# Radiation Control Group Note

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ran[May/Misc.]RCCG Note, 6/4/92

RCG Note 92-009
June 1, 1992

# EVALUATION OF GROUND WATER ANALYSES FOR SAMPLES COLLECTED FROM SEPTEMBER 1989 TO MARCH 1992

*C. Wells*

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# EVALUATION OF GROUND WATER ANALYSES FOR SAMPLES COLLECTED FROM SEPTEMBER 1989 TO MARCH 1992

*C. Wells*

## Introduction

As a result of the issuance of Pollution Abatement Permit No. VPA01001 on June 16, 1989 (VPA89), a ground water monitoring program was begun at CEBAF in September 1989. Initially, six wells and a construction site dewatering location were monitored on a monthly basis, but starting in October 1990 the monitoring frequency was changed to quarterly. The six wells selected for initial site monitoring included one up gradient well, four wells along the down gradient perimeter of the site, and one well inside the accelerator ring. Starting with the September 1991 sample, an additional well sample was added to the sampling contract. The additional well sampled was chosen from amongst the existing monitoring wells that are not sampled routinely, and was identified at the time of sampling.

The results of the analyses have been compiled and examined for trends and signs of addition of contaminants to the ground water system and to document preoperational ground water quality for compliance with the State Water Control Board's antidegradation policy. Plots of the values of several parameters versus time were made and inspected visually for observable trends. A statistical analysis comparing the detection ratios of several radionuclides in the up and down gradient wells was done. Both of these examinations indicated that there is no evidence that CEBAF is adding contaminants to the ground water system.

During the period of March 1991 to March 1992, operation of the accelerator consisted of injector tests, the Front End Test, and a recirculation test using the injector section cavities. The maximum energy reached during the tests was 85 MeV, but only a short time was spent running at this energy. The practical maximum energy used during the tests was 45 MeV. The limited number of neutrons produced in the beam dumps during this test were of relatively low energy, and thus most would have been attenuated in the beam dump shielding and structural concrete of the tunnel wall. The low energy of the neutrons and their almost total absorption in the concrete wall make the likelihood of activation of ground water constituents very small.

During this period construction activities which tended to dramatically disrupt ground water flow were completed, and the excavations were back filled. (Most major excavation work was complete and mostly back filled by the end of the third quarter of 1991.) This will eliminate a possible pathway for introduction of ground water contaminants, and allow ground water flow to establish a steady state condition. Although there is currently no evidence to suggest that any contaminants have been added to the ground water, establishment of a steady state flow regime will enhance our ability to detect any ground water degradation attribuatable to CEBAF.

This note is intended to supplement and extend RCG Note 91-006.

## Trend Analysis

The ground water analysis data were examined to identify potentially anomalous data and determine if any observable trends exist. Most of the parameters continued to show little variation, so trend analysis was performed on those parameters which exhibited the most variability or could be counted on to provide indication of major changes in the ground water system. The parameters chosen were: pH, conductivity, total metals, gross alpha, and gross beta. It was decided to compare the values of these parameters across the gradient identified in the site hydrogeological survey (Law85). The values for the west arc well were compared separately, as this is the only well within the linac "race track". The trend of the parameters was examined over the entire groundwater monitoring period.

For comparison to the up gradient well (GW15), analysis results for the four down gradient wells (GW2, GW3, GW7, and GW8) were averaged and the standard deviations computed. The down gradient well average, the west arc well GW-17 (formerly identified as ARC(W)), and the up gradient well values for each parameter so treated are shown in Tables 2 through 9; the values are shown graphically in Figures 1 through 5.

Examination of the plots of gross alpha and gross beta show that the concentrations of the up and down gradient wells follow closely together. The concentration of gross alpha and gross beta in the water from the west arc well (GW-17) was, in general, greater than both the up and down gradient wells until January of 1991. At this time the analysis results both stabilized and became consistent with the up and down gradient results. An examination of the complete radionuclide results for the west arc well revealed that there are also higher levels of total radium and thorium isotopes until January 1991. After January 1991, the levels of total radium and thorium isotopes are not significantly different than in the other wells. The most probable explanation of this is that the well was drilled through or near a fossilized deposit of organic materials having a high natural uranium/radium concentration (Ehl82, Dav66). These radionulcides leach into the ground water over time, and raise the concentration of these radionuclides in the water. This natural leaching action was probably augmented by the disturbances of the ground water flow wrought by the construction of the accelerator tunnel. (The west arc well is currently the well closest to the accelerator tunnel, and so would have been the most affected by construction activities.) Since the deposit is probably quite localized and ground water flow quite slow, the other wells do not see increased radionuclide levels.

The pH of the established up gradient well (GW-15) continues to be significantly lower than the other wells. This well is located just off of

Jefferson Avenue - a major thoroughfare in Newport News. Rain water run off with dissolved automobile emission gases most likely enter the ground water system near this area. The water in this area could thereby become acidified, causing the lower than average pH trend (Dav66).

Three additional samples were taken from wells that are up gradient of the accelerator site. The pH in these wells is generally higher than that of well GW-15, and closer to the pH of the down gradient wells. This indicates that the extremely low pH of well GW-15 is a local phenomenon, and that additional up gradient wells should be sampled regularly to better determine water quality entering the accelerator site.

The reported tritium result for the west arc well (GW-17) for the third quarter of 1991 exceeded the reporting limit of 1000 pCi/l (the value reported was 1836 pCi/l.) A reanalysis of the sample was requested. The tritium level reported for the reanalysis was 1294 pCi/l. A visit to the laboratory was made by the Operational Health Physicist (R. May) to investigate these results. The analytical methodology and QA procedures were reviewed. It was found that even though the QC "spike" ratios were within a procedurally acceptable range, the activity of the QC samples was over represented by an average of 60%. Using a correction based on this over response and the corrected sample count rate the calculated tritium activity for the GW-17 sample was less than the 1000 pCi/l reporting limit (May92). Samples taken in subsequent quarters show no tritium above the reporting limit.

Several of the parameters monitored have been found to be in excess of state ground water quality standards (Wqs88). (Analytes having the majority of results above the standards are: iron, manganese, pH, hardness, gross alpha. Analytes having occasional results above the standards are: lead, zinc, TOC, total radium, and gross beta.) The Virginia ground water anti-degradation policy states that, in light of the fact that natural ground water quality varies from area to area, if any constituent exceeds the limit in the standard for that constituent, no addition of that constituent to the naturally occurring concentration shall be made. Since the accelerator has experienced only limited operation, and the operations conducted involved energies too low to produce most of the radionuclides of interest, the analytical results of the ground water samples thus far obtained can be said to reflect the naturally occurring concentrations of the analytes.

## Statistical Analysis

A statistical analysis of the radionuclide data was completed to determine if there was evidence of contamination (ie., higher than "background" levels) in the down gradient wells as compared to the up gradient well. The method used was a test of proportions as found in Section 8.1.2 of EPA89. Included in the test of proportions is a check to ensure that the data approximate a normal distribution. For a discussion of the test of proportions, please see the applicable portions of EPA89 or May91.

Prior to performing statistical calculations, the data were visually checked for anomalies. No values were identified as outliers or otherwise anomalous other than those previously so identified (May91).

The three samples taken from wells that are hydrologically up gradient of the accelerator site were checked to verify that they exhibit the same characteristics as well GW-15. A chi squared test ($\chi^2$) was used to test the radionuclide data, and a test of the difference between two means (using small sample statistics) was used for non-radioactive analytes (Men75). These tests showed that, at the 95% confidence level, the sample results from GW-15 and the three additional wells are from the same population. As a result the sample results for the three additional wells were included in the test of proportions as up gradient wells.

