Evaluation of the Representativeness and Reliability of Groundwater Monitoring Well Data, Mixed Waste Landfill, Sandia National Laboratories

New Mexico Environment Department/Hazardous Waste Bureau
By: William P. Moats, David L. Mayerson[1], and Brian L. Salem
November 2006

Introduction

The Mixed Waste Landfill (MWL) was operated by Sandia National Laboratories (SNL), whose research facilities are within the area occupied by Kirtland Air Force Base (KAFB). The MWL was operated for land disposal from 1959 to 1988, and included at various times throughout its operational history disposal of radioactive, hazardous, and mixed wastes. It is comprised of two contiguous areas - the classified and the unclassified waste areas - which together occupy approximately 2.6 acres in the north-central portion of Technical Area 3. During operation of the MWL, classified wastes were buried in small pits, and unclassified wastes were disposed in seven trenches. SNL estimates that the landfill received a total of approximately 100,000 cubic feet of waste containing about 6,300 curies of activity at the time of disposal (SNL, 09/1996).

The MWL is subject to corrective action as a solid waste management unit (SWMU) under the New Mexico Hazardous Waste Management Regulations 20.4.1.500 NMAC, incorporating 40 CFR 264.101. Under the regulatory framework mandated by these regulations, and upon consideration of the Corrective Measures Study for the MWL (SNL, 05/2003), the Secretary of the New Mexico Environment Department (NMED) ordered construction of an evapotranspiration cover with bio-intrusion barrier over the landfill, and the subsequent development and implementation, upon NMED approval, of a long-term monitoring and maintenance plan (NMED, 05/26/2005).

Public comments submitted to NMED on the MWL Corrective Measures Implementation Plan (SNL, 11/2005) include concerns that the groundwater samples from the existing MWL monitoring wells have not yielded representative hydrochemical data due to the effects of residual drilling mud and organic additives. Commenters assert that residual organic additives can induce the formation of iron and manganese precipitates, which, like residual drilling mud, can remove (adsorb) contaminants from the groundwater before they enter a well bore and can reduce the local aquifer permeability in the vicinity of a well. Additionally, commenters maintain that residual organic additives may cause localized reducing conditions around a well bore, which is expressed by low values of Eh, nitrate, and sulfate; undetectable values of dissolved oxygen, and elevated concentrations of ammonia, sulfide, manganese and iron. They maintain that all of these circumstances exist at the MWL.

[1] Now employed with the NMED Ground Water Quality Bureau

The concerns expressed by the public were based in part upon groundwater investigations conducted at Los Alamos National Laboratory (LANL), where these circumstances were found to be true in some monitoring wells (LANL, 11/2005). Given the seriousness of these concerns relative to the NMED Hazardous Waste Bureau's (Bureau) mission and statutory mandates, the Bureau conducted a detailed study of the quality of groundwater data derived from MWL monitoring well samples. This document reports the results of that study.

Purpose

The purpose of this report is to evaluate whether or not groundwater samples from the MWL monitoring wells have produced metals and general chemistry concentration and field parameter data that are reliable and representative of groundwater underlying the MWL. NMED has relied upon these data, in part, to determine the appropriate remedy for the MWL. Other information was considered in the remedy selection process, including the waste inventory (types, amounts, and migration potential and pathways of waste) geologic and climatic conditions, current levels of chemical and radiological contaminants released into the vadose zone, surface soil, and the atmosphere, and short and long term risk to human health and the environment. These facets are not addressed in this study.

Background

The MWL overlies unconsolidated sediments within the Albuquerque Basin that generally can be grouped into two major lithologic units. The upper unit, the Alluvial Fan (AF) Facies, is composed chiefly of medium-grained to fine-grained sediments that are derived from the erosion of Precambrian and Paleozoic rocks forming the uplands east of the landfill. The unit generally becomes finer-grained with depth, and forms the uppermost portion of the saturated zone beneath the MWL. The AF Facies is characterized by low saturated hydraulic conductivity (10^{-7} cm/s), especially in its lower parts (Goering et al., 12/2002).

Underlying the AF Facies are somewhat coarser-grained fluvial sediments believed to have been deposited by an ancestral Rio Grande. This lower unit, the Ancestral Rio Grande (ARG) Facies, is characterized by saturated strata having a larger degree of lateral continuity and having hydraulic conductivities about two orders of magnitude higher than those of the AF Facies (Goering et al., 12/2002).

A total of seven groundwater monitoring wells have been installed at the MWL to monitor whether or not underlying groundwater has been affected by any contamination emanating from the MWL. Wells BW1, MW1, MW2, and MW3 each have a single well screen, and are all completed within the AF Facies (Goering et al., 12/2002). Well MW4 is installed in an angled borehole, and was completed with two well screens that are 20 feet apart and which are separated by a removable packer (Goering et al., 12/2002). The uppermost screen of this well is completed in the AF facies, while the lower screen is completed across the boundary of the AF facies and the underlying ARG Facies. Monitoring well MW5 is also completed across this facies boundary, while MW6 is

screened wholly within the ARG facies (Goering et al., 12/2002). Both MW5 and MW6 are completed with single screens. All of the groundwater underlying the MWL is within the low total dissolved solids (low-TDS) hydrochemical facies as described by Moats and Winn (01/1995).

Nitrate concentrations from MW4 groundwater samples are lower than those observed in groundwater samples from the four monitoring wells that are completed solely within the AF facies (*i.e.*, BW1, MW1, MW2, and MW3), and are very similar to the corresponding analyte data from MW5 and MW6 (see Appendices A and B). The presence of nitrate in the shallower facies groundwater is attributed to contamination from septic systems within the vicinity of Tech Area 3 (IT, 04/1999, cited in Goering et al., 12/2002), as no significant nitrate sources from the MWL are known to exist. This difference in nitrate concentrations between the upper screened zone of MW4 and the other shallow wells may be indicative of small hydrochemical differences related to local areas of lower hydraulic conductivity within the AF facies (Goering, 09/21/2006).

Three drilling methods were used to install monitoring wells at the MWL: mud rotary, air-rotary casing hammer (ARCH), and sonic resonance. According to SNL records, the mud rotary method, which utilizes drilling mud, drilling additives, or both was employed only in the installation of MWL monitoring wells BW1, MW2, and MW3, all of which are completed in the AF Facies (Ecology and Environment, 12/1989). These three wells will be collectively referenced herein as the *mud rotary wells*.

Bentonite drilling mud is composed primarily of the clay mineral montmorillonite, (Na, Ca)(Al, $Mg)_6(Si_4O_{10})_3(OH)_2 \cdot nH_2O$. Bentonite drilling muds also contain other minor components. For example, LANL found drilling mud could include various leachable components such as sulfate, uranium, and fluoride (LANL, 11/2005, Table A-10). The presence of residual drilling mud or additives in a well bore or surrounding aquifer material can affect the properties of groundwater samples. For example, in some cases, alkalinity levels of groundwater contaminated with organic drilling additives may be higher than those of formation water due to the oxidation of organic matter to form bicarbonate.

The only documented drilling additives that have been used in installation of the mud rotary wells are soda ash (Na_2CO_3), sodium carboxymethylcellulose (CMC: used to stabilize drilling fluid), and lost circulation material (Ecology and Environment, 12/1989, p. 3-3). Soda ash was used in the redrilling of BW1 and MW3 (Ecology and Environment, 12/1989, p. 3-4)[2], and was added to increase the pH of the mud when the viscosity could not be controlled by simple water addition. Lost circulation material (*e.g.*, ground fragments and pieces of cedar wood and cellophane) was used only in drilling BW1 (Ecology and Environment, 12/1989, p. 3-4 and Appendix D). CMC was used in the drilling of all three mud rotary wells to control water loss, increase viscosity, and

[2] A typographic error on this page of the referenced report identifies the former as MW1; however Sections 4.1 and 4.4 and Appendix D drilling fluid reports clearly indicate that this well should have been identified as BW1.

inhibit clay swelling. Because of the properties of CMC, it was expected to be easily flushed from the borehole during well development.

Data on the construction of all MWL monitoring wells are summarized in Table 1. Well MW4 was drilled by the sonic resonance method (SNL, 12/07/1992), with the introduction of potable water during well installation (Goering, 07/17/2006). For wells installed using the ARCH method (MW1, MW5, and MW6), only air and potable water were introduced during installation (Ecology and Environment, 12/1989; SNL, 12/07/2000; and SNL, 10/19/2000). However, according to field notes, small quantities of sodium-bentonite grout infiltrated into the filter pack and well screen of MW5 during construction of this particular well.

Compared to the variability of regional background water quality in the low-TDS hydrochemical facies, minor hydrochemical differences exist in the relative concentrations of major ions between groundwater from the AF facies and that of the underlying ARG Faces. Stiff diagrams are commonly used as a means for the rapid comparison of the abundance of major ions between groundwater samples due to their distinctive graphical shapes. Figure 1 represents groundwater data from a sampling event conducted in April 2001 at the MWL. It shows that ARG Facies groundwater has relatively higher concentrations of magnesium (Mg), calcium (Ca), sodium (Na) plus potassium (K), alkalinity (bicarbonate and carbonate), and chloride (Cl) compared to groundwater from the AF Facies. Overall, groundwater from both facies is similar, as shown by a Piper trilinear diagram of major ion chemistry of groundwater samples from all MWL monitoring wells (Figure 2; Goering et al., 12/2002). Piper diagrams are useful for comparing water samples based on their proportions of major ions, and are especially useful for revealing whether or not mixing of groundwater from different sources is occurring. The Piper diagram in Figure 2 indicates that groundwater from both the AF and ARG Facies can be classified as a calcium-sodium bicarbonate water.

Time series concentration plots (Appendix B) show that groundwater alkalinity, sodium and sulfate concentrations have remained stable since sampling began at the MWL. Piper and stiff diagrams prepared by Goering et al. (12/2002) for sampling events conducted from 1993 -2001 further demonstrate that the overall hydrochemistry of groundwater at the MWL has remained generally stable over the time period for which groundwater data are available.

Based on analysis of soil samples from investigational boreholes as well as passive and active soil-gas surveys (SNL, 09/1996), detectable contaminant releases from the MWL are limited to low levels of tritium, radon, and volatile organic compounds in the vadose (*i.e.*, unsaturated) zone. Cadmium has been detected at low concentrations in the vadose zone, but only along the western boundary of the landfill. The fate and transport model of Ho et al (11/2005) predicts that groundwater is unlikely to be affected in the future by any of these contaminants occurring in the vadose zone. The results of up to 14 years of groundwater monitoring conducted at the MWL further support this conclusion.

Data sources

Available historical groundwater hydrochemical and field parameter data for each of the MWL groundwater monitoring wells were compiled from periodic SNL groundwater monitoring data reports (Goering et al., 12/2002; Lyon and Goering, 01/ 2006) and an NMED study (Moats and Winn, 01/1995). Appendix A presents a tabular compilation of available historical data for the analytes used in this evaluation.

Background hydrochemistry, which is used for comparison purposes with corresponding data from the monitoring wells, is taken from a comprehensive study of background groundwater quality throughout the area encompassed chiefly by Kirtland Air Force Base (KAFB), which includes the SNL research facilities (Moats and Winn, 01/1995). Only uranium concentration data are taken from a separate background study (IT Corporation, 03/1996).

Data analysis method

For this study, NMED has modified an effective method utilized by LANL in a similar investigation of the quality of LANL groundwater monitoring data (LANL, 11/2005). The LANL study employed a tiered assessment strategy in which selected key analyte concentrations from the three most recent groundwater sampling events were compared to local background concentrations. The specific analytes used were chosen considering common effects on groundwater samples from the presence of residual drilling mud and organic drilling additives (see Figure 3 for an overview of the LANL process). These effects, if they exist, would be shown by analyte concentrations that are either decreased or increased in comparison to corresponding regional background values by the adsorption or desorption of specific chemical species, by localized alteration of reduction-oxidation (redox) conditions, or both.

The NMED tiered evaluation method is shown as modifications to the LANL process in Figures 4 and 5. Data flag codes used to indicate that data reliability or representativeness may be compromised by the potential presence of residual drilling mud, additives, or both are explained in Table 5. An additional modification to the LANL process is the use of the median concentration values from the entire data set for any specific analyte where possible. This is a major enhancement of the LANL process, as use of median values allows for assessment of the reliability and representativeness of the *entire* data set for the subject wells, while discounting the effects of extreme (*i.e.*, very high or low) data values. For analytical results that are reported by the laboratory as below the analytical detection limit (DL), the NMED generally has used a value equal to one-half the value of the DL in the calculation of the median value. Because all concentration values for ammonia are reported as below the DL, no median concentration has been calculated for this analyte.

As an additional check on data reliability beyond that built into the LANL process, the NMED compared the median value of each analyte for each mud rotary well to the median values for the same analytes from groundwater samples from wells MW1 and

MW4. As stated above, these two wells are completed in the same AF facies, but were drilled without the use of mud or organic additives. Thus, neither of the two wells can possibly demonstrate any of the possible adverse effects of residual drilling mud and or organic additives, including the formation of iron or manganese precipitates that could mask the measurement of groundwater contaminants. Both of these wells should therefore provide analytical data that are representative of aquifer hydrochemistry. For purposes of this study, the NMED assumed that the median analyte concentration from a given mud rotary well that is within one standard deviation of the corresponding median from *either* MW1 or MW4 is strongly indicative of acceptable data representativeness and reliability. The range representing +/- one standard deviation from the median value of a given constituent will be hereinafter referred to as the *target comparison range*. However, small differences outside of the target comparison range do not automatically imply that samples from a well are not representative or reliable, as the background range for any given groundwater constituent generally encompasses an even larger degree of variance. For example, alkalinity in the low-TDS facies ranges from 101.0 to 291.0 mg/L, with a median of 169.5 mg/L and a standard deviation of 52.8 mg/L (Moats and Winn, 01/1995). This establishes a target comparison range of 116.7 to 222.3 mg/L, which excludes the maximum and minimum background values for alkalinity. In such cases, additional analysis may be required to decide whether or not any suspect data are representative and reliable.

As mentioned above, the LANL evaluation process is predicated on inferred geochemical and biochemical interactions among residual drilling mud and/or additives, groundwater, and aquifer materials. However, in some cases the LANL process used different groundwater constituents from those used by the NMED for the MWL. For NMED's examination of the MWL mud rotary wells, the LANL method was modified to utilize extant MWL groundwater data. For example, very little data for strontium are available for the MWL for use as a possible indicator of adsorption onto residual bentonite (see Figure 4, Tier 2.1-2). However, cadmium could be expected to be significantly adsorbed by residual bentonite, as the average adsorption coefficient for cadmium (560 mL/g) is about the same order of magnitude as that for strontium (110 mL/g) (LANL, 11/2005, Table 4-4, p. 62). Cadmium was therefore substituted for strontium in the NMED evaluation. Similarly, there are no analytical data for analytes specified in the LANL Tier 2.2-1 evaluation process available for MWL monitoring wells (see Figure 5), other than ammonia. However, oxidation of residual organic drilling additives would be expected to increase the level of alkalinity (LANL, 11/2005, p. 15). NMED has therefore substituted this analyte in this part of the tiered evaluation method.

MWL monitoring well samples have occasionally yielded low concentrations of acetone. Most of these detections are below the laboratory practical quantitation limit, and are associated with the detection of acetone concentrations in blank samples, which would be indicative of laboratory contamination. Therefore, acetone concentration data were not used in the evaluative process (see Figure 5, Tier 2.2-1).

The NMED further modified the LANL process by evaluating total, rather than dissolved, metal concentrations. With the exception of dissolved zinc, generally no more than four

analyses for any dissolved metals analyte exist. Use of total metal concentrations could overestimate the effect of desorption (see Figure 4, Tier 2.1-1) and Fe/Mn reducing conditions (see Figure 5, Tier 2.2-2), thus producing overly conservative assessments. On the other hand, use of the total metal concentrations could underestimate the effect of adsorption (see Figure 4, Tier 2.1-2) if the turbidity of a sample appreciably exceeds 5 NTU.

Although MW1 should provide sample data that are representative of background hydrochemistry in the AF facies, the concentration of total nickel in MW1 groundwater samples has shown a marked increase over time (see Figure 6). This is inferred to indicate progressive corrosion of the stainless steel well screen in this well (Goering et al., 12/2002). In addition to nickel, stainless steel commonly is comprised of iron and chromium. Therefore total iron concentrations from MW1 groundwater samples were not used in evaluating the mud rotary well sample data (see Table 4, Tier 2.2-2: redox conditions -- iron/manganese reducing conditions evaluation; and Table 6).

