 5.2

18 background measurements exceed 5.2

0 compliance measurements exceed 5.2

p background = 0.0508475 = 18 / 354
p compliance = 0 = 0 / 14
p total = 0.048913 = 18 / 368

nPs = 0 < 5.0
mPb = 18
n(1-Ps) = 14
m(1-Pb = 336

Zp = -0.865144 = -0.0508475 / 0.0587734
Z critical = 1.64485 at 95% confidence level

-0.865144 < 1.64485
No Statistical Significance at 95% Confidence Level
When Compared to Compliance Limit = 5.2

Second Quarter 2005

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 = 10
Comparison Level = 9.4

12 background measurements exceed 9.4

1 compliance measurements exceed 9.4

p background = 0.0528634 = 12 / 227
p compliance = 0.1 = 1 / 10
p total = 0.0548523 = 13 / 237

nPs = 1 < 5.0
mPb = 12
n(1-Ps) = 9
m(1-Pb = 215

Zp = 0.640692 = 0.0471366 / 0.0735713
Z critical = 1.64485 at 95% confidence level

0.640692 < 1.64485
No Statistical Significance at 95% Confidence Level
When Compared to Compliance Limit = 9.4

Third Quarter 2005

Southwest Alluvium

Two-Sample Test of Proportions

Parameter: radium-combined

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL
Background measurements = 354
Compliance measurements = 14
Comparison Level = 5.2

18 background measurements exceed 5.2

0 compliance measurements exceed 5.2

p background = 0.0508475 = 18 / 354
p compliance = 0 = 0 / 14
p total = 0.048913 = 18 / 368

nPs = 0 < 5.0
mPb = 18
n(1-Ps) = 14
m(1-Pb = 336

Zp = -0.865144 = -0.0508475 / 0.0587734
Z critical = 1.64485 at 95% confidence level

-0.865144 < 1.64485
No Statistical Significance at 95% Confidence Level
When Compared to Compliance Limit = 5.2

Third Quarter 2005

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 = 10
Comparison Level = 9.4

12 background measurements exceed 9.4

2 compliance measurements exceed 9.4

p background = 0.0528634 = 12 / 227
p compliance = 0.2 = 2 / 10
p total = 0.0590717 = 14 / 237

nPs = 2 < 5.0
mPb = 12
n(1-Ps) = 8
m(1-Pb = 215

Zp = 1.93148 = 0.147137 / 0.076178
Z critical = 1.64485 at 95% confidence level

1.93148 > 1.64485
Significance is Indicated at 95% Confidence Level
When Compared to Compliance Limit = 9.4

Fourth Quarter 2005

Southwest Alluvium

Two-Sample Test of Proportions

Parameter: radium-combined

Original Data (Not Transformed)
Non-Detects Replaced with 1/2 DL
Background measurements = 354
Compliance measurements = 14
Comparison Level = 5.2

18 background measurements exceed 5.2

0 compliance measurements exceed 5.2

p background = 0.0508475 = 18 / 354
p compliance = 0 = 0 / 14
p total = 0.048913 = 18 / 368

nPs = 0 < 5.0
mPb = 18
n(1-Ps) = 14
m(1-Pb = 336

Zp = -0.865144 = -0.0508475 / 0.0587734
Z critical = 1.64485 at 95% confidence level

-0.865144 < 1.64485
No Statistical Significance at 95% Confidence Level
When Compared to Compliance Limit = 5.2

Fourth Quarter 2005

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 = 10
Comparison Level = 9.4

12 background measurements exceed 9.4

1 compliance measurements exceed 9.4

p background = 0.0528634 = 12 / 227
p compliance = 0.1 = 1 / 10
p total = 0.0548523 = 13 / 237

nPs = 1 < 5.0
mPb = 12
n(1-Ps) = 9
m(1-Pb = 215

Zp = 0.640692 = 0.0471366 / 0.0735713
Z critical = 1.64485 at 95% confidence level

0.640692 < 1.64485
No Statistical Significance at 95% Confidence Level
When Compared to Compliance Limit = 9.4

NA WATERSYSTEMS

Four Quarters 2005

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 = 20
Comparison Level = 9.4

12 background measurements exceed 9.4

2 compliance measurements exceed 9.4

p background = 0.0528634 = 12 / 227
p compliance = 0.1 = 2 / 20
p total = 0.0566802 = 14 / 247

nPs = 2 < 5.0
mPb = 12
n(1-Ps) = 18
m(1-Pb = 215

Zp = 0.873962 = 0.0471366 / 0.0539344
Z critical = 1.64485 at 95% confidence level

0.873962 < 1.64485
No Statistical Significance at 95% Confidence Level
When Compared to Compliance Limit = 9.4