The test of proportions was performed on data for gross alpha, gross beta, calcium 45, total radium, strontium 90, thorium 230, and thorium 232. (The other monitored radionuclides did not have any analysis results greater than the detection limit, and so it was assumed that there was no significant change in concentration levels between the up and down gradient wells.) The test indicated that the data did conform to an approximation of a normal distribution. The computed statistic Z was $\leq 1.96$ for each of above parameters; thus it can be said that, within the 95% confidence level, there is no radioactive contamination being added to the ground water system by CEBAF. Table 1 lists the parameters and the values for the calculation variables as well as the value of Z. (A sample calculation is shown in Appendix A.)

Table 1: Test of Proportions Data

| Parameter | Number of Detections in the Background Well | Number of Detections in the Down Grad. Wells | Number of Samples from the Background Well | Number of Samples from the Down Grad. Wells | Computed Statistic Z |
|---|---|---|---|---|---|
| Gross Alpha | 12 | 64 | 22 | 111 | 0.27 |
| Gross Beta | 13 | 62 | 22 | 111 | 0.28 |
| Total Ra | 9 | 49 | 22 | 111 | 0.28 |
| $Sr^{90}$ | 3 | 17 | 22 | 111 | 0.20 |
| $Th^{230}$ | 3 | 26 | 21 | 105 | 0.99 |
| $Th^{232}$ | 2 | 18 | 22 | 111 | 0.85 |

A Spearmans rank correlation coefficient test (Men75) was performed on data from the west arc well to determine the correlation (if any) between the values for gross alpha and gross beta, and $Th^{230}$ and $Th^{232}$. Data previously identified as outliers were not used in this test. The test showed that the gross alpha and gross beta values had good correlation over the entire sampling history. This indicates that the alpha and beta results are in an equilibrium condition and suggests the presence of a naturally occurring decay chain. The values for $Th^{230}$ and $Th^{232}$ isotopes correlate well over the sampling history.

Thorium 232 is the parent of the thorium decay chain and thorium 230 is a member of the $U^{238}$ decay chain. This, in conjunction with the above test results, suggests the strong probability of a localized concentration of thorium and uranium in fossilized organic matter. This, as previously suggested, would be responsible for the higher concentrations of alpha and beta emitters in the west arc well water, and could also contribute to higher concentrations of other analytes (ie. hardness, conductivity, and metals).

Summary and Future Statistics

The examination of the ground water data accumulated since commencement of sampling (September 1989) shows that, for parameters showing variability in their values, no significant amounts of contaminants has been added to the ground water as it passed through the CEBAF site. The trend analysis revealed that, initially, the samples drawn from the well within the accelerator ring had consistently higher concentrations of alpha and beta emitting radionuclides than the other wells, and that the up gradient well has a much lower pH than the other wells. Both of these trends could be a result of the particular placement of the respective wells and/or construction activities, and not a result of ground water contamination due to CEBAF's operations. A statistical analysis of radionuclide results verifies that there is no radioactive contamination attributable to CEBAF operations.

While the current use of one up gradient well shows that there is no contamination being added to the ground water as it crosses the site, the addition of at least one other up gradient well would narrow the permissible difference between the probabilities of analyte detection in the up and down gradient wells. This would provide a more sensitive and positive indication of possible added contamination in the future. This is based upon the fact that the probability of accepting a false positive indication of non-contamination is reduced as the number of samples is increased, thereby increasing the probability that any contamination will be detected. Additionally, the addition of at least one up gradient well will provide a check on the trends of such parameters as pH, conductivity, and TOC.

Samples were taken from three wells that are up gradient of the site. The sample results showed that the low pH trend shown in well GW-15 is a local phenomenon. These samples also demonstrate the usefulness of having additional up gradient wells which are sampled regularly.

As more data become available, it would be useful and appropriate to normalize the data to account for any seasonal variations, and construct a combined Shewart-Cumulative sum control chart. The seasonal correction helps to minimize the chance of a false positive or false negative indication of well contamination. The control chart can be used to monitor the inherent statistical variation of the data and to flag anomalous values. A sufficiently large data set will have been accumulated prior to the accelerator becoming operational so that these methods can be used. Descriptions of these methods and procedures for accomplishing them can be found in Section 7 of EPA89.

## Acknowledgement

The author wishes to thank Gina Dixon for lending her expertise on environmental matters to this project, and also to Bob May for his editorial skill and thoughtful suggestions.