For MW4, the majority of post-05/23/1994 groundwater sample data are derived from samples from the upper screen, which also samples the AF Facies. However, data from earlier groundwater samples were composites of groundwater from both screens, with groundwater hydrochemistry from the lower more-conductive ARG facies presumably dominant (Goering, 09/21/2006). Nevertheless, groundwater data from MW4 represent a reasonable comparison to correlative data from the mud rotary wells.

As noted above, sodium-bentonite grout inadvertently infiltrated into the filter pack and screen of MW5 during well installation. Based on review of the field notes documenting well construction, it appears that much of the grout was removed prior to completing installation, and that all of the grout residing at the bottom of the well was removed prior to well development. Any remaining smaller amounts of grout within the filter pack should have been fairly easy to evacuate during well development.

If any appreciable grout is still present within the filter pack of MW5, there is a potential that the sodium bentonite contained within the grout could adsorb contaminants in a fashion similar to bentonite drilling mud. The percentage of bentonite in the grout that was used in the construction of MW5 is unknown, but bentonite grouts typically contain 2 to 6% sodium-bentonite by weight (U. S. Environmental Protection Agency, 03/1991). Grout is made chiefly from Portland cement, which is a mixture of various calcium silicates and calcium aluminates and subordinate amounts of hydrated calcium sulfate. Calcium and aluminum are major constituents of sodium-bentonite drilling mud, and, as mentioned previously, sulfate was found to be a leachable constituent of drilling mud made from bentonite mined from Wyoming, the most common source of bentonite used in well installations in the United States (LANL 11/2005).

Because grout is composed chiefly of Portland cement rather than drilling mud, various groundwater constituents in samples from MW5 were specifically evaluated as indicators of the presence of grout. In this case, it is assumed that the presence of grout is strongly indicated in MW5 water samples if all of the median concentrations of calcium, total

aluminum, and sulfate exceed their respective regional background concentrations (Table 9, Tier 3.1). As an additional check, the adsorption of metals was evaluated with the same process used for bentonite drilling mud (Table 9, Tier 3.2), except that total barium was substituted for total cadmium. NMED made this substitution because the levels of cadmium detected in MW5 groundwater samples are significantly less than the detection limit used to establish background, so meaningful comparisons using cadmium are not possible. Dissolved zinc data are not evaluated as such data are not available for water samples from MW5.

Finally, relative to other wells at the MWL, the general hydrochemistry of samples from MW5 should be most comparable to that of samples from MW6, as both of these latter wells are screened at least in part in the ARG Facies. The stiff diagrams shown in Figure 1 are useful for making this comparison.

Discussion

A major objective of this study is to determine whether localized reducing conditions may have become established in well bores by the oxidation of residual organic drilling additives (see Figure 5, tier 2.2-2.). In natural settings, the redox potential of groundwater tends to decrease as groundwater moves along its flow path. Water in the form of rain or snow initially contains appreciable levels of dissolved (free) oxygen due to the interaction of precipitation with the atmosphere. In recharge areas exhibiting sandy or gravelly soils, cavernous limestone, or fractured bedrock, levels of dissolved oxygen can remain high over considerable distances along the flow path of a groundwater system. In the KAFB/SNL area, groundwater commonly contains free oxygen at concentrations exceeding 2 mg/L (Moats and Winn, 01/1995), which is considered here to be indicative of moderate levels of dissolved oxygen (the lower limit of detection for dissolved oxygen is typically about 0.1 mg/L).

Because the solubility of dissolved oxygen in water is low, and because oxygen is not easily replaced in subsurface environments, oxidation of only a small amount of organic matter can consume all of the free oxygen in groundwater. If not sufficiently removed via well development, residual organic drilling additives can take the place of natural organic matter and supply nutrients to oxygen-consuming bacteria. The consumption of dissolved oxygen by bacterially-catalyzed reactions can deplete oxygen levels in groundwater to those below the level of detection. However, once the free oxygen has been consumed, reactions with other constituents in groundwater can cause further decreases in redox potential of the groundwater.

In a closed system, the oxidation of organic matter first consumes free oxygen, then is followed by a reduction of nitrate and manganese oxide. These reactions may be followed, in turn, by the reduction of ferric iron minerals. After sufficiently negative redox levels have been reached, sulfate can be reduced to H_2S and HS^-, along with the reduction of organic matter to carbon dioxide ($CO_{2)}$ and methane (CH_4). However, in most groundwater systems, groundwater does not undergo all of the above redox stages

due to limitations on the availability of nutrients and conditions that allow bacteria to thrive.

Contaminants migrating from the MWL have not been detected in the groundwater beneath the landfill (Goering et al, 12/2002). Furthermore, the fate and transport model completed for the MWL shows that concentrations of contaminants in the vadose zone beneath the MWL are sufficiently low that groundwater is unlikely to be impacted in the future (SNL, 11/2005). Although contaminants do not occur in the groundwater presently (aside from nitrate from septic tanks as previously discussed), the ability of the MWL wells to provide high quality water samples useful for the detection of any unexpected future contamination is of paramount importance.

Tables 2 through 8 present the NMED's evaluation of the quality of MWL groundwater monitoring data using the tiered evaluation method. Wells MW1, MW4, and MW6 do not require further assessment because these wells were not installed with the mud rotary method. Although MW5 was also not installed using the mud rotary method, the quality of water samples from this well was assessed in this study due to the accidental intrusion of sodium-bentonite grout into the well's filter pack and screen. Additional assessment was therefore necessary for mud rotary wells BW1, MW2, and MW3, and ARCH well MW5.

For the mud rotary wells, the median concentrations of all of the analytes examined fall within the expected regional background ranges (Tables 3 and 4). Therefore, no data quality flags (Table 5) are assigned to any of these analytes. This part of the tiered evaluation process shows that there are no bentonite mud components in groundwater samples from the mud rotary wells, and similarly, that there is no evidence of adsorption of groundwater contaminants. This part of the evaluation also suggests that reducing conditions do not exist in the mud rotary wells.

Comparisons of median analyte values of the mud rotary wells to correlative values for MW1 and MW4 are shown in Tables 6 and 7. Analytes with median values that fall outside of the target comparison ranges for MW1 or MW4 are shown in Table 8. Of all of the analytes evaluated, only the median values for alkalinity (for MW3) and nitrate (for BW1, MW2, and MW3) fail to meet the target comparison ranges for both MW1 and MW4.

Relatively higher levels of alkalinity are expected in groundwater adversely affected by drilling mud. Higher alkalinity concentrations are also expected for groundwater subject to severely reducing conditions, such as those caused by the oxidation of organic matter, including organic drilling additives. However, the median value for alkalinity for the MW3 groundwater samples is actually less than the target comparison ranges for both MW1 and MW4. This, combined with the lack of other bentonite leaching indicators (Tier 2.2-1), strongly suggests that residual drilling mud is not affecting the quality of water samples collected from MW3. Additionally, the lower alkalinity in groundwater samples from this well, as well as moderate concentrations of sulfate and nitrate, high

levels of dissolved oxygen, and nondetectable levels of ammonia indicate that reducing conditions are not present within the well bore.

In general, higher values of nitrate are indicative of high redox potential. The median values for nitrate from MW2 and MW3 samples are slightly lower than the target comparison range for MW1. The median values of nitrate for samples from all three mud rotary wells are higher than the target comparison range for MW4. For all of the mud rotary wells, the levels of nitrate detected in water samples are relatively high compared to the background concentration of 4 mg/L and the median value for nitrate in the low-TDS facies (1.065 mg/L, Moats and Winn, 01/1995). These data, as well as moderate to high concentrations of dissolved oxygen, moderate levels of sulfate, and nondetectable levels of ammonia, further indicate that low redox conditions are not present in the groundwater at any of the mud rotary wells.

For the three mud rotary wells, the median values for total iron as compared to MW4, and the median values for total manganese as compared to both MW1 and MW4, are within their respective target comparison ranges, demonstrating that iron and manganese are not being dissolved into the groundwater as a result of reducing conditions. It is therefore no surprise that the formation of iron and manganese precipitates is not evident at any of the mud rotary wells. The median values for sulfate and ammonia (all non-detects) for these three wells are also within their respective target comparison ranges for both MW1 and MW4, further demonstrating that highly reducing conditions are not present in any of the mud rotary wells.

For ARCH well MW5, comparison of the median values for sulfate, calcium, and total aluminum to their respective maximum regional background concentrations indicate that grout contamination is not present in the well (see Table 9, Tier 3.1). Additionally, comparison of the median values for uranium, total zinc, and total barium to minimum regional background levels suggest that adsorption of contaminants is not taking place. Finally, Figure 1, as well as the series of stiff diagrams in Goering et al (12/2002), show that the general hydrochemistry of water samples from MW5 matches that of groundwater samples collected from MW6, providing yet further evidence that MW5 water samples are free from grout contamination.

Conclusions

MWL wells MW1, MW4, and MW6 were completed without the use of drilling muds and organic drilling additives. Water samples from these wells provide data that are reliable and representative of the hydrochemistry of the aquifer beneath the landfill. Evaluation of groundwater analytical data from MWL mud rotary well samples confirms that these data are not compromised. Therefore, none of the data examined is assigned a qualifying data flag. This study further shows that there are no bentonite drilling mud components that adversely affect sample chemistry in groundwater samples from the mud rotary wells, that there is no evidence of adsorption of groundwater contaminants or evidence of reducing conditions, and that grout contamination was adequately removed from ARCH well MW5 before the well was placed into service.

Nitrate in MWL groundwater samples is attributed to the oxidation of ammonia from Tech Area 3 septic systems. In particular, the consistent detection of relatively high concentrations of nitrate and moderate to high levels of dissolved oxygen in groundwater samples from the mud rotary wells provides strong evidence that localized reducing (low redox) conditions do not exist in the vicinity of these wellbores. Otherwise, concentrations of these analytes would be markedly lower or altogether absent under the slightest reducing conditions. The totality of evidence indicates that the three monitoring wells that were installed with mud rotary method (BW1, MW2, and MW3), and ARCH well MW5 have yielded reliable and representative hydrochemical data.

The NMED encourages the use of monitoring well installation methods that avoid potential impacts to groundwater quality. The NMED will evaluate new or replacement groundwater monitoring wells associated with the MWL long-term monitoring and maintenance plan in light of this recommendation. Nevertheless, the results of the tier evaluation process show that there are no adverse effects in any of the mud rotary wells caused by the presence of residual drilling mud and organic drilling additives. Thus, development of the mud rotary wells at the MWL was adequate, and the quality of water samples retrieved from these wells is representative of general aquifer chemistry.

References:

Ecology and Environment, Inc., December 1989. "Groundwater Monitoring Wells Installation Mixed Waste Landfill." Prepared for Sandia National Laboratories Environmental Restoration Program, Albuquerque, New Mexico.

Freeze, R. A. and Cherry, J. A., 1979, Groundwater: Prentice-Hall, Inc., Englewood, New Jersey, 604 p.

Goering, Timothy J. Grace M. Haggerty, Dirk Van Hart, and Jerry L. Peace, December 2002, "Mixed Waste Landfill Groundwater Report, 1990 through 2001, Sandia National Laboratories, Albuquerque, New Mexico." Prepared by Sandia National Laboratories, Albuquerque, New Mexico. SAND Report SAND2002-4098.

Goering, Timothy J., July 17, 2006. "MWL Well Installation Details." Email to W. Moats, New Mexico Environment Department/Hazardous Waste Bureau.

Goering, Timothy J., September 21, 2006. "Depth from which MWL-MW4 samples were collected." Email to D. L. Mayerson, New Mexico Environment Department/Hazardous Waste Bureau.

Ho, Clifford K.; T. Goering; J. L. Peace; and M. L. Miller, November 2005. "Probabilistic Performance-Assessment Modeling of the Mixed Waste Landfill at Sandia National Laboratories." Sandia National Laboratories, Albuquerque, New Mexico.

IT Corporation, March 1996. "Background Concentrations of Constituents of Concern to the Sandia National Laboratories/New Mexico Environmental Restoration Project and the Kirtland Air Force Base Installation Restoration Program." Prepared for Sandia National Laboratories/New Mexico.

IT Corporation, April 1999. "Mixed Waste Landfill Semiannual Groundwater Monitoring Report, November 1998/January 1999, Sandia National Laboratories/New Mexico," prepared for Sandia National Laboratories, Albuquerque, New Mexico.

Los Alamos National Laboratory, November 2005. "Well Screen Analysis Report." LA-UR-05-8615, ER2005-0841.

Lyon, Mark L. and T. J. Goering, January 2006, "Mixed Waste Landfill Annual Groundwater Monitoring Report, April 2005." Prepared by Sandia National Laboratories, Albuquerque, New Mexico 87185 and Livermore, California 94550.

Moats, William P. and L. Winn, January 1995, "Background Groundwater Quality of the Kirtland Air Force Base Area, Bernalillo County, New Mexico." New Mexico Environment Department Report NMED/DOE/AIP-95/4.

New Mexico Environment Department, April 20, 2005. "Hearing Officer's Report, Proposed Findings of Fact and Conclusions of Law in the matter of request for a Class 3 Permit modification for corrective measures for the Mixed Waste Landfill," Sandia National Laboratories, Bernalillo County, New Mexico, EPA ID No. NM5890110518.

New Mexico Environment Department, May 26, 2005. "In the matter of request for a Class 3 Permit modification for corrective measures for the Mixed Waste Landfill, Sandia National Laboratories, Bernalillo County, New Mexico, EPA ID No. NM5890110518—Final Order." HWB 04-11(M).

Sandia National Laboratories, December 7, 1992. MW4 Field Notebook.

Sandia National Laboratories, September 1996, "Report of the Mixed Waste Landfill Phase 2 RCRA Facility Investigation." Environmental Restoration Project. United States Department of Energy, Office of Kirtland Site Operations.

Sandia National Laboratories, October 19, 2000. MW6 well file.

Sandia National Laboratories, December 7, 2000. "Mixed Waste Landfill Final Well Summary, Monitor Well MW5." SHEARS #199913.

Sandia National Laboratories, May 2003. "Mixed Waste Landfill Corrective Measures Study Final Report, Sandia National Laboratories/New Mexico." Environmental Restoration Project. United States Department of Energy, Office of Kirtland Site Operations.

Sandia National Laboratories, November 2005. "Mixed Waste Landfill Corrective Measures Implementation Plan." United States Department of Energy Sandia Site Office.

U. S. Environmental Protection Agency, March 1991, Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells, EPA 160014-891034, 221 p.