Figure 1: Graph of Gross Alpha Concentration

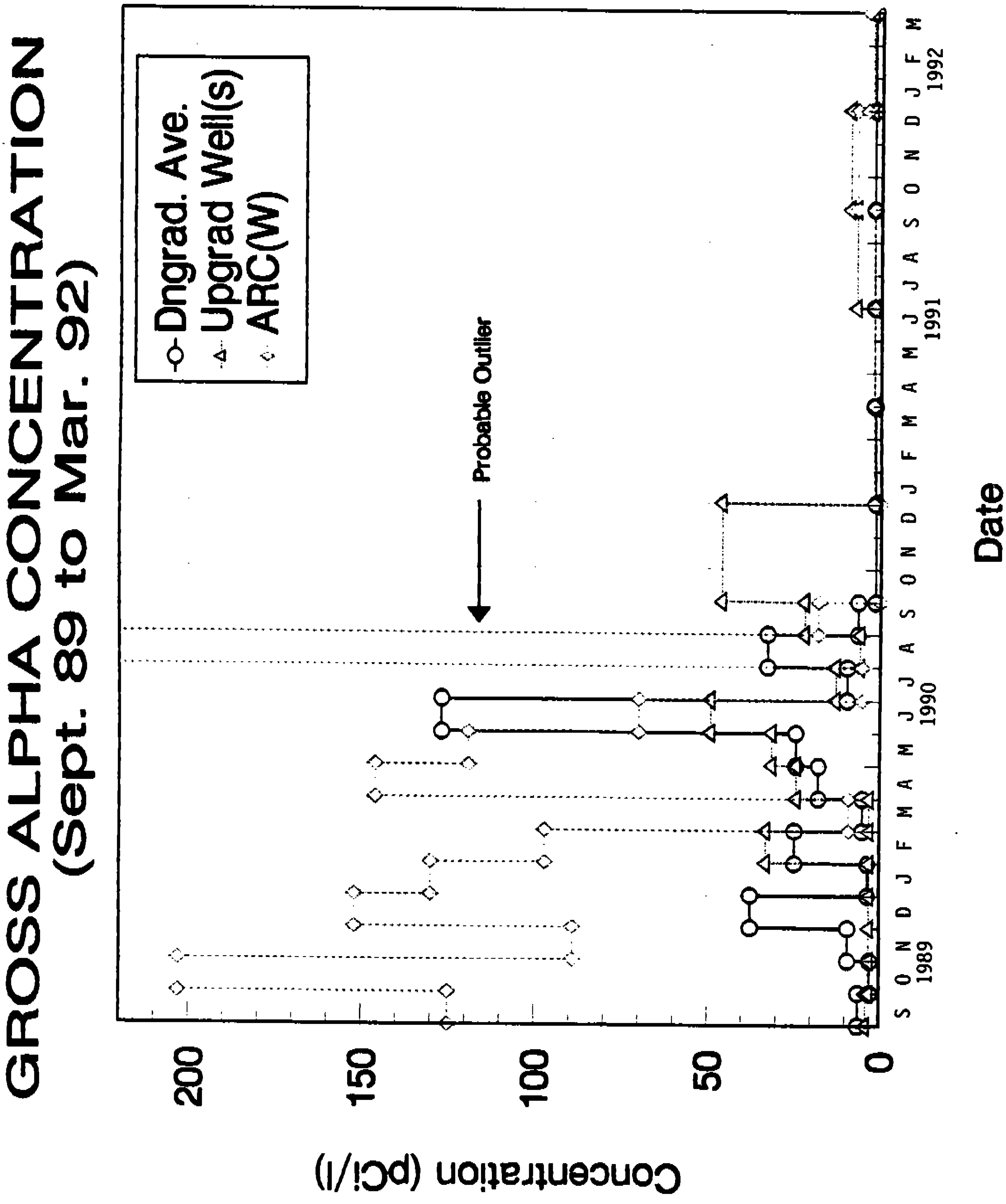

Figure 2: Graph of Gross Beta Concentration

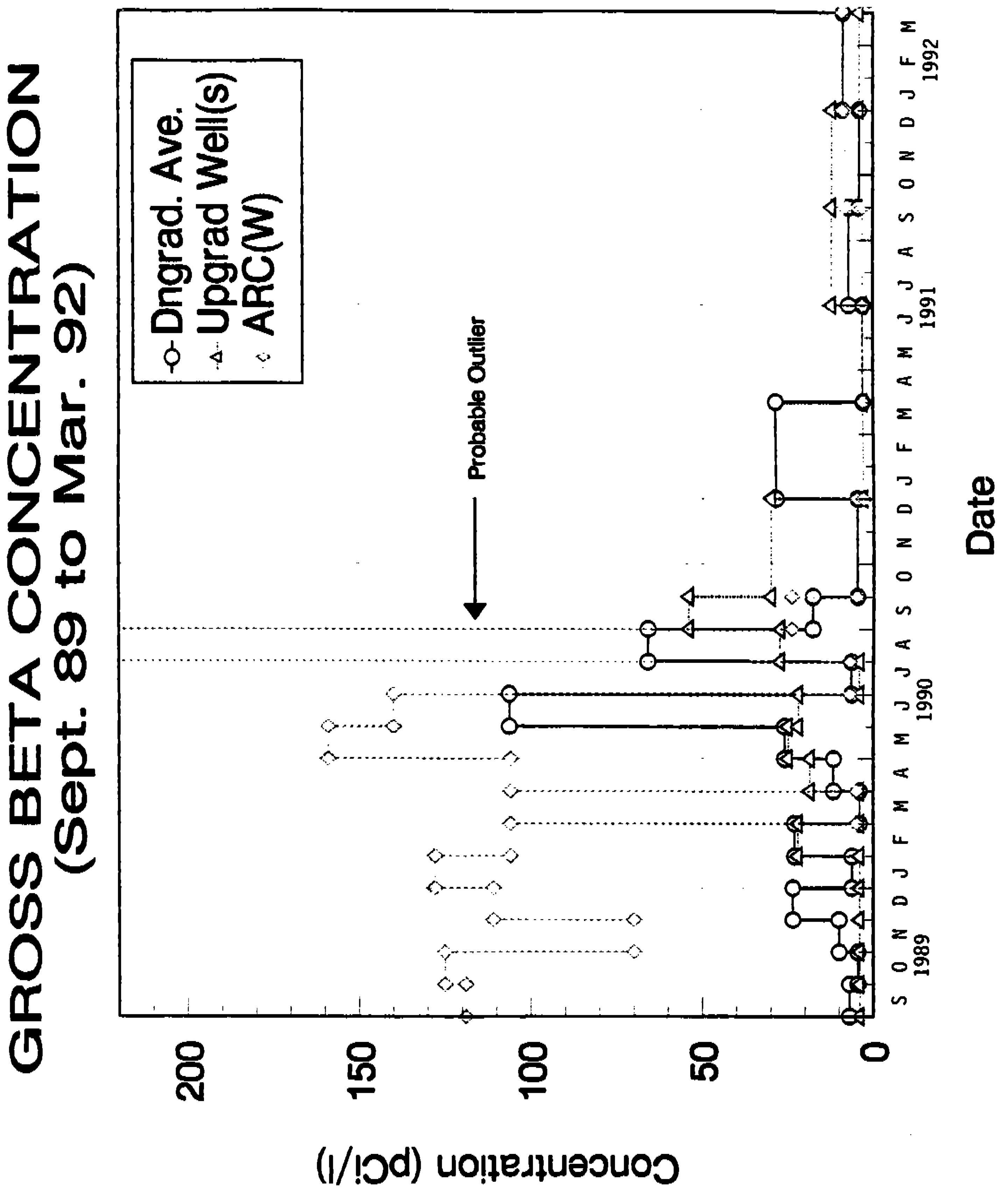

Figure 3: Graph of Ground Water pH

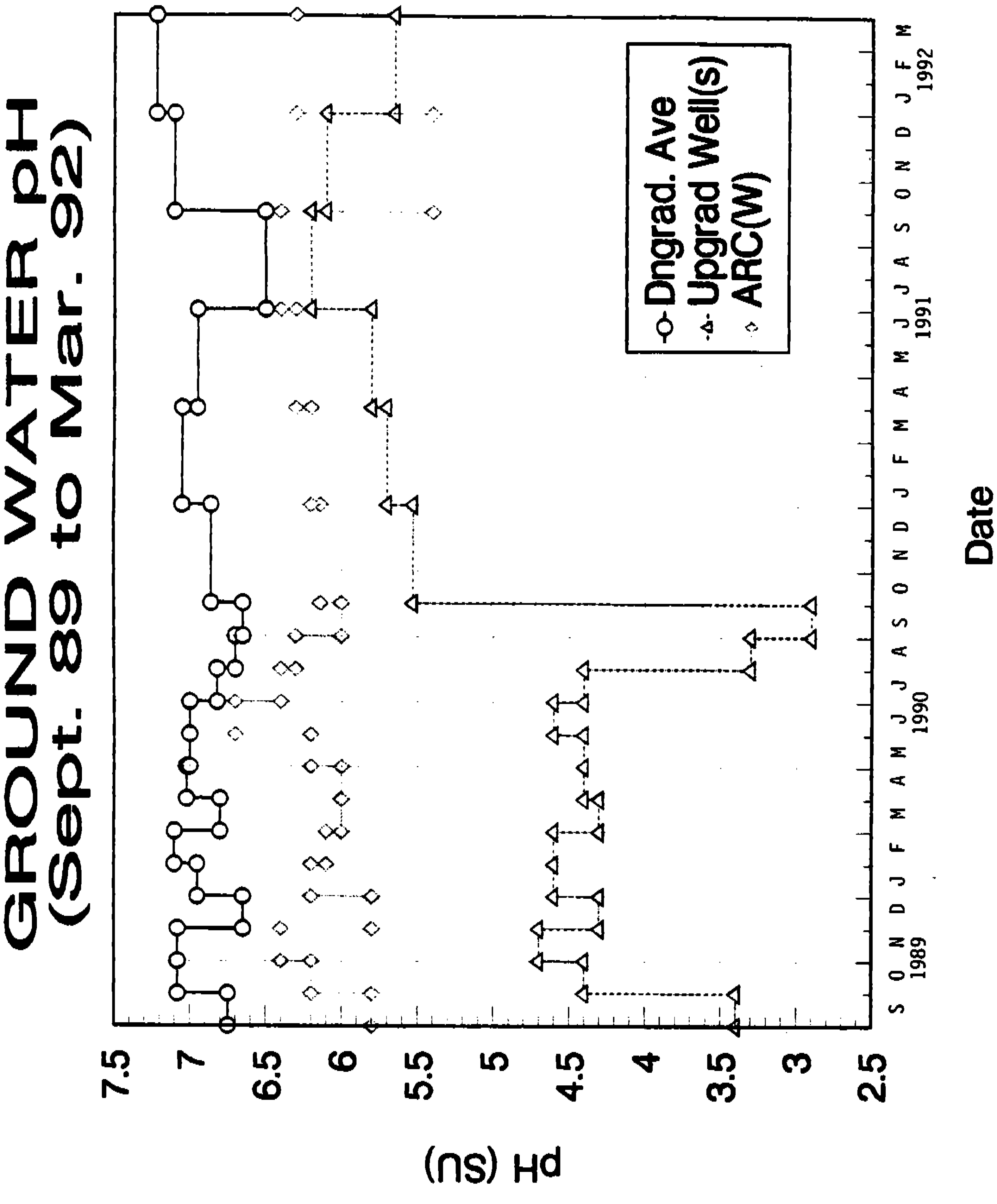

Figure 4: Graph of Ground Water Conductivity

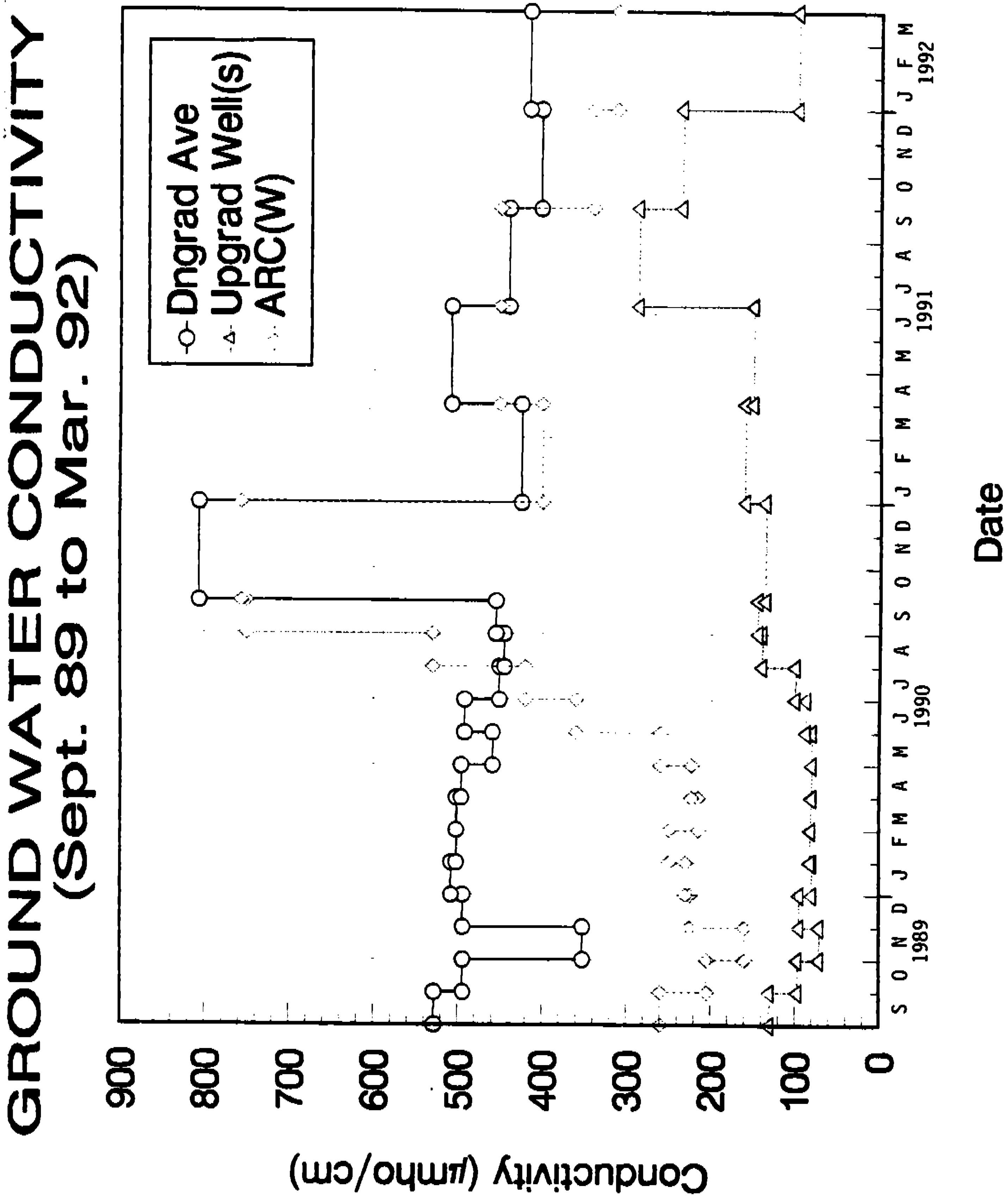

Figure 5: Graph of Total Metals Concentration

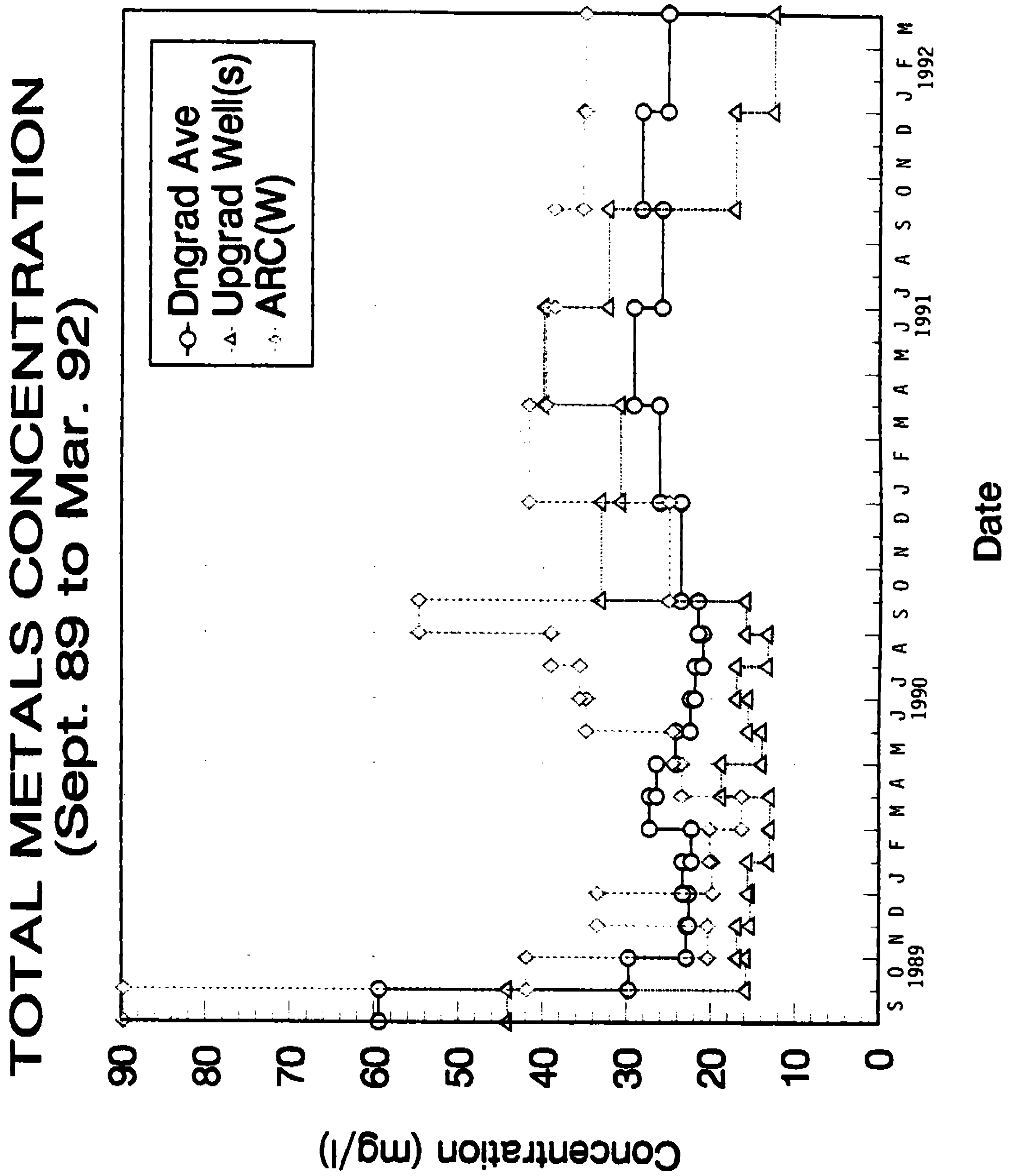

Table 2: Analysis Data for Well GW2 - March 1991 to March 1992

| MONTH | YEAR | pH | COND | TOC | GR ALPHA | (±) | GR BETA | (±) | TRITIUM | (±) | Na-22 | Na-24 | Be-7 | Ca-45 | (±) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAR | 91 | 7.00 | 450.00 | 3.04 | < 2.00 | | < 3.00 | | < 1000.00 | | < 15.00 | < 20.00 | < 127.00 | < 1.00 | |
| JUN | 91 | 6.90 | 700.00 | 5.88 | < 2.00 | | < 3.00 | | < 1000.00 | | < 20.00 | < 20.00 | < 71.00 | < 1.00 | |
| SEP | 91 | 5.50 | 450.00 | 8.18 | 4.00 | (2.00) | 16.00 | (4.00) | < 1000.00 | | < 20.00 | < 20.00 | < 242.00 | < 1.00 | |
| DEC | 91 | 7.40 | 430.00 | 2.85 | < 2.00 | | 7.00 | (4.00) | < 1000.00 | | < 20.00 | < 20.00 | < 131.00 | < 5.00 | |
| MAR | 92 | 7.70 | 423.00 | 1.36 | < 2.00 | | 7.00 | (3.00) | < 1000.00 | | < 5.00 | < 20.00 | < 40.00 | < 5.00 | |

| MONTH | YEAR | TOTAL Ra | (±) | Sr-90 | (±) | Mn-54 | Co-60 | Cs-134 | Th-230 | (±) | Th-232 | (±) | CaCO3 | COD | Cu | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAR | 91 | < 1.00 | | < 0.70 | | < 15.00 | < 10.00 | < 10.00 | note 1 | | < 1.00 | | 230.00 | < 25.00 | 0.002 | 4.33 |
| JUN | 91 | 3.00 | (1.00) | < 0.70 | | < 8.00 | < 8.00 | < 77.00 | < 1.00 | | < 1.00 | | 1500.00 | 31.00 | 0.002 | 11.00 |
| SEP | 91 | < 1.00 | | < 0.70 | | < 20.00 | < 17.00 | < 17.00 | < 1.00 | | < 1.00 | | 230.00 | < 25.00 | 0.002 | 2.77 |
| DEC | 91 | 2.00 | (1.00) | < 0.70 | | < 11.00 | < 11.00 | < 9.00 | < 1.00 | | < 1.00 | | 290.00 | 34.00 | 0.007 | 2.25 |
| MAR | 92 | < 1.00 | | < 0.70 | | < 4.00 | < 4.00 | < 4.00 | < 1.00 | | < 1.00 | | 230.00 | 53.00 | <0.001 | 2.50 |

| MONTH | YEAR | Pb | Mn | Ni | Zn | Na | GWELEV |
|---|---|---|---|---|---|---|---|
| MAR | 91 | < 0.010 | 0.134 | < 0.01 | < 0.01 | 31.60 | 6.00 |
| JUN | 91 | < 0.050 | 0.960 | < 0.04 | 0.07 | 30.80 | 18.90 |
| SEP | 91 | < 0.010 | 0.152 | < 0.01 | 0.05 | 22.30 | 22.30 |
| DEC | 91 | < 0.010 | 0.096 | < 0.01 | 0.02 | 24.80 | 24.80 |
| MAR | 92 | < 0.050 | 0.100 | < 0.04 | 0.01 | 30.00 | 23.25 |

Note 1: Analysis not performed, reason unknown.
Note 2: See Table 10 for units.

Table 3: Analysis Data for Well GW3 - March 1991 to March 1992

| MONTH | YEAR | pH | COND | TOC | GR ALPHA | (±) | GR BETA | (±) | TRITIUM | (±) | Na-22 | Na_24 | Be-7 | Ca-45 | (±) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAR | 91 | 7.60 | 400.00 | 3.69 | < 2.00 | | < 3.00 | | < 1000.00 | | < 10.00 | < 20.00 | < 82.00 | < 1.00 | |
| JUN | 91 | 7.10 | 500.00 | 4.54 | < 2.00 | | < 3.00 | | < 1000.00 | | < 20.00 | < 20.00 | < 135.00 | < 1.00 | |
| SEP | 91 | 7.00 | 400.00 | 6.85 | < 2.00 | | < 3.00 | | < 1000.00 | | < 20.00 | < 20.00 | < 112.00 | < 1.00 | |