Figure 1: Stiff Diagrams of Major Ion Chemistry for all MWL Wells, April 2001
(Goering et al., 12/2002, Figure 4-14)

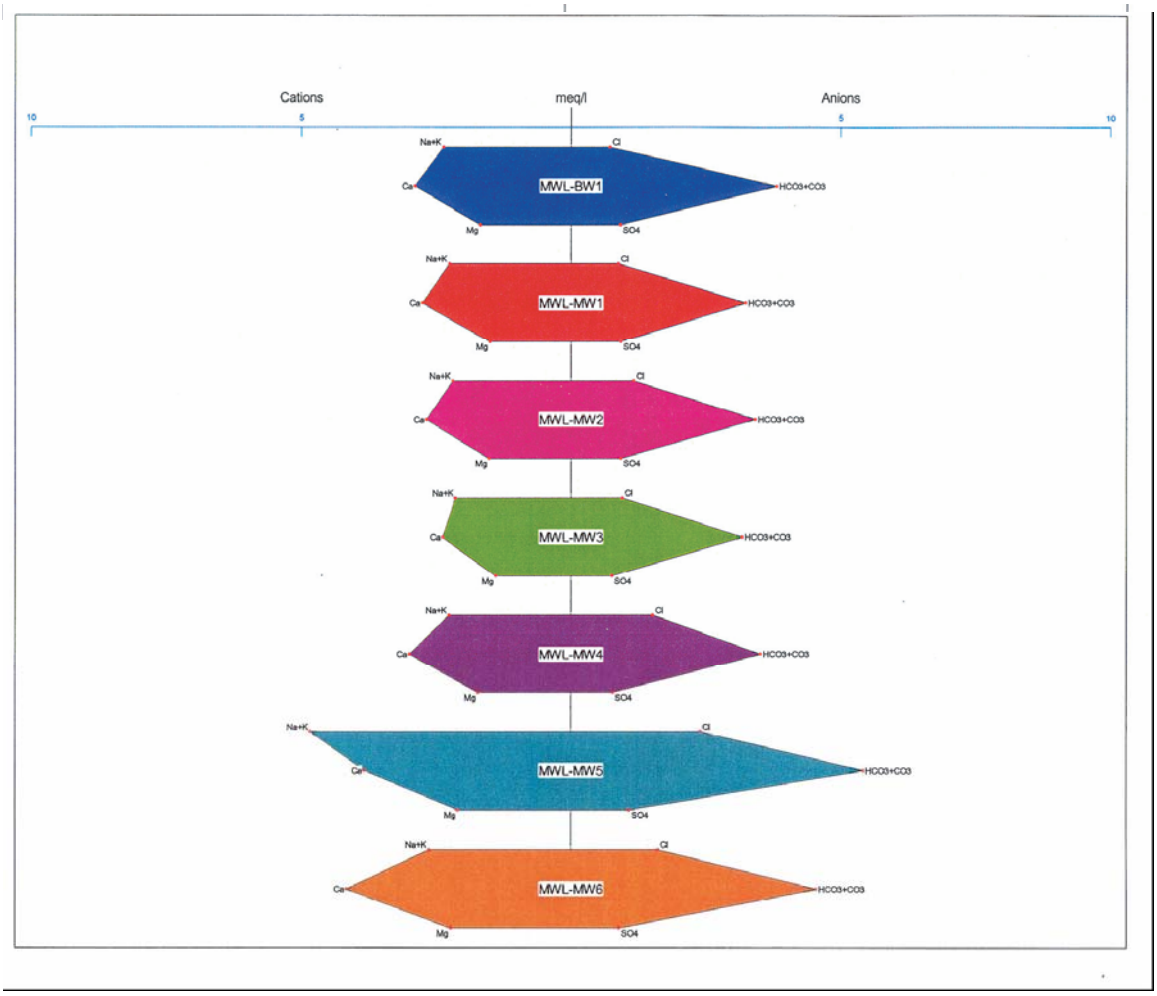


Figure 2: Piper trilinear diagram of major ion chemistry for all MWL wells, April 2001
(Goering et al, 12/2002, Figure 4-7)

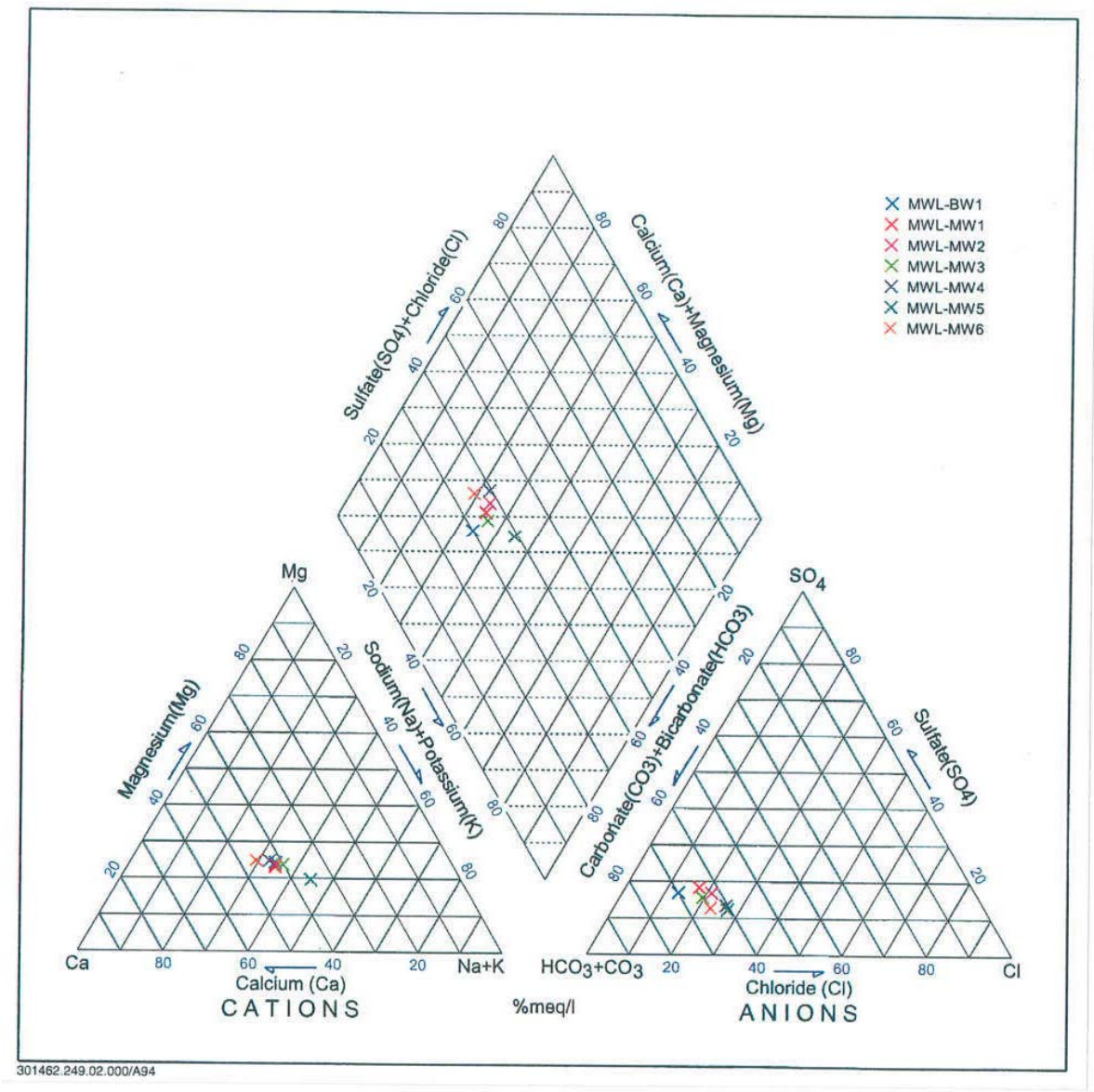


Figure 3: Overview of LANL evaluation process for monitoring well groundwater sample representativeness and reliability
(LANL, 11/2005, figure 4-1)

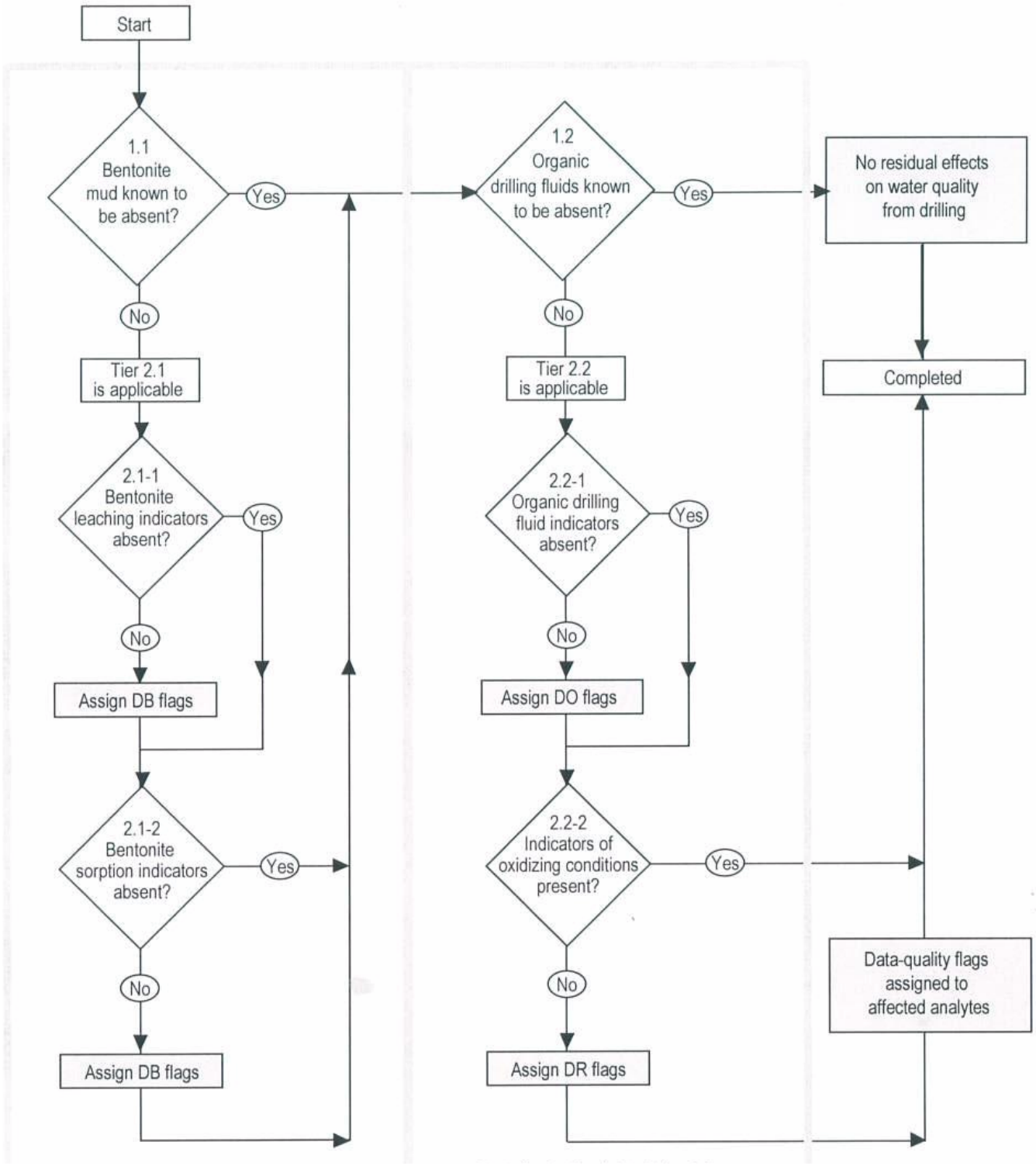


Figure 4: NMED modification of LANL Tier 2.1 evaluation process
(Modified from LANL, 11/2005, figure 4-3)

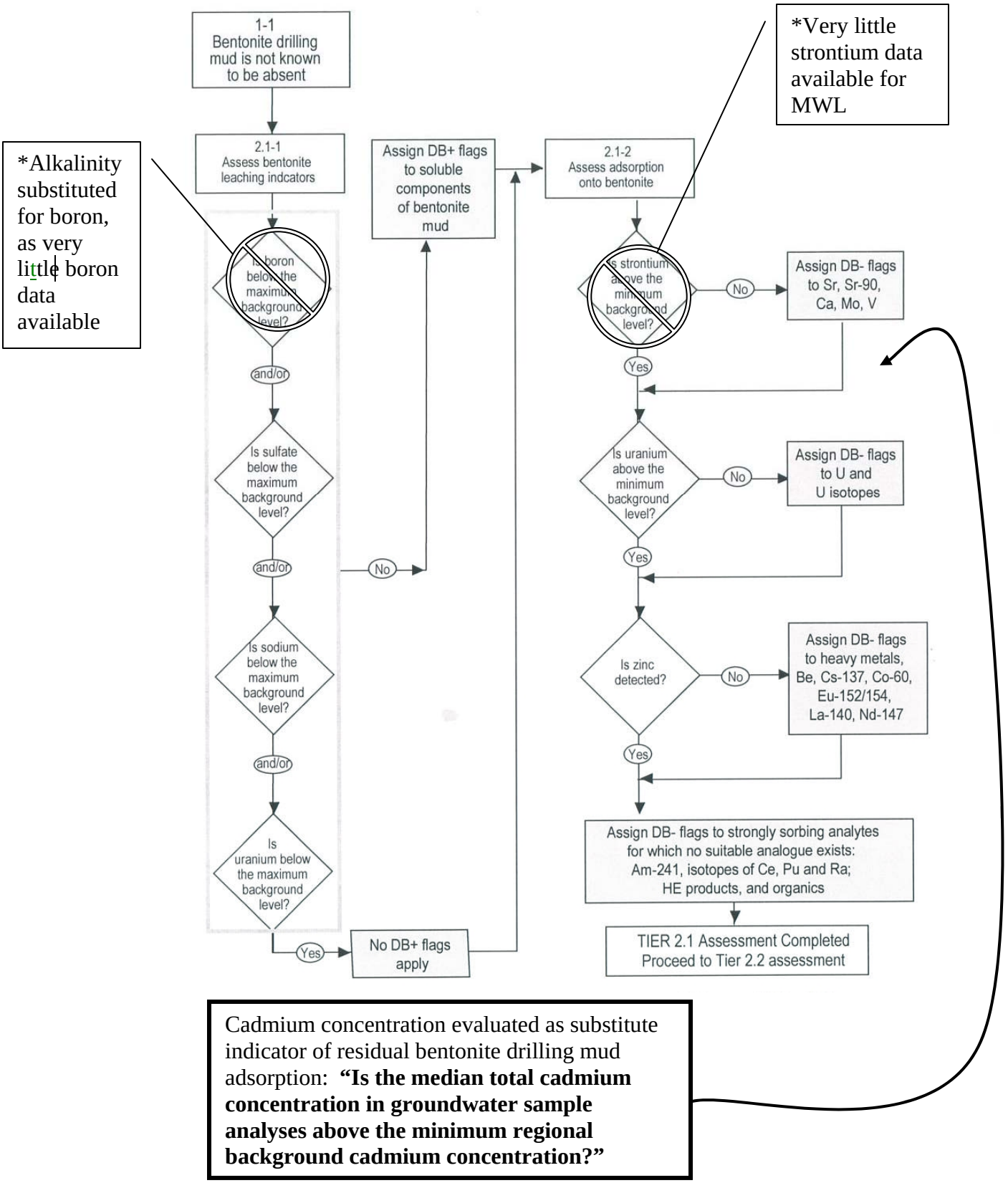


Figure 5: NMED modification of LANL Tier 2.2 evaluation process
(Modified from LANL, 2005, figure 4-10)