| DEC | 91 | 7.50 | 440.00 | 4.21 | < 2.00 | | < 3.00 | | < 1000.00 | | < 17.00 | < 20.00 | < 158.00 | < 1.00 | |
| MAR | 92 | 7.40 | 422.00 | 1.41 | < 2.00 | | 14.00 | (3.00) | < 1000.00 | | < 13.00 | < 20.00 | < 113.00 | < 1.00 | |

| MONTH | YEAR | TOTAL Ra | (±) | Sr-90 | (±) | Mn-54 | Co-60 | Cs-134 | Th-230 | (±) | Th-232 | (±) | CaCO3 | COD | Cu | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAR | 91 | < 1.00 | | < 0.60 | | < 9.00 | < 10.00 | < 10.00 | note 1 | | < 1.00 | | 220.00 | 38.00 | < 0.001 | 1.03 |
| JUN | 91 | < 1.00 | | < 0.90 | | <15.00 | < 10.00 | < 10.00 | < 1.00 | | < 1.00 | | 250.00 | 44.00 | 0.002 | 3.20 |
| SEP | 91 | < 1.00 | | < 0.70 | | < 9.00 | < 8.00 | < 8.00 | < 1.00 | | < 1.00 | | 230.00 | 41.00 | 0.002 | 1.35 |
| DEC | 91 | < 1.00 | | < 0.70 | | <16.00 | < 18.00 | < 16.00 | < 1.00 | | < 1.00 | | 230.00 | 26.00 | 0.002 | 9.11 |
| MAR | 92 | < 1.00 | | < 0.70 | | <11.00 | < 12.00 | < 22.00 | < 1.00 | | < 1.00 | | 280.00 | 38.00 | < 0.001 | 1.11 |

| MONTH | YEAR | Pb | Mn | Ni | Zn | Na | GWELEV |
|---|---|---|---|---|---|---|---|
| MAR | 91 | 0.020 | 0.053 | < 0.01 | 0.01 | 29.90 | 19.00 |
| JUN | 91 | < 0.050 | 0.050 | < 0.04 | 0.02 | 29.60 | 41.50 |
| SEP | 91 | 0.010 | 0.032 | < 0.01 | 0.03 | 29.40 | 19.80 |
| DEC | 91 | 0.010 | 0.122 | < 0.01 | 0.01 | 33.00 | 3.90 |
| MAR | 92 | < 0.050 | 0.040 | < 0.04 | < 0.01 | 27.00 | 3.25 |

Note 1: Analysis not performed, reason unknown.
Note 2: See Table 10 for units.