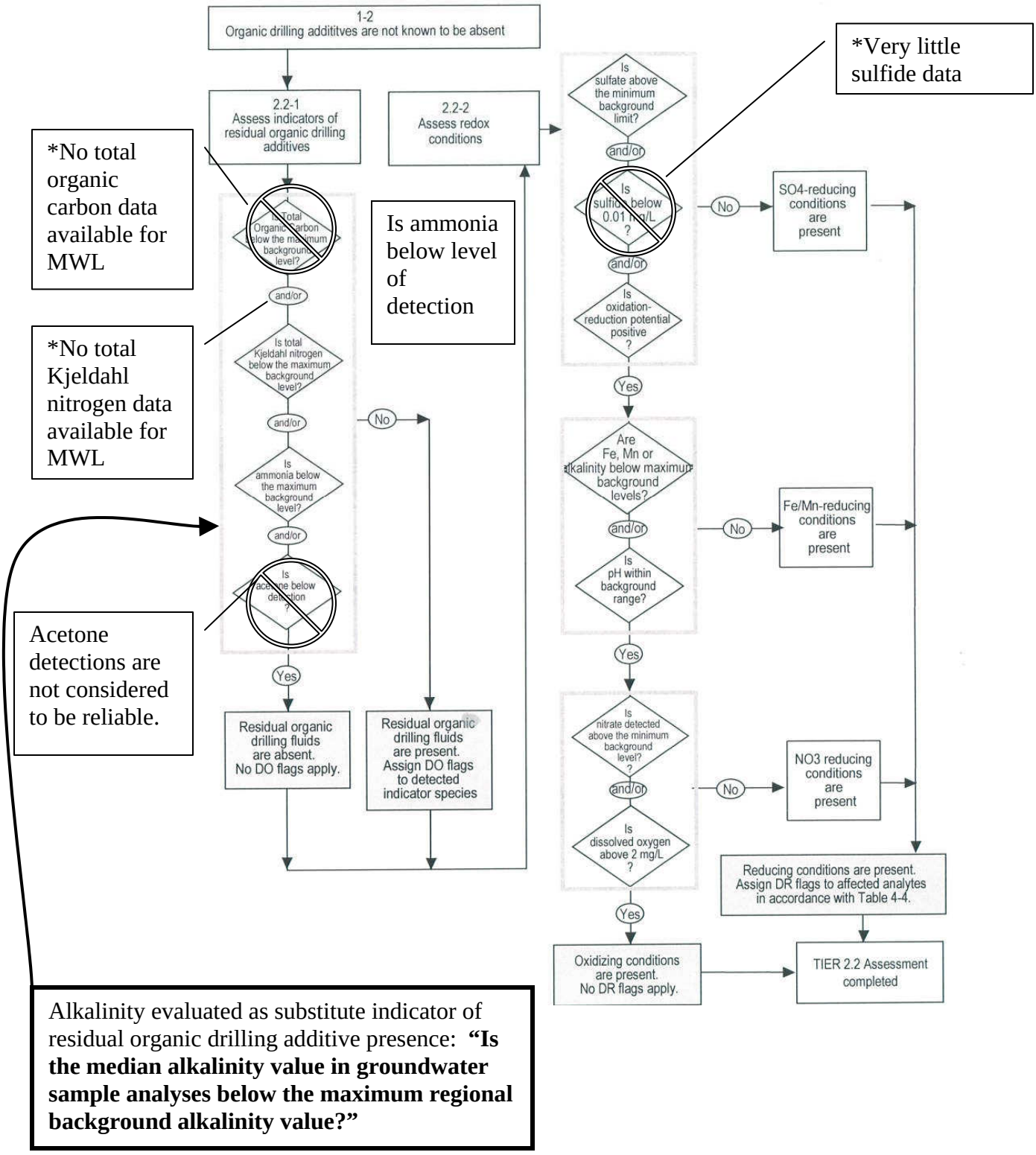


Figure 6: MWL--total nickel concentrations in groundwater samples vs. time

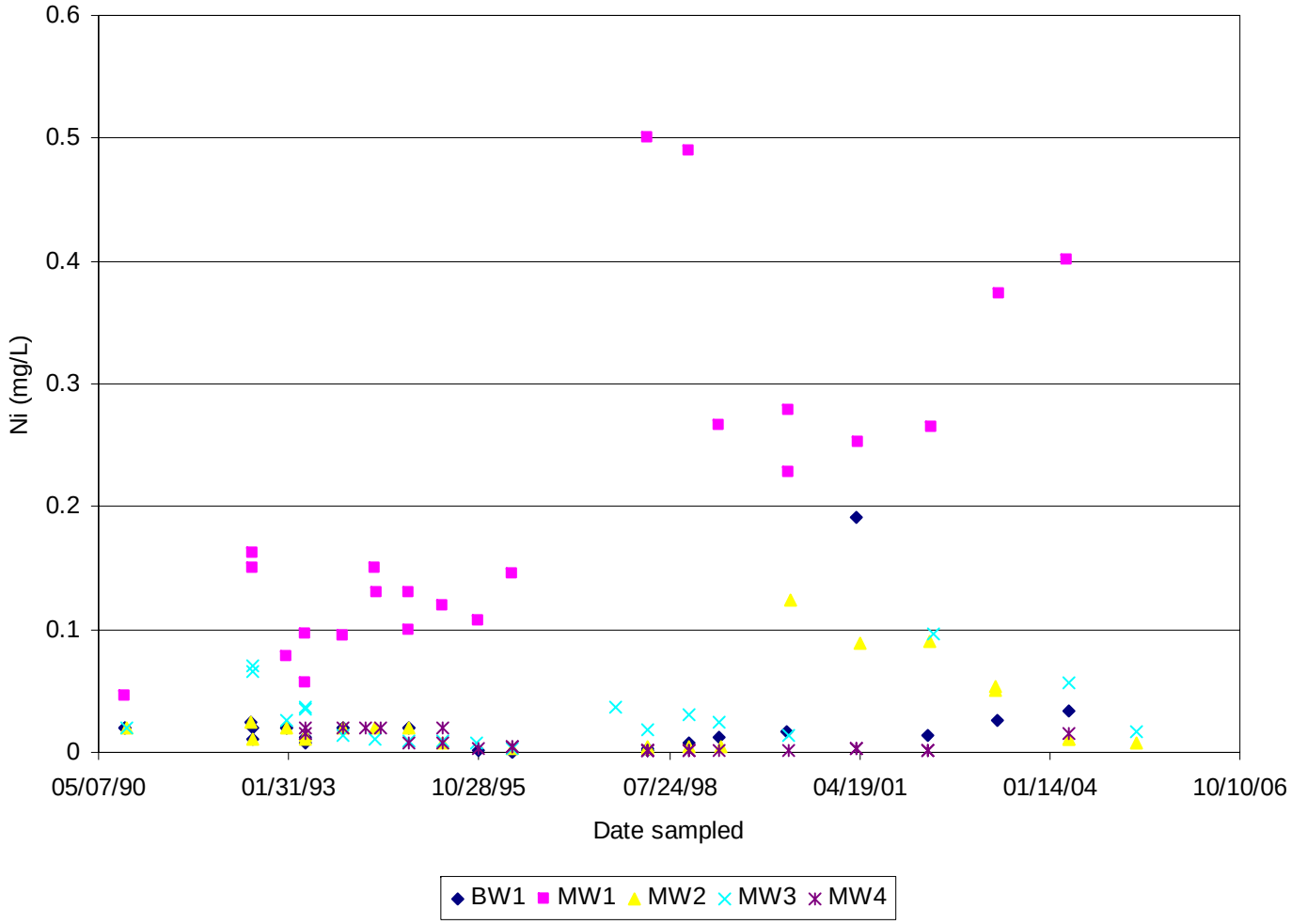


Table 1: MWL Monitoring well construction details

	BW1	MW1	MW2	MW3	MW4	MW5	MW6
Drilling method	mud rotary	air-rotary casing hammer	mud rotary	mud rotary	sonic resonance	air-rotary casing hammer	air-rotary casing hammer
Sedimentary facies at well screen	alluvial fan	alluvial fan	alluvial fan	alluvial fan	**top screen**: alluvial fan **bottom screen:** alluvial fan/ancestral Rio Grande	alluvial fan/ancestral Rio Grande	Ancestral Rio Grande
Screen interval (feet above mean sea level)	4930.53-4910.53	4923.12-4903.12	4923.71-4903.71	4927.67-4907.67	4904.75-4881.86 4861.97-4842.08	4881.15-4861.15	4864.46-4844.46
Date of completion	1989	1988	1989	1989	1993	2000	2000
Additional notes	Background monitoring well for MWL, located cross-gradient	cross-gradient	cross-gradient	down-gradient	6º angle well from vertical with dual completion. Sited beneath Trench D.	downgradient	downgradient

Table 2: Tier 1-1 evaluation

MWL monitoring well	Bentonite mud and/or soda ash known to be absent?	Organic drilling fluids (e.g., CMC) known to be absent?	Outcome
BW1	no		Tier 2.1 is applicable
MW1	yes	yes	no residual effects on water quality from drilling
MW2	no		Tier 2.1 is applicable
MW3	no		Tier 2.1 is applicable
MW4	yes	yes	no residual effects on water quality from drilling
MW5	yes	yes	no residual effects on water quality from drilling, but grout infiltrated filter pack and screen during well installation
MW6	yes	yes	no residual effects on water quality from drilling

Table 3: Tier 2.1 evaluation
(See Figure 4)

Tier 2.1-1: desorption

MWL monitoring well	Median sulfate concentration from groundwater sample analyses (mg/L)	Is the median sulfate concentration in groundwater sample analyses below the maximum regional background concentration (*i.e.*, 124.7 mg/L at 95% confidence level [Moats and Winn, 1995])?	DB flag?
BW1	43.5	yes	none
MW2	41.1	yes	none
MW3	39.2	yes	none

MWL monitoring well	Median total sodium concentration from groundwater sample analyses (mg/L)	Is the median total sodium concentration in groundwater sample analyses below the maximum regional background total sodium concentration (*i.e.*, 74.0 mg/L at 95% confidence level [Moats and Winn, 1995])?	DB flag?
BW1	52.8	yes	none
MW2	49.6	yes	none
MW3	50.7	yes	none

Table 3 continued

Tier 2.1-1: desorption (concluded)

MWL monitoring well	Median total uranium concentration from groundwater sample analyses (mg/L)	Is the median total uranium concentration in groundwater sample analyses below the maximum regional background total uranium concentration? (*i.e.*, 0.0149 mg/L [IT Corporation, March, 1996])?	DB flag?
BW1	0.0066	yes	none
MW2	0.0066	yes	none
MW3	0.0055	yes	none

MWL monitoring well	Median alkalinity (as $CaCO_3$) value from groundwater sample analyses (mg/L)	Is the median alkalinity value in groundwater sample analyses below the maximum regional background alkalinity value (*i.e.*, 289.5 mg/L at 95% confidence level [Moats and Winn, 1995])?	DB flag?
BW1	229	yes	none
MW2	200	yes	none
MW3	191	yes	none

Table 3 continued

Tier 2.1-2: adsorption

MWL monitoring well	Median total uranium concentration from groundwater sample analyses (mg/L)	Is the median total uranium concentration in groundwater sample analyses above the minimum background total uranium concentration, (*i.e.*, 0.0005 mg/L [IT Corp., 03/1996])?	DB flag?
BW1	0.0066	yes	none
MW2	0.0066	yes	none
MW3	0.0055	yes	none

MWL monitoring well	Median total cadmium concentration from groundwater sample analyses (mg/L)	Is the median total cadmium concentration in groundwater sample analyses above the minimum background total cadmium concentration (*i.e.*, <0.001 mg/L [Moats and Winn, 1995])?	DB flag?
BW1	0.0025	yes	none
MW2	0.001	yes	none
MW3	0.002	yes	none

Table 3 concluded

Tier 2.1-2: adsorption (concluded)

MWL monitoring well	Median total zinc concentration (mg/L)	Is total zinc detected?	DB flag?
BW1	0.046	yes	none
MW2	0.071	yes	none

MW3	0.030	yes	none

MWL monitoring well	Median dissolved zinc concentration (mg/L)	Is dissolved zinc detected?	DB flag?
BW1	0.040	yes	none
MW2	0.037	yes	none
MW3	0.038	yes	none

Table 4: Tier 2-2 evaluation
(See Figure 5)

Tier 2.2-1: indicators of residual organic drilling additive

MWL monitoring well	Median alkalinity (as $CaCO_3$) value from groundwater sample analyses (mg/L)	Is the median alkalinity value in groundwater sample analyses below the maximum regional background alkalinity value (*i.e.*, 289.5 mg/L as $CaCO_3$ at 95% confidence level [Moats and Winn, 1995])?	DO flag?
BW1	229	yes	none
MW2	200	yes	none
MW3	191	yes	none

MWL monitoring well	Ammonia value from groundwater sample analyses (mg/L)	Is ammonia below the level of detection?	DO flag?
BW1	< 0.1	yes	none
MW2	< 0.1	yes	none
MW3	< 0.1	yes	none

Table 4 continued

Tier 2.2-2: redox conditions—sulfate reducing conditions evaluation

MWL monitoring well	Median sulfate concentration from groundwater sample analyses (mg/L)	Is the median sulfate concentration in groundwater sample analyses above the minimum regional background sulfate concentration (*i.e.*, 22.0 mg/L [Moats and Winn, 1995])?	DR flag?
BW1	43.5	yes	none
MW2	41.1	yes	none
MW3	39.2	yes	none

MWL monitoring well	Median Eh value from groundwater sample analyses	Is the Eh value positive?	DR flag?
BW1	141.8	yes	none
MW2	151.0	yes	none
MW3	144.5	yes	none

Table 4 continued

Tier 2.2-2: redox conditions—iron/manganese reducing conditions evaluation

MWL monitoring well	Median total iron concentration from groundwater sample analyses (mg/L)	Is the median total iron concentration in groundwater sample analyses below the maximum regional background total iron concentration (*i.e., 8*.570 mg/L at 95% confidence level [Moats and Winn, 1995])?	DR flag?
BW1	0.05	yes	none
MW2	0.09	yes	none
MW3	0.24	yes	none

MWL monitoring well	Median total manganese concentration from groundwater sample analyses (mg/L)	Is the median total manganese concentration in groundwater sample analyses below the maximum regional background total manganese concentration (*i.e.*, 0.100 mg/L [Moats and Winn, 1995])?	DR flag?
BW1	0.005	yes	none
MW2	0.005	yes	none
MW3	0.01	yes	none

MWL monitoring well	Median pH value from groundwater sample analyses	Is the median pH value in groundwater sample analyses below the maximum regional background pH value (*i.e.*, 7.9 at 95% confidence level [Moats and Winn, 1995])?	DR flag?
BW1	7.62	yes	none
MW2	7.55	yes	none
MW3	7.65	yes	none

Table 4 concluded

Tier 2.2-2: redox conditions—nitrate reducing conditions evaluation

MWL monitoring well	Median nitrate concentration from groundwater sample analyses (mg/L, as nitrogen)	Is the median nitrate concentration in groundwater sample analyses above the minimum regional background nitrate concentration (*i.e.*, <0.100 mg/L, as nitrogen [Moats and Winn, 1995])?	DR flag? (*n.b.*, Presence suggests reducing conditions do not exist in wellbore vicinity)
BW1	5.68	yes	none
MW2	3.83	yes	none
MW3	4.03	yes	none

MWL monitoring well	Median dissolved oxygen concentration from groundwater sample analyses	Is the median dissolved oxygen concentration in groundwater sample analyses above 2 mg/L?	DR flag?
BW1	6.8	yes	none
MW2	3.9	yes	none
MW3	7.29	yes	none

Table 5: Validation flag codes to indicate that analyte concentrations may not be reliable or representative of groundwater predrilling conditions
(LANL, 11/2005, Table 4-3)

Flag	Definition	Applicable Tier
DB+	Analyte concentration may be elevated above that in predrilling groundwater due to leaching from bentonite drilling mud	2.1
DB-	Analyte concentration may be less than that in predrilling groundwater due to adsorption onto residual bentonite drilling mud	2.1
DB	[Uranium and uranium isotopes] Analyte concentration may not be the same as that in predrilling groundwater due to effects of residual bentonite drilling mud, but nature of effect is indeterminate	2.1
DO+	Analyte concentration may be elevated above that in predrilling groundwater due to presence of residual organic drilling fluids	2.2
DR+	Analyte concentration may be elevated above that in predrilling groundwater due to reducing conditions caused by residual organic drilling fluids	2.2
DR-	Analyte concentration may be less than that in predrilling groundwater due to reducing conditions caused by residual organic drilling fluids	2.2
DR	Analyte concentration may not be representative of that in predrilling groundwater due to reducing conditions caused by residual organic drilling fluids, but nature of effect is indeterminate	2.2

Table 6: Comparison of mud rotary well median analyte values to target comparison ranges for MW1

Is the median analyte concentration in groundwater sample analyses within 1 standard deviation of the median analyte concentration in groundwater sample analyses from **MW1**?							
Analyte	MW1 target comparison range (i.e., +/- 1 standard deviation) [mg/L except Eh and pH]	**BW1**		**MW2**		**MW3**	
		median value [mg/L except Eh and pH]	comparison result	median value [mg/L except Eh and pH]	comparison result	median value [mg/L except Eh and pH]	comparison result
alkalinity [as $CaCO_3$]	192 – 230	229	yes	200	yes	191	**no**
ammonia	all analyses below detection limit	all analyses below detection limit	yes	all analyses below detection limit	yes	all analyses below detection limit	yes
cadmium (total)	0 – 0.0094	0.0025	yes	0.001	yes	0.0019	yes
dissolved oxygen	6.05 – 7.03	6.8	yes	3.9	**no**	7.29	**no**
Eh	99.3-242.9	141.8	yes	151.0	yes	144.5	yes
iron (total)	not used	0.05		0.09		0.24	
manganese (total)	0.0048 – 0.0172	0.005	yes	0.005	yes	0.010	yes
nitrate (as nitrogen)	4.65 – 5.74	5.68	yes	3.83	**no**	4.03	**no**
pH	7.32 – 7.73	7.62	yes	7.55	yes	7.65	yes
sodium (total)	48.2 – 52.8	52.8	yes	49.6	yes	50.7	yes
sulfate	39.1 – 48.3	43.5	yes	41.1	yes	39.2	yes
uranium (total)	0.0036 – 0.0068	0.0066	yes	0.0066	yes	0.0055	yes
zinc (total)	0 – 0.034	0.046	**no**	0.071	**no**	0.030	yes
zinc (dissolved)	0.003 – 0.014	0.040	**no**	0.037	**no**	0.038	**no**

Table 7: Comparison of mud rotary well median analyte values to target comparison ranges for MW4

Is the median analyte concentration in groundwater sample analyses within 1 standard deviation of the median analyte concentration in groundwater sample analyses from **MW4**?							
Analyte	MW4 target comparison range (i.e., +/- 1 standard deviation) [mg/L except Eh and pH]	**BW1**		**MW2**		**MW3**	
		median value [mg/L except Eh and pH]	comparison result	median value [mg/L except Eh and pH]	comparison result	median value [mg/L except Eh and pH]	comparison result
alkalinity [as $CaCO_3$]	198.1 – 254.6	229	yes	200	yes	191	**no**
ammonia	all analyses below detection limit	all analyses below detection limit	yes	all analyses below detection limit	yes	all analyses below detection limit	yes
cadmium (total)	0 – 0.0019	0.0025	**no**	0.001	yes	0.0019	yes
dissolved oxygen	insufficient data	6.8		3.9		7.29	
Eh	190.4-380.0	141.8	**no**	151.0	**no**	144.5	**no**
iron (total)	0.0042 – 0.276	0.05	yes	0.09	yes	0.24	yes
manganese (total)	0 – 0.056	0.005	yes	0.005	yes	0.010	yes
nitrate (as nitrogen)	1.3 – 2.4	5.68	**no**	3.83	**no**	4.03	**no**
pH	7.01 – 7.45	7.62	**no**	7.55	**no**	7.65	**no**
sodium (total)	40.2 – 66.0	52.8	yes	49.6	yes	50.7	yes
sulfate	32.4 – 44.6	43.5	yes	41.1	yes	39.2	yes
uranium (total)	0.0056 – 0.0067	0.0066	yes	0.0066	yes	0.0055	**no**
zinc (total)	0 – 0.49	0.046	yes	0.071	yes	0.030	yes
zinc (dissolved)	insufficient data	0.040		0.037		0.038	

Table 8: Mud rotary well median analytes exhibiting concentrations outside of target comparison range from MW1 and/or MW4

	Mud rotary well affected					
Analyte	**BW1**	**MW2**	**MW3**	**Issue**	**Failure to MW1?**	**Failure to MW4?**
alkalinity			X	Median value is greater than one standard deviation below the comparative median value	X	X
cadmium (total)	X			Median value is greater than one standard deviation above the comparative median value		X
dissolved oxygen		X	X	Median value is greater than one standard deviation above or below the comparative median value	X	N/A
Eh	X	X	X	Median value is greater than one standard deviation below the comparative median value		X
nitrate		X	X	Median value is greater than one standard deviation above or below the comparative median value	X	X
pH	X	X	X	Median value is greater than one standard deviation above the comparative median value		X
uranium (total)			X	Median value is greater than one standard deviation below the comparative median value		X
zinc (total)	X	X		Median value is greater than one standard deviation above the comparative median value	X	
zinc (dissolved)	X	X	X	Median value is greater than one standard deviation above the comparative median value	X	N/A

Note: N/A means not analyzed.

Table 9: Indicator Constituents of Grout Contamination and Adsorption

Tier 3.1 Indicator Constituents of Grout Contamination

MWL monitoring well	Median sulfate concentration from groundwater sample analyses (mg/L)	Is the median sulfate concentration in groundwater sample analyses less than the maximum regional background sulfate concentration **(*i.e.,*** 124.7 mg/L at 95% confidence level [Moats and Winn, 1995]**)**?	Presence of Grout Indicated?
MW5	54.5	yes	no

MWL monitoring well	Median total calcium concentration from groundwater sample analyses (mg/L)	Is the median total calcium concentration in groundwater sample analyses less than the maximum regional background total calcium concentration (*i.e.*, 105.1 mg/L at 95% confidence level [Moats and Winn, 1995]**)**?	Presence of Grout Indicated?
MW5	79.5	yes	no

MWL monitoring well	Median total aluminum concentration from groundwater sample analyses (mg/L)	Is the median total aluminum concentration in groundwater sample analyses less than the maximum regional background total aluminum concentration? (*i.e.*, 3.6 mg/L [Moats and Winn, 1995]**)**?	Presence of Grout Indicated?
MW5	0.029	yes	no

Table 9 continued

Tier 3.2 Indicators of Adsorption

MWL monitoring well	Median total uranium concentration from groundwater sample analyses (mg/L)	Is the median total uranium concentration in groundwater sample analyses greater than the minimum background total uranium concentration, (*i.e.*, 0.0005 mg/L [IT Corp., 03/1996])?	DB flag?
MW5	0.0094	yes	none

MWL monitoring well	Median total zinc concentration (mg/L)	Is total zinc detected?	DB flag?
MW5	0.0057	yes	none

MWL monitoring well	Median total barium concentration from groundwater sample analyses (mg/L)	Is the median total barium concentration in groundwater sample analyses greater than the minimum background total barium concentration (*i.e.*, <0.100 mg/L [Moats and Winn, 1995])?	DB flag?
MW5	0.134	yes	none

Appendix A: MWL monitoring well groundwater analytical data for wells BW1, MW1, MW3, and MW4

Alkalinity (mg/L)

Date sampled	BW1	MW1	MW2	MW3	MW4
04/26/93			207.7		
04/26/93			200		
04/27/93		215.7			
04/27/93		220			
04/27/93				193.4	
04/27/93				197	
04/28/93	233				
04/28/93	257.3				
04/28/93	291				
04/30/93					231.7
11/08/93			208		
11/09/93		211			
11/09/93				193	
11/10/93	229				
11/11/93					218
10/24/94			185		
10/25/94		207			
10/25/94				177	
10/27/94	217				
10/28/94					234
03/14/95	230				
04/17/95			196		
04/17/95				182	
04/19/95		226			
04/19/95					266
04/19/95					267
10/16/95			199		
10/16/95				191	
10/20/95		234			
10/20/95					257
10/20/95					276
10/23/95	229				
04/15/96			195		
04/15/96				182	
04/16/96	212				
04/16/96					
04/18/96		220			
04/18/96					217
04/13/99	199				
04/05/01					215
04/06/01	233				
04/08/01				194	
04/13/01		198			
04/23/01			209		

Date sampled	BW1	MW1	MW2	MW3	MW4
04/15/02	246				
04/16/02					208
04/16/02					221
04/24/02			201		
04/30/02		191			
05/08/02				212	
04/08/03			204		
04/16/03					238
04/21/03		187			
04/22/03				186	
04/16/04		178			
04/20/04	214				
04/20/04					189
04/22/04				169	
04/26/04			187		
04/15/05	192				
04/19/05					185
count	13	11	11	11	14
Median values	229	211	200	191	226.35
1 STANDARD DEVIATION	26.76115	18.83997	8.43768	12.24745	28.28613
-1 STANDARD DEVIATION	202.2389	192.16	191.5623	178.7526	198.0639
+1 STANDARD DEVIATION	255.7611	229.84	208.4377	203.2474	254.6361

Ammonia (mg/L)

N.B., all analytical results are reported as below detection limit, except sample result for MW4 dated 5/31/94 (1.3 mg/L) which is likely erroneous.

Date sampled	BW1	MW1	MW2	MW3	MW4
11/08/93			0.05		
11/09/93		0.05			
11/09/93				0.05	
11/10/93	0.05				
11/10/93	0.05				
11/11/93					0.05
03/14/94					0.05
05/02/94			0.05		
05/03/94		0.05			
05/03/94				0.05	
05/04/94		0.05			
05/31/94					1.3
10/24/94			0.05		
10/25/94		0.05			
10/25/94		0.05			
10/25/94				0.05	
10/27/94	0.05				
10/27/94	0.05				
10/28/94					0.05
03/14/95	0.1				
10/16/95				0.0085	
10/20/95		0.0085			
10/20/95					0.0085
10/20/95					0.0085
10/23/95	0.009				
04/15/96			0.0085		
04/15/96				0.0085	
04/15/96				0.01	
04/16/96	0.009				
04/18/96		0.0085			
04/18/96					0.0085
04/18/96					0.0085
count	7	7	4	6	8
Median values	0.05	0.05	0.05	0.03	0.02925
1 STANDARD DEVIATION	0.030865	0.02025	0.02075	0.022463	0.450794
-1 STANDARD DEVIATION	0.019135	0.02975	0.02925	0.007537	-0.42154
+1 STANDARD	0.080865	0.07025	0.07075	0.052463	0.480044

Date sampled	BW1	MW1	MW2	MW3	MW4
DEVIATION					

Cadmium (mg/L)

Date sampled	BW1	MW1	MW2	MW3	MW4
09/27/90	0.0025				
09/27/90	0.0025				
09/27/90		0.046			
09/28/90			0.0025		
09/28/90				0.0025	
01/24/91	0.0025				
01/24/91	0.0025				
01/24/91		0.0025			
01/28/91			0.0025		
01/28/91				0.0025	
04/02/91			0.0025		
04/02/91				0.0025	
05/07/91	0.0025				
05/07/91	0.0025				
05/07/91		0.0025			
07/31/91		0.0025			
08/01/91			0.0025		
08/05/91				0.0025	
08/06/91	0.0025				
08/06/91	0.0025				
10/14/91			0.0025		
10/15/91		0.0025			
10/15/91				0.0025	
10/16/91	0.0025				
10/16/91	0.0025				
10/16/91	0.0025				
07/27/92			0.0025		
07/27/92			0.00025		
07/28/92		0.0025			
07/28/92		0.0006			
07/28/92				0.0025	
07/28/92				0.0024	
07/29/92	0.00025				
07/29/92	0.0025				
01/18/93			0.016		
01/19/93		0.0086			
01/19/93				0.029	
01/20/93	0.031				
01/20/93	0.023				
04/26/93			0.0025		
04/26/93			0.0008		
04/27/93		0.0005			
04/27/93		0.00025			
04/27/93				0.0025	

Date sampled	BW1	MW1	MW2	MW3	MW4
04/27/93				0.0014	
04/28/93	0.00025				
04/28/93	0.0025				
04/28/93					0.0025
04/28/93					0.0025
04/28/93					0.0025
11/08/93			0.0025		
11/09/93		0.0025			
11/09/93				0.0025	
11/10/93	0.0025				
11/10/93	0.0025				
11/10/93					0.0025
03/14/94					0.0025
05/02/94			0.0025		
05/02/94				0.0025	
05/03/94		0.0025			
05/04/94		0.0025			
05/31/94					0.0025
10/24/94			0.0025		
10/25/94		0.0025			
10/25/94		0.0025			
10/25/94				0.0025	
10/27/94	0.0025				
10/27/94	0.0025				
10/28/94					0.0025
04/17/95			0.0025		
04/17/95				0.0025	
04/19/95		0.0025			
04/19/95					0.0025
04/19/95					0.0025
10/16/95				0.0002	
10/20/95		0.00013			
10/20/95					0.00093
10/23/95	0.00012				
04/15/96			0.00017		
04/16/96	0.00005				
04/18/96		0.00005			
04/18/96				0.00005	
04/18/96					0.00005
04/28/96	0.00028				
04/23/97		0.00057			
04/23/97					0.00031
04/24/97			0.00065		
04/24/97				0.00046	
10/15/97		0.000105			
10/15/97		0.000105			

Date sampled	BW1	MW1	MW2	MW3	MW4
10/15/97				0.00022	
10/16/97			0.00045		
10/17/97	0.00024				
10/17/97					0.00035
03/31/98	0.0003				
03/31/98	0.00011				
04/01/98		0.000105			
04/01/98					0.0001
04/01/98					0.0001
04/01/98					0.0003
04/02/98			0.00032		
04/02/98			0.00025		
04/02/98				0.00011	
11/05/98	0.00011				
11/06/98		0.00086			
11/06/98			0.00028		
11/06/98				0.00011	
11/06/98					0.00026
11/06/98					0.00011
04/12/99				0.00011	
04/13/99	0.00011				
04/14/99		0.00011			
04/14/99					0.00025
04/19/99			0.00023		
04/06/00	0.00032				
04/07/00					0.00066
04/13/00				0.00064	
04/14/00		0.0012			
04/14/00		0.00032			
04/24/00			0.0011		
04/05/01					0.00033
04/05/01					0.00037
04/06/01	0.00067				
04/08/01				0.00011	
04/13/01		0.00013			
04/23/01			0.0004		
04/15/02	0.000578				
04/16/02					0.000126
04/16/02					0.000126
04/24/02			0.000488		
04/30/02		0.000387			
05/08/02				0.00111	
04/08/03			0.0152		
04/14/03	0.000181				
04/16/03					0.00309
04/16/03					0.00304

Date sampled	BW1	MW1	MW2	MW3	MW4
04/21/03		0.00222			
04/22/03				0.000508	
09/09/03		0.00168			
09/09/03			0.000502		
09/09/03					0.0017
04/16/04		0.000096			
04/20/04	0.000134				
04/20/04					0.000966
04/22/04				0.00036	
04/26/04			0.00013		
04/26/04			0.000143		
count	34	31	28	26	28
Median values	0.0025	0.0012	0.00095	0.0019	0.000795
1 STANDARD DEVIATION	0.006282	0.008165	0.003892	0.005517	0.001146
-1 STANDARD DEVIATION	-0.00378	-0.00696	-0.00294	-0.00362	-0.00035
+1 STANDARD DEVIATION	0.008782	0.009365	0.004842	0.007417	0.001941

Dissolved oxygen (mg/L)

Date sampled	BW1	MW1	MW2	MW3	MW4
04/28/93	6.8				
04/16/03		6.19			
04/20/03	6.16				
04/20/03					2.66
04/22/03				7.29	
04/26/03			3.9		
08/31/04		6.89			
09/01/04	7.99				
count	3	2	1	1	1
Median values	6.8	6.54	3.9	7.29	2.66
1 STANDARD DEVIATION	0.928673	0.494975	----	----	----
-1 STANDARD DEVIATION	5.871327	6.045025	----	----	----
+1 STANDARD DEVIATION	7.728673	7.034975	----	----	----

Eh (mV)

Date Sampled	BW1	MW1	MW2	MW3	MW4
01/18/93			86		
01/19/93		95		131	
01/20/93	109				
04/26/93			135		
04/27/93		162		112	
04/28/93	121				
11/08/93			39		
11/09/93		61		67	
11/10/93	85				
11/11/93					97
03/14/95	113				
04/17/95			279	279	
04/19/95		317			294
04/15/96			105	88	
04/16/96	77				
04/18/96		72			73
04/23/96					351
04/28/96	306				
04/23/97		146			
04/24/97			278	270	
10/15/97		228			317
10/16/97			235	230	
10/17/97	134				
03/31/98	217				
04/01/98		246			239
04/02/98			240	239	
11/05/98	201				
11/06/98		271	151	158	285
01/19/99		102			
01/20/99	120		130	117	
01/21/99					341
04/12/99				130	
04/13/99	168				
04/14/99		125			222
04/19/99			170		
04/06/00	194				
04/07/00					231
04/13/00				186	
04/14/00		224			
04/24/00			169		

Date Sampled	BW1	MW1	MW2	MW3	MW4
10/31/00					250
11/01/00	136				
02/07/01					195
02/09/01					192
04/06/01	200				
04/08/01				225	
04/13/01		180			
04/23/01			110		
11/13/01					301
04/16/02					334
04/24/02			204		
04/30/02		134			
05/08/02				128	
04/08/03			154.7		
04/14/03	123				
04/16/03					104.6
04/21/03		145.8			
04/22/03				253.2	
09/08/03		250.6			
09/09/03			220.8		376
04/16/04		222.9			
04/20/04	313				409.9
04/22/04				214	
04/26/04			144.3		
08/31/04		170.1			
09/01/04	157.3				
11/15/04	254.8				
11/16/04		215.7			
02/16/05	147.6				
02/21/05		172.1			
04/11/05		263.3			
04/12/05			75.6		
04/13/05				56	
04/06/06					290.5
04/10/06			68.3		
04/12/06		75.7			
04/13/06				83.6	
04/18/06	42.8				
count	20	22	19	18	19
Median values	141.8	171.1	151	144.5	285

1 Standard Deviation)	71.9670	71.8301	70.2655	73.1214	94.6265
-1 Standard Deviation	69.8329	99.2698	80.7344	71.3785	190.373
+1 Standard Deviation)	213.767	242.930	221.265	217.621	379.626

Iron (total) (mg/L)

Date sampled	BW1	MW1	MW2	MW3	MW4
01/24/91	0.28				
01/24/91	0.05				
01/24/91	0.05				
01/24/91	0.05				
01/24/91		0.44			
01/24/91		0.05			
01/28/91			0.85		
01/28/91			0.05		
01/28/91				0.05	
01/28/91				0.05	
04/01/91	0.02				
05/02/91			0.2		
05/02/91			0.05		
05/02/91				0.24	
05/02/91				0.05	
05/07/91	0.05				
05/07/91	0.05				
05/07/91	0.1				
05/07/91	0.05				
05/07/91		0.76			
05/07/91		0.05			
07/01/91	0.05				
07/01/91			0.05		
07/01/91				0.25	
07/31/91		0.71			
07/31/91		0.05			
08/01/91			0.085		
08/01/91			0.05		
08/05/91				0.25	
08/05/91				0.1	
08/06/91	0.05				
08/06/91	0.05				
08/06/91	0.05				
08/06/91	0.05				
10/14/91			0.12		
10/14/91			0.05		
10/15/91		0.49			
10/15/91		0.05			
10/15/91				0.14	
10/15/91				0.05	
10/16/91	0.05				
10/16/91	0.05				
10/16/91	0.05				
10/16/91	0.05				

Date sampled	BW1	MW1	MW2	MW3	MW4
07/27/92			0.1		
07/27/92			0.05		
07/28/92		0.19			
07/28/92		0.05			
07/28/92				1.3	
07/28/92				0.05	
07/29/92	0.23				
07/29/92	0.05				
07/29/92	0.05				
07/29/92	0.05				
01/18/93			0.045		
01/19/93				0.37	
01/20/93	0.058				
01/20/93	0.09				
04/26/93			0.05		
04/26/93			0.06		
04/27/93		0.05			
04/27/93		0.05			
04/27/93		0.118			
04/27/93				0.38	
04/27/93				0.315	
04/27/93				0.033	
04/28/93	0.121				
04/28/93	0.055				
04/28/93	0.15				
04/28/93					0.14
04/28/93					0.12
04/30/93					0.21
04/30/93					0.05
11/08/93			0.05		
11/09/93		0.22			
11/09/93				0.12	
11/10/93	0.054				
11/10/93	0.041				
11/11/93					0.1
03/14/94					0.1
05/02/94			0.048		
05/03/94		0.11			
05/03/94				0.25	
05/04/94		0.048			
05/31/94					0.036
10/24/94			0.05		
10/25/94		0.058			
10/25/94		0.05			
10/25/94				0.078	
10/27/94	0.057				