Table 4: Analysis Data for Well GW7 - March 1991 to March 1992

| MONTH | YEAR | pH | COND | TOC | GR ALPHA | (±) | GR BETA | (±) | TRITIUM | (±) | Na-22 | Na-24 | Be-7 | Ca-45 | (±) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAR | 91 | 6.80 | 300.00 | 3.42 | 59.00 | (6.00) | 105.00 | (7.00) | < 1000.00 | | < 20.00 | < 20.00 | < 164.00 | < 1.00 | |
| JUN | 91 | 6.90 | 311.00 | 5.29 | < 2.00 | | < 3.00 | | < 1000.00 | | < 20.00 | < 20.00 | < 99.00 | < 1.00 | |
| SEP | 91 | 6.80 | 310.00 | 6.76 | < 2.00 | | < 3.00 | | < 1000.00 | | < 20.00 | < 20.00 | < 112.00 | < 1.00 | |
| DEC | 91 | 6.60 | 250.00 | 2.56 | < 2.00 | | < 3.00 | | < 1000.00 | | < 16.00 | < 20.00 | < 143.00 | < 1.00 | |
| MAR | 92 | 6.70 | 320.00 | 3.40 | < 2.00 | | 10.00 | (3.00) | < 1000.00 | | < 12.00 | < 20.00 | < 193.00 | < 1.00 | |

| MONTH | YEAR | TOTAL Ra | (±) | Sr-90 | (±) | Mn-54 | Co-60 | Cs-134 | Th-230 | (±) | Th-232 | (±) | CaCO3 | COD | Cu | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAR | 91 | 3.00 | (1.00) | < 0.60 | | < 18.00 | < 10.00 | < 10.00 | note 1 | | < 1.00 | | 210.00 | < 25.00 | 0.001 | 2.52 |
| JUN | 91 | < 1.00 | | < 0.70 | | < 11.00 | < 12.00 | < 10.00 | < 1.00 | | < 1.00 | | 170.00 | < 25.00 | 0.004 | 5.10 |
| SEP | 91 | < 1.00 | | < 0.70 | | < 8.00 | < 9.00 | < 8.00 | < 1.00 | | < 1.00 | | 150.00 | 38.00 | 0.002 | 6.19 |
| DEC | 91 | < 1.00 | | < 0.70 | | < 16.00 | < 15.00 | < 14.00 | < 1.00 | | < 1.00 | | 130.00 | 28.00 | 0.002 | 6.01 |
| MAR | 92 | < 1.00 | | < 0.70 | | < 10.00 | < 21.00 | < 19.00 | < 1.00 | | < 1.00 | | 150.00 | 42.00 | < 0.001 | 3.50 |

| MONTH | YEAR | Pb | Mn | Ni | Zn | Na | GWELEV |
|---|---|---|---|---|---|---|---|
| MAR | 91 | 0.010 | 0.231 | < 0.01 | 0.04 | 13.00 | 12.00 |
| JUN | 91 | < 0.050 | 0.250 | < 0.09 | 0.08 | 14.20 | 19.75 |
| SEP | 91 | < 0.010 | 0.172 | 0.17 | 0.07 | 14.20 | 25.60 |
| DEC | 91 | 0.050 | 0.420 | < 0.01 | 0.06 | 12.50 | 21.36 |
| MAR | 92 | < 0.050 | 0.170 | < 0.04 | 0.05 | 14.00 | 20.19 |

Note 1: Analysis not performed, reason unknown.
Note 2: See Table 10 for units.

Table 5: Analysis Data for Well GW8 - March 1991 to March 1992

| MONTH | YEAR | pH | COND | TOC | GR ALPHA | (±) | GR BETA | (±) | TRITIUM | (±) | Na-22 | Na-24 | Be-7 | Ca-45 | (±) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAR | 91 | 6.80 | 550.00 | 3.42 | < 2.00 | | < 3.00 | | < 1000.00 | | < 12.00 | < 20.00 | < 110.00 | < 1.00 | |
| JUN | 91 | 6.90 | 520.00 | 3.83 | < 2.00 | | < 3.00 | | < 1000.00 | | < 20.00 | < 20.00 | < 130.00 | < 1.00 | |
| SEP | 91 | 6.70 | 600.00 | 12.80 | < 2.00 | | < 3.00 | | < 1000.00 | | < 20.00 | < 20.00 | < 131.00 | < 1.00 | |
| DEC | 91 | 6.90 | 490.00 | 3.51 | < 2.00 | | < 3.00 | | < 1000.00 | | < 19.00 | < 20.00 | < 160.00 | < 6.00 | |
| MAR | 92 | 7.10 | 500.00 | 2.02 | < 2.00 | | 4.00 | (3.00) | < 1000.00 | | < 12.00 | < 20.00 | < 187.00 | < 5.00 | |

| MONTH | YEAR | TOTAL Ra | (±) | Sr-90 | (±) | Mn-54 | Co-60 | Cs-134 | Th-230 | (±) | Th-232 | (±) | CaCO3 | COD | Cu | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAR | 91 | < 1.00 | | < 0.70 | | < 12.00 | < 10.00 | < 10.00 | note 1 | | < 1.00 | | 380.00 | < 25.00 | 0.002 | 8.97 |
| JUN | 91 | < 1.00 | | 1.00 | (0.20) | < 20.00 | < 10.00 | < 10.00 | < 1.00 | | < 1.00 | | 350.00 | 34.00 | 0.001 | 8.90 |
| SEP | 91 | < 1.00 | | < 0.70 | | < 11.00 | < 11.00 | < 9.00 | < 1.00 | | < 1.00 | | 390.00 | 30.00 | 0.003 | 9.14 |
| DEC | 91 | < 1.00 | | < 0.70 | | < 18.00 | < 17.00 | < 15.00 | < 1.00 | | < 1.00 | | 330.00 | 26.00 | 0.002 | 9.38 |
| MAR | 92 | < 1.00 | | < 0.70 | | < 21.00 | < 11.00 | < 19.00 | < 1.00 | | < 1.00 | | 380.00 | 25.00 | <0.001 | 9.70 |

| MONTH | YEAR | Pb | Mn | Ni | Zn | Na | GWELEV |
|---|---|---|---|---|---|---|---|
| MAR | 91 | < 0.010 | 0.266 | < 0.01 | 0.01 | 12.50 | 12.00 |
| JUN | 91 | < 0.050 | 0.290 | < 0.04 | 0.03 | 11.90 | 19.70 |
| SEP | 91 | < 0.010 | 0.233 | < 0.01 | 0.04 | 9.40 | 26.00 |
| DEC | 91 | < 0.010 | 0.258 | < 0.01 | 0.02 | 10.10 | 21.95 |
| MAR | 92 | < 0.050 | 0.320 | < 0.04 | 0.01 | 13.00 | 20.67 |

Note 1: Analysis not performed, reason unknown.
Note 2: See Table 10 for units.