Date sampled	BW1	MW1	MW2	MW3	MW4
10/28/94					0.15
03/14/95	0.07				
04/17/95			0.024		
04/17/95				0.071	
04/19/95		0.094			
04/19/95					0.07
04/19/95					0.098
10/16/95				0.266	
10/20/95		0.565			
10/20/95					0.0134
10/20/95					0.0161
10/23/95	0.321				
04/15/96			0.273		
04/15/96				0.0608	
04/15/96				0.0608	
04/16/96	0.0462				
04/18/96		0.0051			
04/18/96		0.272			
04/18/96					0.011
04/18/96					0.0051
08/27/98		0.26			
08/27/98		1.8			
04/12/99				0.0993	
04/13/99	0.0967				
04/14/99		0.583			
04/14/99					0.0917
04/19/99			0.18		
04/19/99			0.0906		
04/14/00		0.96			
04/05/01					0.486
04/05/01					0.304
04/06/01	1.82				
04/08/01				0.248	
04/13/01		0.409			
04/23/01			0.169		
04/15/02	0.0304				
04/16/02					0.199
04/16/02					0.248
04/24/02			0.357		
04/30/02		0.272			
05/08/02				0.731	
04/08/03			0.31		
04/08/03			0.399		
04/14/03	0.115				
04/16/03					0.299
04/16/03					0.303

Date sampled	BW1	MW1	MW2	MW3	MW4
04/21/03		0.464			
04/22/03				0.669	
04/16/04		0.886			
04/20/04	0.271				
04/20/04					0.206
04/22/04				1.1	
04/26/04			0.21		
04/26/04			0.204		
04/11/05		0.697			
04/11/05		0.135			
04/12/05			0.235		
04/13/05				0.473	
04/15/05	0.2				
04/19/05					0.303
04/19/05					0.318
04/06/06					0.441
04/10/06			0.377		
04/12/06		1.67			
04/12/06		1.64			
04/13/06				0.422	
04/18/06	0.361				
count	40	34	29	29	25
Median values	0.05	0.24	0.0906	0.24	0.14
1 Standard deviation	0.285691	0.488327	0.173678	0.314261	0.135825
-1 STANDARD DEVIATION	-0.23569	-0.24833	-0.08308	-0.07426	0.004175
+1 STANDARD DEVIATION	0.335691	0.728327	0.264278	0.554261	0.275825

Manganese (total) (mg/L)

Date sampled	BW1	MW1	MW2	MW3	MW4
01/24/91	0.005				
01/24/91		0.019			
01/28/91			0.016		
01/28/91				0.005	
05/02/91			0.005		
05/02/91				0.005	
05/07/91	0.005				
05/07/91	0.005				
05/07/91		0.015			
07/01/91	0.005				
07/01/91			0.005		
07/01/91				0.005	
07/31/91		0.019			
08/01/91			0.005		
08/05/91				0.005	
08/06/91	0.005				
08/06/91	0.005				
10/14/91			0.005		
10/15/91		0.017			
10/15/91				0.005	
10/16/91	0.005				
10/16/91	0.005				
07/27/92			0.005		
07/28/92		0.005			
07/28/92				0.005	
07/29/92	0.005				
07/29/92	0.005				
01/18/93			0.005		
01/19/93		0.011			
01/19/93				0.005	
01/20/93	0.005				
01/20/93	0.005				
04/26/93			0.005		
04/26/93			0.005		
04/27/93		0.0095			
04/27/93				0.047	
04/27/93				0.056	
04/27/93				0.056	
04/28/93	0.005				
04/28/93	0.0098				
04/30/93					0.16
11/08/93			0.005		
11/09/93		0.005			
11/09/93				0.0043	

Date sampled	BW1	MW1	MW2	MW3	MW4
11/10/93	0.005				
11/10/93	0.005				
11/11/93					0.04
05/02/94			0.0089		
05/03/94		0.012			
05/03/94				0.012	
05/04/94		0.0078			
05/31/94					0.094
10/24/94			0.005		
10/25/94		0.011			
10/25/94				0.021	
10/27/94	0.005				
10/27/94	0.005				
10/28/94					0.045
04/17/95			0.0025		
04/17/95				0.0025	
04/19/95		0.0025			
04/19/95					0.028
04/19/95					0.027
10/16/95			0.00787		
10/16/95				0.013	
10/20/95		0.0128			
10/20/95					0.0284
10/20/95					0.0295
10/23/95	0.00955				
04/15/96			0.0121		
04/15/96				0.00341	
04/16/96	0.0019				
04/18/96		0.0109			
04/18/96					0.0166
04/18/96					0.016
04/12/99				0.0228	
04/13/99	0.00238				
04/14/99		0.00793			
04/14/99					0.00959
04/19/99			0.00802		
04/06/00	0.0324				
04/05/01					0.0198
04/05/01					0.0179
04/08/01				0.00983	
04/13/01		0.00655			
04/23/01			0.00197		
04/15/02	0.00535				
04/16/02					0.022
04/16/02					0.0212
04/24/02			0.00197		

Date sampled	BW1	MW1	MW2	MW3	MW4
04/30/02		0.00646			
05/08/02				0.00429	
04/08/03			0.00183		
04/08/03			0.00223		
04/14/03	0.00081				
04/16/03					0.00589
04/16/03					0.00609
04/21/03		0.00599			
04/22/03				0.0105	
04/16/04		0.0172			
04/20/04	0.00479				
04/20/04					0.00187
04/22/04				0.0157	
04/26/04			0.00278		
04/26/04			0.00279		
04/11/05		0.019			
04/12/05			0.0005		
04/12/05			0.00415		
04/13/05				0.0259	
04/15/05	0.00282				
04/19/05					0.00457
04/19/05					0.00483
04/06/06					0.00844
04/10/06			0.00551		
04/12/06		0.0236			
04/12/06		0.0232			
04/13/06				0.0771	
04/18/06	0.0054				
count	27	22	25	23	21
Median values	0.005	0.011	0.005	0.00983	0.0198
1 STANDARD DEVIATION	0.005582	0.0062	0.003395	0.020799	0.036183
-1 STANDARD DEVIATION	-0.00058	0.0048	0.001605	-0.01097	-0.01638
+1 STANDARD DEVIATION	0.010582	0.0172	0.008395	0.030629	0.055983

Nickel (total) (mg/L)

Date sampled	BW1	MW1	MW2	MW3	MW4
09/27/90	0.02				
09/27/90	0.02				
09/27/90		0.046			
09/28/90			0.02		
09/28/90				0.02	
07/17/92	0.025				
07/17/92			0.025		
07/27/92			0.01		
07/28/92		0.15			
07/28/92		0.162			
07/28/92				0.066	
07/28/92				0.07	
07/29/92	0.01				
07/29/92	0.02				
01/18/93			0.02		
01/19/93		0.078			
01/19/93				0.026	
01/20/93	0.02				
01/20/93	0.02				
04/26/93			0.014		
04/26/93			0.01		
04/27/93		0.097			
04/27/93		0.057			
04/27/93				0.037	
04/27/93				0.035	
04/28/93	0.01				
04/28/93	0.012				
04/28/93	0.0075				
04/28/93					0.016
04/28/93					0.02
11/08/93			0.02		
11/09/93		0.095			
11/09/93				0.014	
11/10/93	0.02				
11/10/93	0.02				
11/10/93					0.02
03/14/94					0.02
05/02/94			0.02		
05/02/94				0.011	
05/03/94		0.15			
05/04/94		0.13			
05/31/94					0.02
10/24/94			0.02		

Date sampled	BW1	MW1	MW2	MW3	MW4
10/25/94		0.1			
10/25/94		0.13			
10/25/94				0.0098	
10/27/94	0.02				
10/27/94	0.02				
10/28/94					0.0082
04/17/95			0.0075		
04/17/95				0.0093	
04/19/95		0.12			
04/19/95					0.02
04/19/95					0.0082
10/16/95				0.00799	
10/20/95		0.107			
10/20/95					0.00307
10/23/95	0.00196				
04/15/96			0.00342		
04/16/96	0.0004				
04/18/96		0.145			
04/18/96				0.00367	
04/18/96					0.004
04/18/96					0.004
10/15/97				0.0362	
03/31/98	0.0029				
03/31/98	0.00114				
04/01/98		0.5			
04/01/98					0.00114
04/01/98					0.00114
04/01/98					0.0008
04/02/98			0.00351		
04/02/98			0.005		
04/02/98				0.018	
11/05/98	0.00719				
11/06/98		0.49			
11/06/98			0.00449		
11/06/98				0.031	
11/06/98					0.00189
11/06/98					0.00159
04/12/99				0.0251	
04/13/99	0.0128				
04/14/99		0.266			
04/14/99					0.00093
04/19/99			0.00531		
04/06/00	0.0165				
04/07/00					0.00155
04/13/00				0.0141	
04/14/00		0.279			

Date sampled	BW1	MW1	MW2	MW3	MW4
04/14/00		0.228			
04/24/00			0.124		
04/05/01					0.00355
04/05/01					0.00355
04/06/01	0.191				
04/13/01		0.252			
04/23/01			0.0882		
04/15/02	0.0136				
04/16/02					0.00172
04/16/02					0.00115
04/24/02			0.0897		
04/30/02		0.265			
05/08/02				0.0961	
04/08/03			0.0512		
04/08/03			0.0529		
04/14/03	0.0266				
04/21/03		0.374			
04/16/04		0.401			
04/20/04	0.0332				
04/20/04					0.0159
04/22/04				0.056	
04/26/04			0.0105		
04/26/04			0.0106		
04/12/05			0.00802		
04/13/05				0.0173	
count	25	23	23	20	23
Median values	0.02	0.15	0.014	0.02255	0.00355

Nitrate (as nitrogen) (mg/L)

Date sampled	BW1	MW1	MW2	MW3	MW4
10/14/91			5.1		
10/15/91		5.5			
10/15/91				4.3	
10/16/91	5.6				
10/16/91	5.6				
07/29/92	5.4				
04/26/93			4.6		
04/26/93			4.5		
04/27/93		5.5			
04/27/93		5.0			
04/27/93				4	
04/27/93				3.7	
04/28/93	5.7				
04/28/93	5.4				
11/08/93			4.9		
11/09/93		5.4			
11/09/93				4.2	
11/10/93	5.9				
11/10/93	5.8				
11/11/93					1.9
03/14/94					1.5
05/02/94			4.70		
05/03/94		5.0			
05/03/94				3.9	
05/04/94		5.2			
05/31/94					1.2
10/24/94			4.90		
10/25/94		5.2			
10/25/94		5.2			
10/25/94				4.3	
10/27/94	5.6				
10/27/94	5.7				
10/28/94					0.6
10/31/94	5.7				
04/17/95			5.00		
04/17/95				4.7	
04/19/95		5.5			
04/19/95					0.14
04/19/95					0.15
04/15/96			4.65		
04/15/96				4.05	
04/15/96				4.05	
04/16/96	5.65				
04/18/96		5.2			

Date sampled	BW1	MW1	MW2	MW3	MW4
04/18/96					1.89
04/18/96					1.92
04/28/96	5				
04/23/97		5.2			
04/23/97					1.2
04/24/97			3.70		
04/24/97				2.8	
10/15/97		4.9			
10/15/97		5.1			
10/15/97					1.81
10/16/97			3.93		
10/16/97				4.05	
10/17/97	5.75				
03/31/98	6.08				
04/01/98		5.4			
04/01/98					1.71
04/01/98					1.92
04/02/98			3.44		
04/02/98				3.56	
11/05/98	5.36				
11/06/98		5.4			
11/06/98			4.00		
11/06/98				4.4	
11/06/98					2
11/06/98					2.05
11/06/98					2.05
04/12/99				4.08	
04/13/99	6.15				
04/14/99		5.2			
04/14/99					1.9
04/19/99			3.72		
04/06/00	5.55				
04/07/00					2
04/13/00				4.15	
04/14/00		4.5			
04/14/00		4.4			
04/24/00			3.45		
04/05/01					1.59
04/05/01					1.61
04/06/01	6.75				
04/08/01				2.59	
04/13/01		3.0			
04/23/01			3.35		
04/15/02	5				
04/16/02					1.85
04/16/02					1.75

Date sampled	BW1	MW1	MW2	MW3	MW4
04/24/02			2.20		
04/30/02		4.8			
05/08/02				3.75	
04/08/03			2.58		
04/14/03	5.7				
04/16/03					1.63
04/16/03					1.75
04/21/03		4.7			
04/22/03				3.7	
04/16/04		5.2			
04/20/04	5.9				
04/20/04					1.85
04/22/04				2.25	
04/26/04			2.75		
04/26/04			1.58		
04/12/05			1.83		
04/13/05				3.25	
04/15/05	2.82				
04/19/05					1.94
04/19/05					1.94
count	22	22	20	20	26
Median values	5.675	5.195	3.825	4.025	1.83
1 STANDARD DEVIATION	0.712971	0.547111	1.091544	0.628916	0.537181
-1 STANDARD DEVIATION	4.962029	4.647889	2.733456	3.396084	1.292819
+1 STANDARD DEVIATION	6.387971	5.742111	4.916544	4.653916	2.367181

pH

Date sampled	BW1	MW1	MW2	MW3	MW4
09/27/90	7.67				
09/27/90		7.49			
09/28/90			6.91		
09/28/90				7.59	
01/24/91	7.57				
01/24/91		7.46			
01/28/91			7.15		
01/28/91				7.9	
05/02/91			7.47		
05/02/91				7.46	
05/07/91		7.26			
07/31/91		7.34			
08/01/91			7.74		
08/05/91				7.51	
08/06/91	7.34				
10/14/91			7.84		
10/15/91		7.43			
10/15/91				7.57	
10/16/91	7.4				
01/13/92			8.05		
01/14/92				7.79	
01/15/92	7.65				
07/27/92			7.65		
07/28/92		7.33			
07/28/92				7.68	
07/29/92	7.45				
01/18/93			7.44		
01/19/93		7.45			
01/19/93				7.68	
01/20/93	7.52				
04/26/93			7.63		
04/27/93		7.6			
04/27/93				7.8	
04/28/93	7.62				
04/28/93	7.56				
04/28/93					7.23
11/08/93			7.36		
11/09/93		7.19			
11/09/93				5.58	
11/10/93	7.46				
11/11/93					7.16
04/28/94	7.75				
05/02/94			7.67		
05/03/94		7.67			

Date sampled	BW1	MW1	MW2	MW3	MW4
05/03/94				8.06	
05/04/94		7.59			
10/24/94			7.68		
10/25/94				7.69	
10/27/94	7.57				
10/28/94					7.25
03/14/95	7.63				
04/17/95			7.97		
04/17/95				7.88	
04/19/95		7.35			
04/19/95					7.21
10/16/95			7.6		
10/16/95				7.44	
10/20/95		7.54			
10/20/95					7.11
10/23/95	7.76				
04/15/96			7.39		
04/15/96				7.65	
04/16/96	7.53				
04/18/96		7.51			
04/18/96					7.23
04/18/96					7.09
04/28/96	7.66				
04/23/97		7.35			
04/24/97			7.46		
04/24/97				7.79	
10/15/97		7.45			
10/15/97					7.21
10/16/97			7.36		
10/16/97				7.57	
10/17/97	7.62				
03/31/98	7.43				
04/01/98		7.37			
04/01/98					6.92
04/02/98			7.16		
04/02/98				7.37	
11/05/98	7.62				
11/06/98		7.46			
11/06/98			7.04		
11/06/98				7.58	
11/06/98					7.11
01/20/99	8.17				
01/20/99			7.64		
01/20/99				7.81	
01/21/99					6.97
04/12/99				7.64	

Date sampled	BW1	MW1	MW2	MW3	MW4
04/13/99	7.68				
04/14/99		7.36			
04/14/99					7.3
04/19/99			7.49		
04/06/00	8.06				
04/07/00					7.23
04/13/00				7.72	
04/14/00		7.57			
04/14/00		7.57			
04/24/00			7.44		
10/31/00					7.29
11/01/00	7.4				
02/07/01					6.96
02/09/01					7.1
04/05/01					7.3
04/06/01	7.49				
04/08/01				7.57	
04/13/01		7.34			
04/23/01			7.35		
11/13/01					7.24
04/15/02	7.68				
04/16/02					7.2
04/24/02			7.44		
04/30/02		7.63			
05/08/02				7.87	
04/08/03			7.52		
04/14/03	7.98				
04/16/03		7.83			7.5
04/16/03					7.5
04/20/03					7.88
04/21/03		7.73			
04/22/03				7.4	
04/22/03				7.89	
04/26/03			7.93		
09/08/03		7.8			
09/09/03			7.57		
09/09/03					7.7
04/16/04		7.83			
04/20/04	8.06				
04/26/04			7.73		
08/31/04		8.19			
09/01/04	7.81				
11/15/04	8.02				
11/16/04		7.73			
02/16/05	8.21				
02/21/05		7.65			

Date sampled	BW1	MW1	MW2	MW3	MW4
04/11/05		7.75			
04/12/05			7.85		
04/13/05				7.1	
04/15/05	7.51				
04/19/05					7.07
04/06/06					7.39
04/10/06			7.78		
04/12/06		7.64			
04/13/06				7.56	
04/18/06	7.24				
count	32	32	30	28	25
Median values	7.62	7.525	7.545	7.645	7.23
1 STANDARD DEVIATION	0.242766	0.207255	0.269015	0.438812	0.219507
-1 STANDARD DEVIATION	7.377234	7.317745	7.275985	7.206188	7.010493
+1 STANDARD DEVIATION	7.862766	7.732255	7.814015	8.083812	7.449507

Sodium (total) (mg/L)

Date sampled	BW1	MW1	MW2	MW3	MW4
01/24/91		50.2			
01/28/91			56.5		
01/28/91				55.4	
04/01/91	51				
04/01/91		50.3			
04/02/91			55.4		
04/02/91				55.3	
10/14/91			55.1		
10/15/91		50.7			
10/15/91				55.9	
10/16/91	57				
01/15/92	49.1				
04/26/93			45.7		
04/26/93			55.4		
04/27/93		45.7			
04/27/93		52.8			
04/27/93				45.7	
04/27/93				55.5	
04/28/93	54.7				
04/28/93	46.9				
04/28/93	47.4				
04/30/93					46.9
11/08/93			55.4		
11/09/93		50.9			
11/09/93				51.5	
11/10/93	56				
11/11/93					46.2
10/24/94			53.9		
10/25/94		53.6			
10/25/94				53.2	
10/27/94	56.9				
10/28/94					67.1
03/14/95	51				
04/17/95			46.8		
04/17/95				49.9	
04/19/95		52.1			
04/19/95					80.7
04/19/95					75.9
10/16/95			47.9		
10/16/95				49.2	
10/20/95		52.2			
10/20/95					76.6
10/20/95					78.5

Date sampled	BW1	MW1	MW2	MW3	MW4
10/23/95	56.6				
04/15/96			49.5		
04/15/96				50.8	
04/16/96	55.5				
04/18/96		49.4			
04/18/96					53.1
04/05/01					49.9
04/05/01					48.9
04/06/01	52.5				
04/08/01				47.1	
04/13/01		50.1			
04/23/01			49.6		
04/15/02	54.2				
04/16/02					49.1
04/16/02					48.9
04/24/02			52.7		
04/30/02		53.0			
05/08/02				50.6	
04/08/03			49.4		
04/08/03			54.8		
04/14/03	52				
04/16/03					56.9
04/16/03					56
04/21/03		49.8			
04/22/03				50.7	
04/16/04		46.7			
04/20/04	52.8				
04/20/04					49.7
04/22/04				45.5	
04/26/04			46.9		
04/26/04			46.8		
04/12/05			47.9		
04/13/05				47.2	
count	15	14	17	15	15
Median values	52.8	50.5	49.6	50.7	53.1
1 STANDARD DEVIATION	3.345459	2.257503	3.845624	3.583494	12.93361
-1 STANDARD DEVIATION	49.45454	48.2425	45.75438	47.11651	40.16639
+1 STANDARD DEVIATION	56.14546	52.7575	53.44562	54.28349	66.03361

Sulfate (mg/L)

Date sampled	BW1	MW1	MW2	MW3	MW4
09/27/90	45.1				
09/27/90	43.9				
09/27/90		43.1			
09/28/90			44.7		
09/28/90				44.1	
01/24/91	41.7				
01/24/91	43.4				
01/24/91		42.3			
01/28/91			41.3		
01/28/91				41.1	
04/01/91	43.2				
05/02/91			45.2		
05/02/91				42.7	
05/07/91	42.6				
05/07/91	42.8				
05/07/91		42.4			
07/31/91		41.0			
08/01/91			41.2		
08/05/91				38.6	
08/06/91	43.3				
08/06/91	44.3				
10/14/91			42.7		
10/15/91		43.1			
10/15/91				40.0	
10/16/91	44.8				
10/16/91	44.6				
01/15/92	58.9				
07/27/92			38.4		
07/28/92		40.6			
07/28/92				37.5	
07/29/92	42.8				
07/29/92	42.5				
01/18/93			22.5		
01/19/93		22.9			
01/19/93				21.1	
01/20/93	23.9				
01/20/93	23.8				
04/26/93			47.3		
04/26/93			39		
04/27/93		43.7			
04/27/93		43.0			
04/27/93				39.7	
04/27/93				39.0	

Date sampled	BW1	MW1	MW2	MW3	MW4
04/28/93	43				
04/28/93	46.7				
04/28/93	46.7				
04/28/93					46.7
04/30/93					38.7
11/08/93			40.5		
11/09/93		41.9			
11/09/93				38.3	
11/10/93	43.5				
11/10/93	43.6				
11/11/93					34.8
03/14/94					49.6
05/02/94			40.5		
05/03/94				38.0	
05/04/94		43.7			
05/31/94					34.2
10/24/94			42.9		
10/25/94		45.4			
10/25/94		46.0			
10/25/94				40.5	
10/27/94	42.5				
10/27/94	42.7				
10/28/94					43.9
03/14/95	52				
04/17/95			42.4		
04/17/95				41.0	
04/19/95		44.4			
04/19/95					49.8
04/19/95					49.7
10/16/95			41.3		
10/16/95				39.1	
10/20/95		46.6			
10/20/95					52.2
10/20/95					52
10/23/95	46.9				
04/15/96			41.2		
04/15/96				39.3	
04/15/96				39.3	
04/16/96	42.7				
04/18/96		44.4			
04/18/96					35.5
04/18/96					35.7
04/05/01					37.1
04/05/01					37.1
04/06/01	44				
04/08/01				36.3	

Date sampled	BW1	MW1	MW2	MW3	MW4
04/13/01		44.3			
04/23/01			44.3		
04/15/02	47.1				
04/16/02					38.3
04/16/02					38.2
04/24/02			40.9		
04/30/02		45.6			
05/08/02				38.4	
04/08/03			41		
04/14/03	44.7				
04/16/03					41.5
04/16/03					42.5
04/21/03		44.9			
04/22/03				40.4	
04/16/04		45.0			
04/20/04	43.9				
04/20/04					42.4
04/22/04				36.9	
04/26/04			37.3		
04/26/04			37.5		
04/11/05		41.9			
04/12/05			33.7		
04/13/05				37.4	
04/15/05	42.2				
04/19/05					36.7
04/19/05					36.6
04/06/06					35.5
04/10/06			38.6		
04/12/06		43.6			
04/12/06		44.2			
04/13/06				39.2	
04/18/06	42.2				
count	32	23	22	22	22
Median values	43.45	43.7	41.1	39.15	38.5
1 STANDARD DEVIATION	6.079407	4.604608	4.95244	4.300239	6.089841
-1 STANDARD DEVIATION	37.37059	39.09539	36.14756	34.84976	32.41016
+1 STANDARD DEVIATION	49.52941	48.30461	46.05244	43.45024	44.58984

Uranium (total) (ug/L)

Date sampled	BW1	MW1	MW2	MW3	MW4
10/24/94			7.84		
10/25/94		1.34			
10/25/94		5.48			
10/25/94				4.82	
10/27/94	5.09				
04/17/95			6.64		
04/17/95				5.49	
04/19/95					6.17
04/19/95					6.5
04/05/01					5.37
04/05/01					5.53
04/06/01	5.9				
04/08/01				4.61	
04/13/01		5.27			
04/15/02	6.63				
04/16/02					6.24
04/16/02					6.19
04/24/02			6.72		
04/30/02		5.09			
05/08/02				5.68	
04/08/03			6.48		
04/08/03			6.78		
04/14/03	6.61				
04/16/03					6.45
04/16/03					6.52
04/21/03		5.12			
04/22/03				5.86	
04/16/04		5.45			
04/20/04	7.19				
04/20/04					5.12
04/22/04				5.55	
04/26/04			6.07		
04/26/04			6.2		
04/12/05			6.54		
04/13/05				5.14	
count	5	6	8	7	9
Median values	6.61	5.195	6.59	5.49	6.19
1 STANDARD DEVIATION	0.809308	1.617415	0.536828	0.463383	0.528772
-1 STANDARD DEVIATION	5.800692	3.577585	6.053172	5.026617	5.661228

Date sampled	BW1	MW1	MW2	MW3	MW4
+1 STANDARD DEVIATION	7.419308	6.812415	7.126828	5.953383	6.718772

Zinc (total) (mg/L)

Date sampled	BW1	MW1	MW2	MW3	MW4
09/27/90	0.096				
09/27/90	0.074				
09/27/90	0.097				
09/27/90	0.086				
09/28/90			0.18		
09/28/90			0.094		
09/28/90				0.029	
09/28/90				0.01	
07/27/92			0.094		
07/27/92			0.01		
07/27/92			0.105		
07/28/92		0.021			
07/28/92		0.01			
07/28/92		0.018			
07/28/92				0.06	
07/28/92				0.01	
07/28/92				0.071	
07/29/92	0.055				
07/29/92	0.01				
07/29/92	0.041				
07/29/92	0.01				
07/29/92	0.062				
01/18/93			0.075		
01/18/93			0.069		
01/19/93		0.01			
01/19/93				0.074	
01/20/93	0.11				
01/20/93	0.12				
04/26/93			0.01		
04/26/93			0.069		
04/26/93			0.073		
04/27/93		0.011			
04/27/93		0.0089			
04/27/93		0.038			
04/27/93				0.03	
04/27/93				0.036	
04/27/93				0.014	
04/28/93	0.036				
04/28/93	0.033				
04/28/93	0.045				
04/28/93					0.086
04/28/93					0.031
04/30/93					0.012

Date sampled	BW1	MW1	MW2	MW3	MW4
04/30/93					0.01
11/08/93			0.054		
11/09/93		0.016			
11/09/93				0.03	
11/10/93	0.048				
11/10/93	0.04				
11/11/93					0.0057
03/14/94					2.1
05/02/94			0.098		
05/03/94		0.017			
05/03/94				0.019	
05/04/94		0.016			
05/31/94					0.14
10/24/94			0.068		
10/25/94		0.028			
10/25/94		0.024			
10/25/94				0.043	
10/27/94	0.037				
10/28/94					0.07
03/14/95	0.04				
04/17/95			0.014		
04/17/95				0.0068	
04/19/95		0.0044			
04/19/95					0.07
04/19/95					0.069
10/16/95				0.018	
10/20/95		0.00673			
10/20/95					0.0597
10/20/95					0.0618
10/23/95	0.0636				
04/15/96			0.104		
04/15/96				0.011	
04/15/96				0.011	
04/16/96	0.0197				
04/18/96		0.00636			
04/18/96					0.0172
04/18/96					0.0179
08/27/98		0.023			
08/27/98		0.023			
04/12/99				0.0809	
04/13/99	0.0241				
04/14/99		0.00394			
04/14/99		0.00394			
04/14/99					0.507
04/19/99			0.0833		
04/14/00		0.023			

Date sampled	BW1	MW1	MW2	MW3	MW4
04/05/01					0.452
04/05/01					0.441
04/06/01	0.255				
04/08/01				0.0195	
04/13/01		0.0257			
04/23/01			0.0224		
04/15/02	0.214				
04/16/02					0.118
04/16/02					0.0969
04/24/02			0.0798		
04/30/02		0.0587			
05/08/02				0.25	
04/08/03			0.167		
04/08/03			0.159		
04/14/03	0.035				
04/16/03					0.0704
04/16/03					0.0705
04/21/03		0.0922			
04/22/03				0.02	
04/16/04		0.017			
04/20/04	0.0551				
04/20/04					0.0258
04/22/04				0.0576	
04/26/04			0.019		
04/26/04			0.0214		
04/11/05		0.0127			
04/11/05		0.0111			
04/12/05			0.0245		
04/13/05				0.0484	
04/15/05	0.0222				
04/19/05					0.023
04/19/05					0.0225
04/06/06					0.0197
04/10/06			0.0286		
04/12/06		0.0111			
04/12/06		0.0105			
04/13/06				0.126	
04/18/06	0.0455				
count	27	28	24	23	25
Median values	0.0455	0.016	0.071	0.03	0.069
1 STANDARD DEVIATION	0.056875	0.018312	0.049163	0.053245	0.423607
-1 STANDARD	-0.01138	-0.00231	0.021837	-0.02324	-0.35461

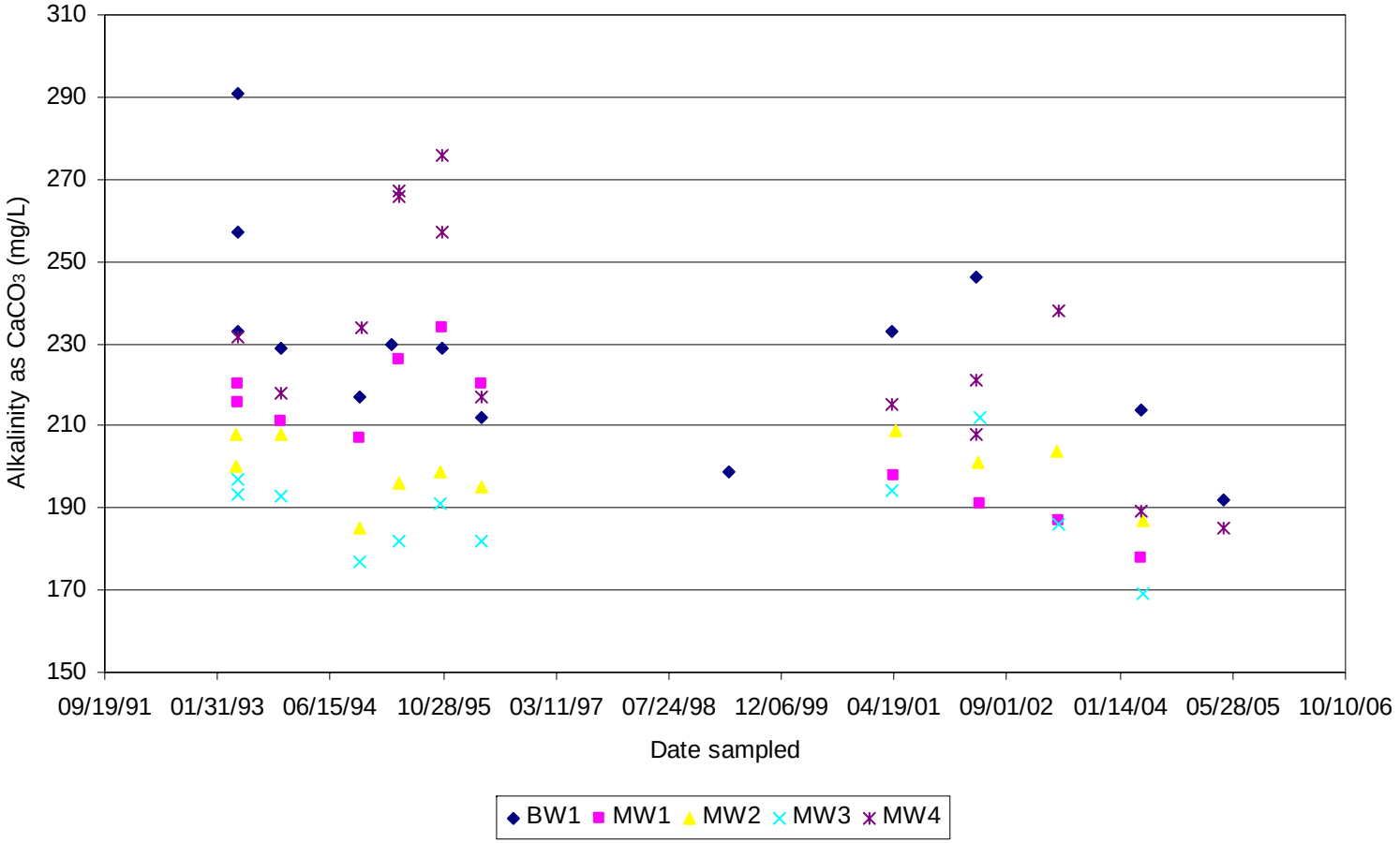
Date sampled	BW1	MW1	MW2	MW3	MW4
DEVIATION					
+1 STANDARD DEVIATION	0.102375	0.034312	0.120163	0.083245	0.492607