Table 6: Analysis Data for Well GW15 - March 1991 to March 1992

| MONTH | YEAR | pH | COND | TOC | GR ALPHA | (±) | GR BETA | (±) | TRITIUM | (±) | Na-22 | Na-24 | Be-7 | Ca-45 | (±) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAR | 91 | 5.70 | 160.00 | 3.21 | < 2.00 | | < 3.00 | | < 1000.00 | | < 20.00 | < 20.00 | < 161.00 | < 1.00 | |
| JUN | 91 | 5.80 | 150.00 | 3.30 | < 2.00 | | < 3.00 | | < 1000.00 | | < 20.00 | < 20.00 | < 138.00 | < 1.00 | |
| SEP | 91 | 6.20 | 293.00 | 6.90 | < 2.00 | | < 3.00 | | < 1000.00 | | < 20.00 | < 20.00 | < 280.00 | < 1.00 | |
| DEC | 91 | 5.40 | 100.00 | 5.24 | 9.00 | (2.00) | 12.00 | (4.00) | < 1000.00 | | < 18.00 | < 20.00 | < 158.00 | < 5.00 | |
| MAR | 92 | 5.00 | 81.00 | 1.05 | < 2.00 | | 4.00 | (3.00) | < 1000.00 | | < 12.00 | < 20.00 | < 108.00 | < 5.00 | |

| MONTH | YEAR | TOTAL Ra | (±) | Sr-90 | (±) | Mn-54 | CO-60 | Cs-134 | Th-230 | (±) | Th-232 | (±) | CaCO3 | COD | Cu | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAR | 91 | < 1.00 | | < 0.70 | | < 18.00 | < 10.00 | < 10.00 | note 1 | | < 1.00 | | 44.00 | 41.00 | 0.001 | 17.30 |
| JUN | 91 | < 1.00 | | 0.70 | (0.20) | < 12.00 | < 10.00 | < 10.00 | < 1.00 | | < 1.00 | | 52.00 | < 25.00 | 0.004 | 21.80 |
| SEP | 91 | < 1.00 | | < 0.70 | | < 25.00 | < 23.00 | < 20.00 | < 1.00 | | < 1.00 | | 64.00 | 30.00 | <0.001 | 16.60 |
| DEC | 91 | 2.00 | (1.00) | < 0.70 | | < 16.00 | < 17.00 | < 15.00 | < 1.00 | | < 1.00 | | 32.00 | < 25.00 | 0.002 | 3.35 |
| MAR | 92 | < 1.00 | | < 0.70 | | < 11.00 | < 13.00 | < 11.00 | < 1.00 | | < 1.00 | | 24.00 | < 25.00 | 0.001 | 0.90 |

| MONTH | YEAR | Pb | Mn | Ni | Zn | Na | GWELEV |
|---|---|---|---|---|---|---|---|
| MAR | 91 | < 0.010 | 0.183 | 0.05 | 0.05 | 13.20 | 6.00 |
| JUN | 91 | < 0.050 | 0.250 | < 0.04 | 0.06 | 17.70 | 26.30 |
| SEP | 91 | < 0.010 | 0.229 | 0.01 | 0.03 | 15.90 | 22.70 |
| DEC | 91 | < 0.010 | 0.099 | 0.01 | 0.03 | 13.30 | 24.10 |
| MAR | 92 | < 0.050 | 0.100 | < 0.04 | 0.02 | 11.00 | 23.39 |

Note 1: Analysis not performed, reason unknown.
Note 2: See Table 10 for units.

Table 7: Analysis Data for Well GW17 - March 1991 to March 1992

| MONTH | YEAR | pH | COND | TOC | GR ALPHA | (±) | GR BETA | (±) | TRITIUM | (±) | Na-22 | Na-24 | Be-7 | Ca-45 | (±) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAR | 91 | 6.20 | 400.00 | 4.05 | < 2.00 | | < 3.00 | | < 1000.00 | | < 16.00 | < 20.00 | < 137.00 | < 1.00 | |
| JUN | 91 | 6.30 | 451.00 | 5.05 | < 2.00 | | < 3.00 | | note 3 | | < 20.00 | < 20.00 | < 92.00 | < 1.00 | |
| SEP | 91 | 6.40 | 450.00 | 9.08 | < 2.00 | | < 3.00 | | < 1000.00 | | < 20.00 | < 20.00 | < 140.00 | < 1.00 | |
| DEC | 91 | 5.40 | 340.00 | 5.64 | 7.00 | (2.00) | 8.00 | (4.00) | < 1000.00 | | < 24.00 | < 20.00 | < 117.00 | < 5.00 | |
| MAR | 92 | 6.30 | 312.00 | 2.27 | 4.00 | (2.00) | 9.00 | (3.00) | < 1000.00 | | < 22.00 | < 20.00 | < 127.00 | < 5.00 | |

| MONTH | YEAR | TOTAL Ra | (±) | Sr-90 | (±) | Mn-54 | Co-60 | Cs-134 | Th-230 | (±) | Th-232 | (±) | CaCO3 | COD | Cu | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAR | 91 | < 1.00 | | < 0.70 | | < 16.00 | < 10.00 | < 10.00 | note 1 | | < 1.00 | | 190.00 | < 25.00 | 0.004 | 16.90 |
| JUN | 91 | 3.00 | (1.00) | 0.80 | (0.20) | < 9.00 | < 10.00 | < 9.00 | < 1.00 | | < 1.00 | | 180.00 | < 25.00 | 0.004 | 16.40 |
| SEP | 91 | < 1.00 | | < 0.70 | | < 13.00 | < 13.00 | < 11.00 | < 1.00 | | < 1.00 | | 210.00 | < 25.00 | 0.001 | 15.80 |
| DEC | 91 | < 1.00 | | < 0.70 | | < 23.00 | < 25.00 | < 20.00 | < 1.00 | | < 1.00 | | 150.00 | 34.00 | 0.002 | 14.30 |
| MAR | 92 | < 1.00 | | < 0.70 | | < 21.00 | < 3.00 | < 4.00 | < 1.00 | | < 1.00 | | 130.00 | 44.00 | <0.001 | 12.80 |

| MONTH | YEAR | Pb | Mn | Ni | Zn | Na | GWELEV |
|---|---|---|---|---|---|---|---|
| MAR | 91 | < 0.010 | 0.146 | < 0.01 | < 0.01 | 24.60 | 8.00 |
| JUN | 91 | < 0.050 | 0.120 | < 0.04 | 0.02 | 23.00 | 19.75 |
| SEP | 91 | < 0.010 | 0.117 | < 0.01 | 0.01 | 22.70 | 19.40 |
| DEC | 91 | < 0.010 | 0.120 | < 0.01 | 0.02 | 20.80 | 22.10 |
| MAR | 92 | < 0.050 | 0.140 | < 0.04 | < 0.01 | 22.00 | 23.88 |

Note 1: Analysis not performed, reason unknown.
Note 2: See Table 10 for units.
Note 3: Originally reported as 1836 (±632) pCi/l, subsequent investigation showed value to be < 1000 pCi/l.

Table 8: Analysis Data for Construction Dewater Samples - March 1991 to March 1992

| MONTH | YEAR | pH | COND | TOC | GR ALPHA | (±) | GR BETA | (±) | TRITIUM | Na-22 | Na-24 | Be-7 | Ca-45 | (±) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAR | 91 | 7.50 | 350.00 | 3.06 | 8.00 | (3.00) | 194.00 | (9.00) | < 1000.00 | < 21.00 | < 20.00 | < 170.00 | < 1.00 | |
| JUN | 91 | 8.00 | 500.00 | 9.55 | 4.00 | (2.00) | 15.00 | (8.00) | < 1000.00 | < 20.00 | < 20.00 | < 130.00 | < 1.00 | |
| SEP | 91 | note 2 | | | | | | | | | | | | |
| DEC | 91 | 7.20 | 790.00 | 7.39 | 6.00 | (3.00) | 8.00 | (4.00) | < 1000.00 | < 18.00 | < 20.00 | < 176.00 | < 5.00 | |
| MAR | 92 | 7.20 | 750.00 | 2.76 | 6.00 | (2.00) | 22.00 | (4.00) | < 1000.00 | < 15.00 | < 20.00 | < 128.00 | < 5.00 | |

| MONTH | YEAR | TOTAL Ra | (±) | Sr-90 | (±) | Mn-54 | Co-60 | (±) | Cs-134 | Th-230 | (±) | Th-232 | (±) | CaCO3 | COD | Cu | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAR | 91 | < 1.00 | | < 0.60 | | < 19.00 | < 10.00 | | < 10.00 | note 1 | | < 1.00 | | 220.00 | 26.00 | 0.003 | 1.76 |
| JUN | 91 | 3.00 | (1.00) | 1.10 | (0.40) | < 19.00 | < 10.00 | | < 10.00 | < 1.00 | | < 1.00 | | 250.00 | 67.00 | 0.025 | 16.00 |
| SEP | 91 | | | | | | | | | | | | | | | | |
| DEC | 91 | 2.00 | (1.00) | < 0.70 | | < 16.00 | < 17.00 | | < 15.00 | < 1.00 | | < 1.00 | | 470.00 | 34.00 | 0.003 | 2.17 |
| MAR | 92 | 2.00 | (1.00) | < 0.70 | | < 15.00 | < 5.00 | | < 4.00 | < 1.00 | | < 1.00 | | 760.00 | 42.00 | 0.004 | 5.70 |

| MONTH | YEAR | Pb | Mn | Ni | Zn | Na | GWELEV |
|---|---|---|---|---|---|---|---|
| MAR | 91 | 0.010 | 0.094 | < 0.01 | 0.03 | 17.70 | 0.00 |
| JUN | 91 | < 0.050 | 0.110 | < 0.04 | 0.09 | 24.70 | 0.00 |
| SEP | 91 | | | | | | |
| DEC | 91 | < 0.010 | 0.175 | < 0.01 | 0.01 | 29.30 | 0.00 |
| MAR | 92 | < 0.050 | 0.280 | < 0.04 | 0.06 | 29.00 | 0.00 |

Note 1: Analysis not performed, reason unknown.
Note 2: No sample taken due to no surface water available.
Note 3: See Table 10 for units.

Table 9: Analysis Data for Additional Samples - March 1991 to March 1992

| WELL | MONTH | YEAR | pH | COND | TOC | GR ALPHA | (±) | GR BETA | (±) | TRITIUM | Na-22 | Na-24 | Be-7 | Ca-45 | (±) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GW-14 | SEP | 91 | 6.20 | 278.00 | 7.80 | 12.00 | (8.00) | 21.00 | (14.00) | < 1000.00 | < 20.00 | < 20.00 | < 220.00 | < 1.00 | |
| GW-13 | DEC | 91 | 6.80 | 370.00 | 1.70 | 9.00 | (2.00) | 12.00 | (4.00) | < 1000.00 | < 26.00 | < 20.00 | < 200.00 | < 5.00 | |
| GW-16 | MAR | 92 | 6.30 | 115.00 | 0.41 | 3.00 | (1.00) | 4.00 | (3.00) | < 1000.00 | < 14.00 | < 20.00 | < 103.00 | < 5.00 | |

| WELL | MONTH | YEAR | TOTAL Ra | (±) | Sr-90 | (±) | Mn-54 | Co-60 | (±) | Cs-134 | Th-230 | (±) | Th-232 | (±) | CaCO3 | COD | Cu | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GW-14 | SEP | 91 | 9.00 | (1.00) | < 0.70 | | < 19.00 | < 18.00 | | < 16.00 | < 1.00 | | < 1.00 | | 50.00 | 150.00 | 0.002 | 15.00 |
| GW-13 | DEC | 91 | < 1.00 | | < 0.70 | | < 22.00 | < 23.00 | | < 21.00 | < 1.00 | | < 1.00 | | 220.00 | 26.00 | 0.002 | 1.57 |
| GW-16 | MAR | 92 | < 1.00 | | < 0.70 | | < 12.00 | < 14.00 | | < 11.00 | < 1.00 | | < 1.00 | | 40.00 | 37.00 | <0.001 | 3.50 |

| WELL | MONTH | YEAR | Pb | Mn | Ni | Zn | Na | GWELEV |
|---|---|---|---|---|---|---|---|---|
| GW-14 | SEP | 91 | < 0.010 | 0.375 | < 0.01 | 0.03 | 16.20 | 27.00 |
| GW-13 | DEC | 91 | < 0.010 | 0.114 | < 0.01 | 0.01 | 15.80 | 10.50 |
| GW-16 | MAR | 92 | < 0.050 | 0.480 | < 0.04 | 0.03 | 9.00 | 29.19 |

Note 1: Analysis not performed, reason unknown.
Note 2: See Table 10 for units.

Table 10: Units

| | |
|---|---|
| pH | Standard pH units |
| Conductivity | µmhos/cm |
| TOC, CaCO3, COD, metals (Cu, Fe, Pb, Mn, Ni, Zn, Na) | mg/l |
| radio-isotopes | pCi/l |
| GW Elevation | feet above sea level |

## References

Dav66 Hydrogeology; Stanley N. Davis and Roger J. M. DeWiest; John Wiley & Sons; 1966

Ehl82 Petrology: Igneous, Sedimentary, and Metamorphic; Ernest G. Ehlers and Harvey Blatt; WH Freeman & Co.; 1982

EPA89 Statistical Analysis of Ground-water Monitoring at RCRA Facilities; USEPA Publication; 1989

Law85 Report of the Preliminary Geotechnical Exploration Continuous Electron Beam Accelerator Facility; Law Engineering Testing Company; Oct. 3, 1985

May91 Statistical Evaluation of CEBAF Ground Water Analyses of Samples Collected September 1989 - March 1991; RCG Note 91-006; R. May and C. Wells

May92 Radiation Control Office Memorandum to file dated 3/25/92

Men75 Introduction to Probability and Statistics; William Mendenhall; Duxbury Press; 1975

Vpa89 Commonwealth of Virginia State Water Control Board Regulations, Water Quality Standards

Wqs88 Commonwealth of Virginia State Water Control Board Regulations, Water Quality Standards; July 1988

## Appendix A Sample Calculation for Test of Proportions

The sample calculation will be done with the values for gross alpha. The variables and their values are:

- X - number of up gradient well samples with detectable concentrations of gross alpha. Value for this calculation: 12
- Y - number of down gradient well samples with detectable concentrations of gross alpha. Value for this calculation: 64
- $n_b$ - number of up gradient well samples analyzed. Value for this calculation: 22
- $n_c$ - number of down gradient well samples analyzed. Value for this calculation: 111

$$\hat{P} = \frac{(X+Y)}{(n_b+n_c)} = \frac{(64+12)}{(22+111)} = \frac{76}{133} = 0.571$$

$$n\hat{P} = 133(0.571) = 76$$

$$n(1-\hat{P}) = 133(1-0.571) = 57$$

Since $P_b$ and $P_c$ are greater than 5, the normal approximation may be used. The next step is to compute the proportion of detects in the up and down gradient wells.

$$\hat{P}_b = \frac{X}{n_b} = \frac{12}{22} = 0.545$$

$$\hat{P}_c = \frac{Y}{n_c} = \frac{64}{111} = 0.577$$

The standard error of the difference of the proportions is calculated:

$$SD = \left[\frac{(X+Y)}{(n_b+n_c)}\left(1-\frac{(X+Y)}{(n_b+n_c)}\right)\left(\frac{1}{n_b}+\frac{1}{n_c}\right)\right]^{0.5}$$
$$= \left[\frac{(12+64)}{(22+111)}\left(1-\frac{(12+64)}{(22+111}\right)\left(\frac{1}{22}+\frac{1}{111}\right)\right]^{0.5}$$
$$= 0.116$$

Then the statistic Z is formed:

$$Z = \frac{(\hat{P}_b - \hat{P}_c)}{SD} = \frac{(0.577-0.545)}{0.116} = 0.270$$

Since this value is less than 1.96 we can say that there is no statistical evidence of contamination.