Zinc (dissolved) (mg/L)

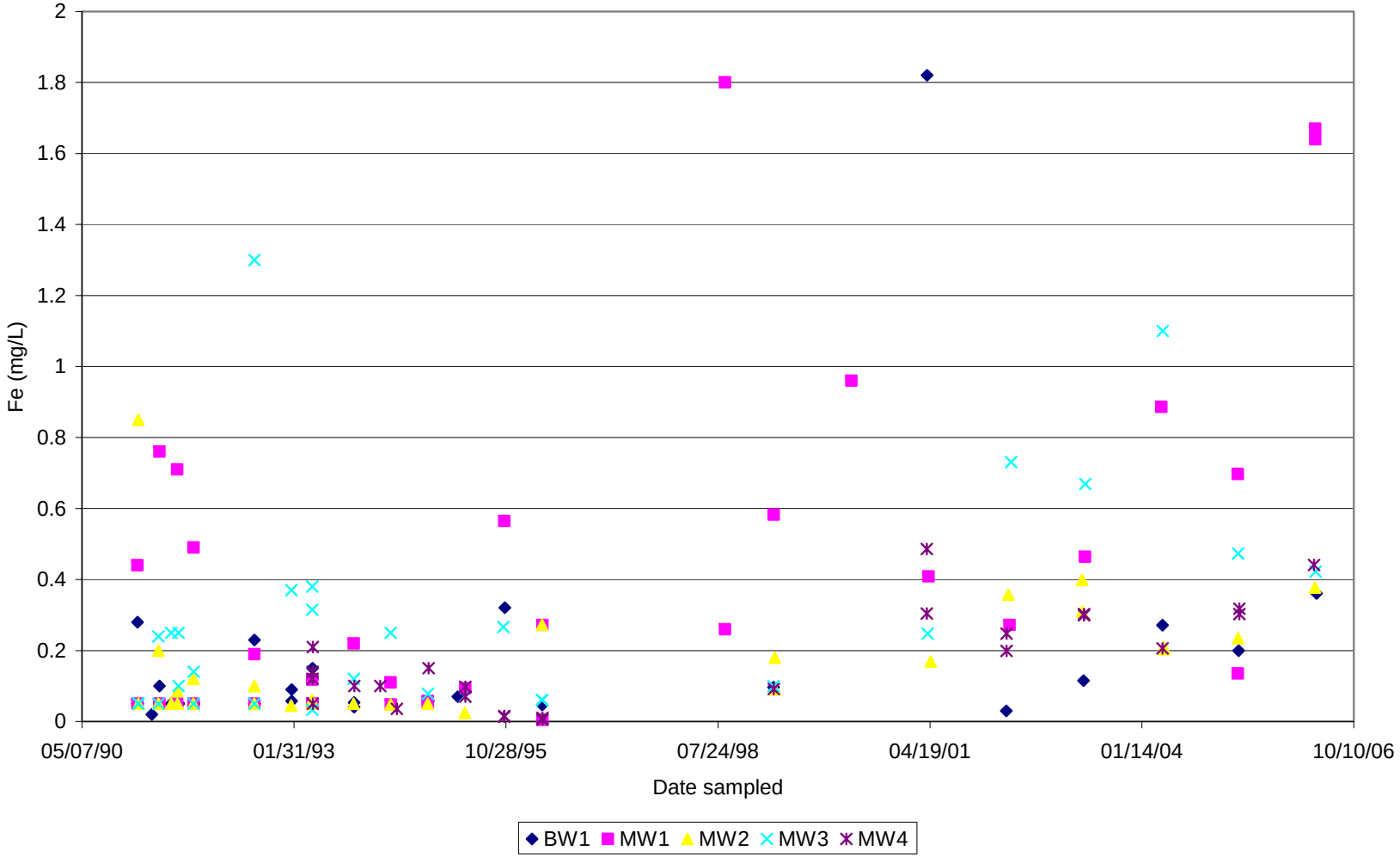
Date sampled	BW1	MW1	MW2	MW3	MW4
01/19/93		0.01			
01/20/93	0.11				
01/20/93	0.12				
04/28/93	0.012				
11/09/93		0.016			
11/10/93	0.048				
11/10/93	0.04				
05/03/94		0.017			
05/04/94		0.016			
10/27/94	0.037				
03/14/95	0.04				
04/19/95		0.0044			
10/20/95		0.00673			
10/23/95	0.0636				
04/16/96	0.0197				
04/18/96		0.00636			
04/12/99				0.0687	
04/13/99	0.015				
04/14/99					0.461
04/19/99			0.0657		
04/11/05		0.00513			
04/12/05			0.00886		
04/13/05				0.00658	
count	10	8	2	2	1
Median values	0.04	0.008365	0.03728	0.03764	0.461
1 STANDARD DEVIATION	0.037479	0.005341	0.040192	0.043925	----
-1 STANDARD DEVIATION	0.002521	0.003024	-0.00291	-0.00629	----
+1 STANDARD DEVIATION	0.077479	0.013706	0.077472	0.081565	----

Appendix B: time-series analytical data plots

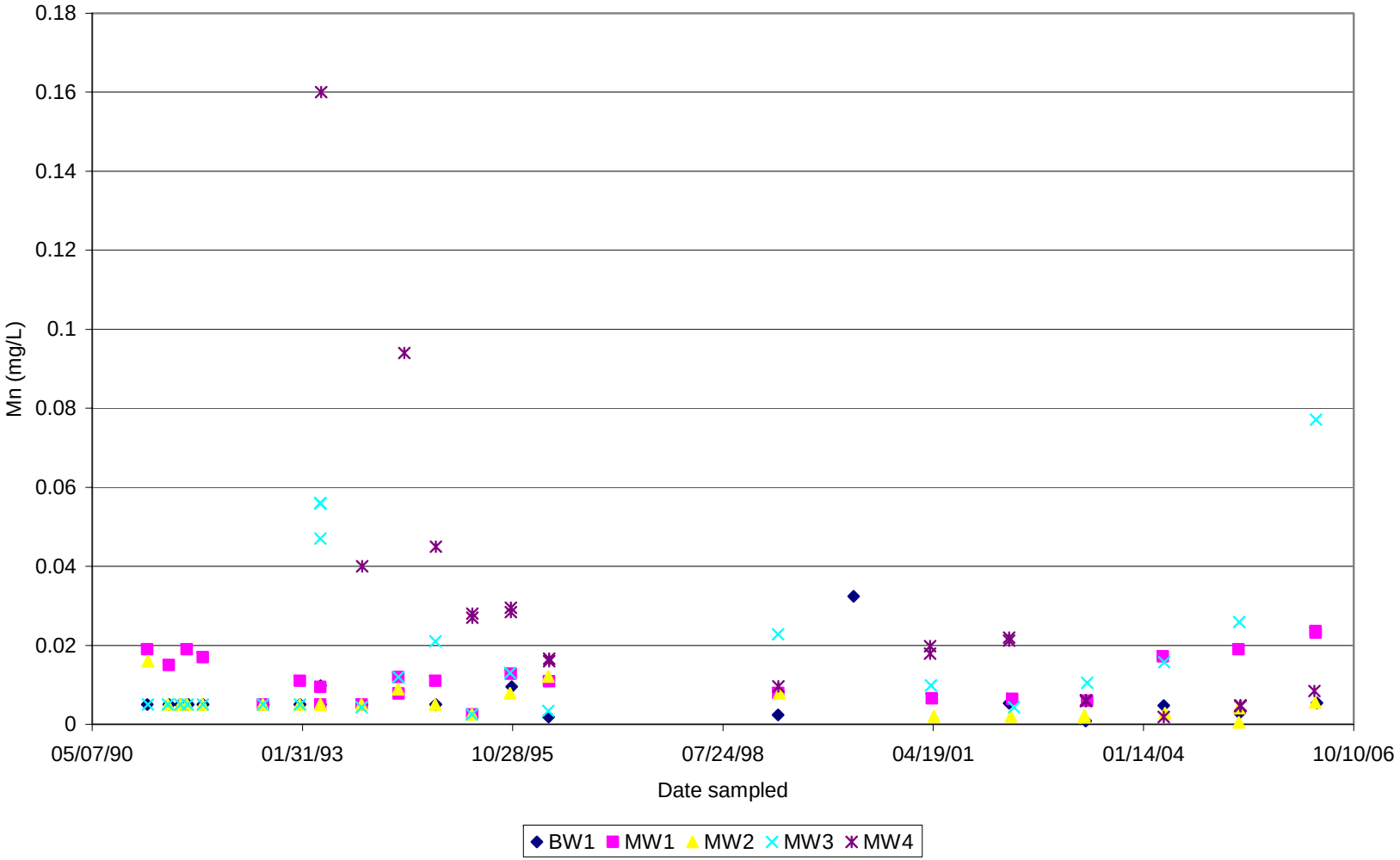
MWL--Alkalinity as $CaCO_3$



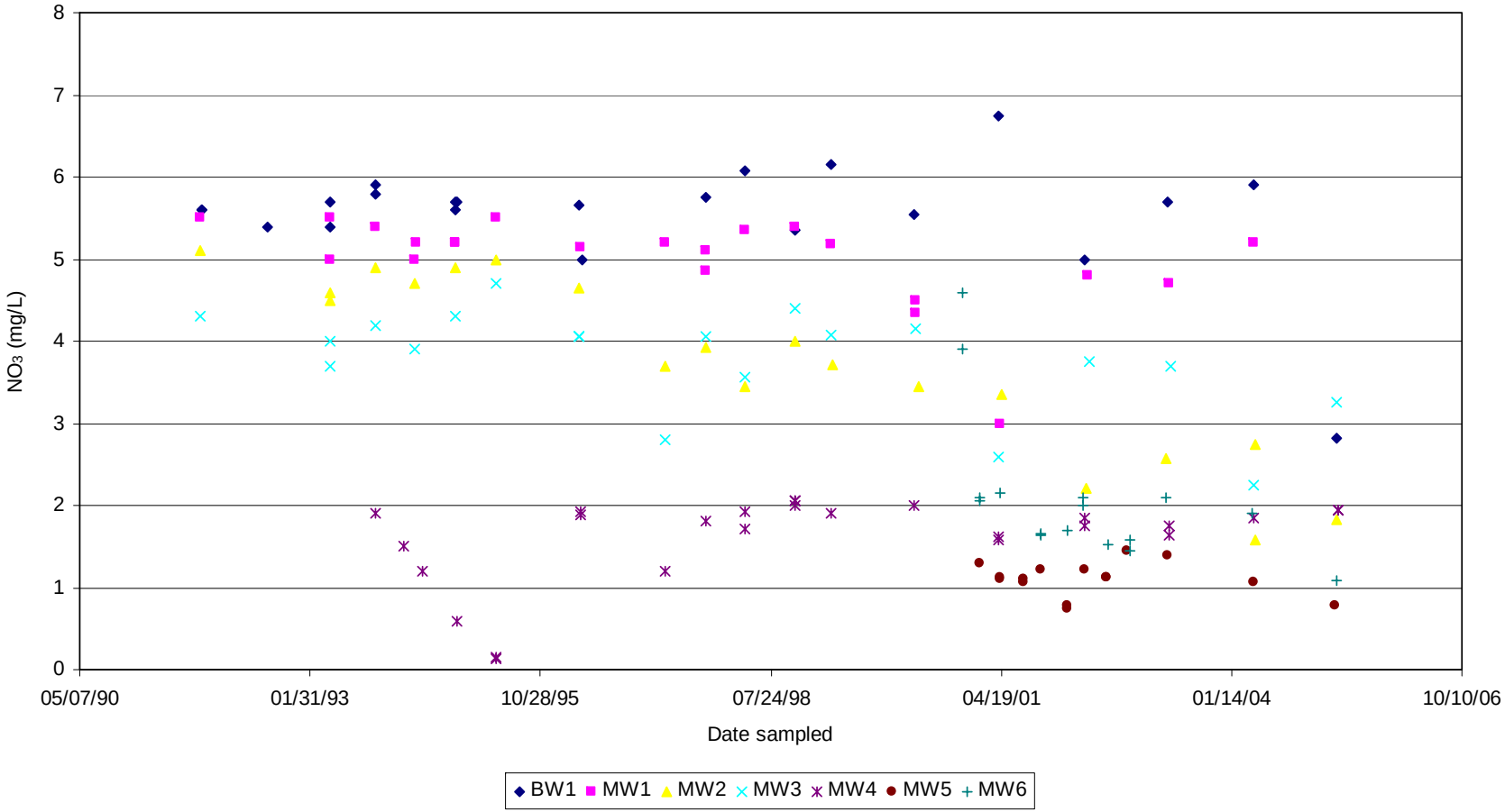
MWL--total Fe concentrations



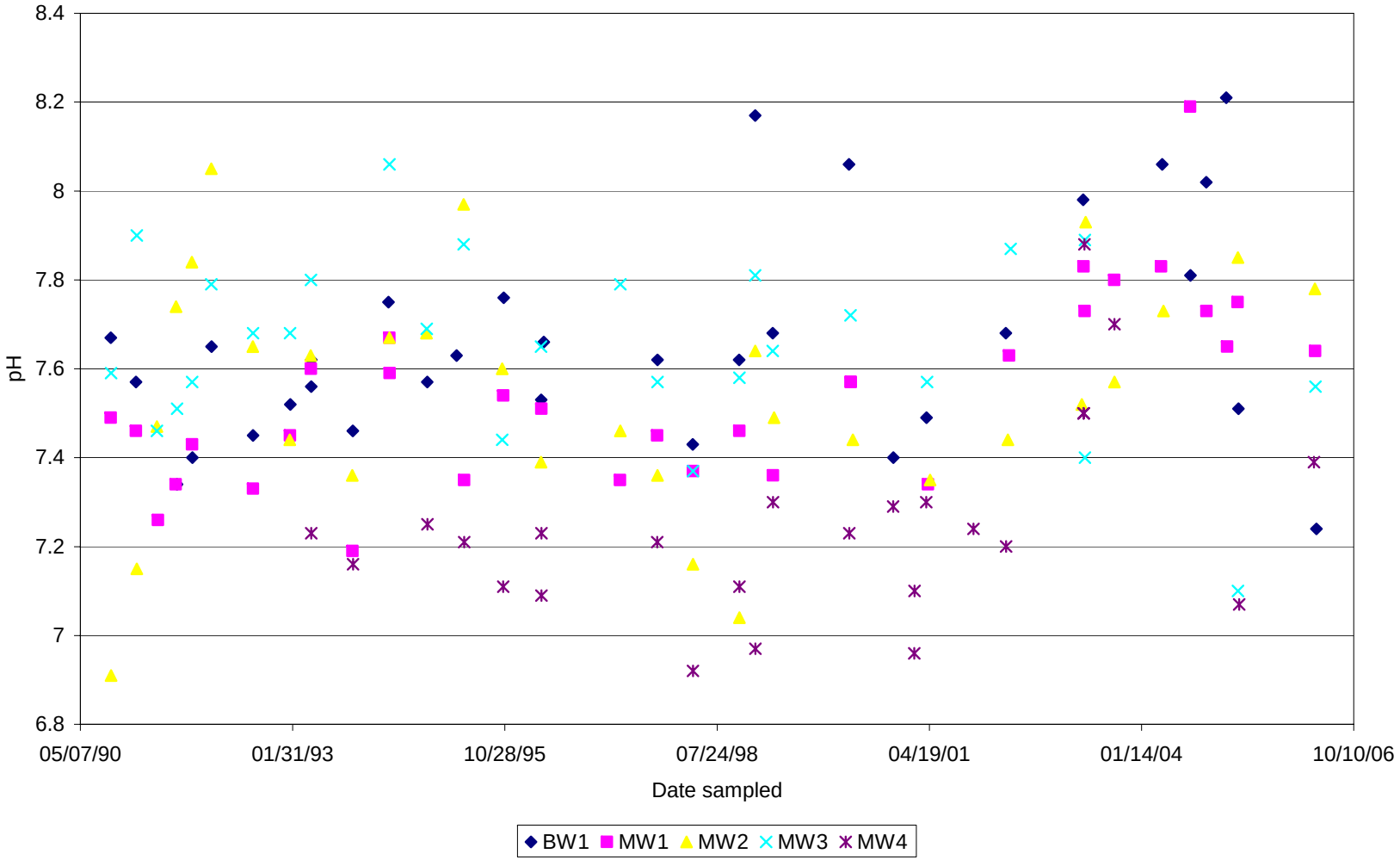
MWL--total Mn concentrations



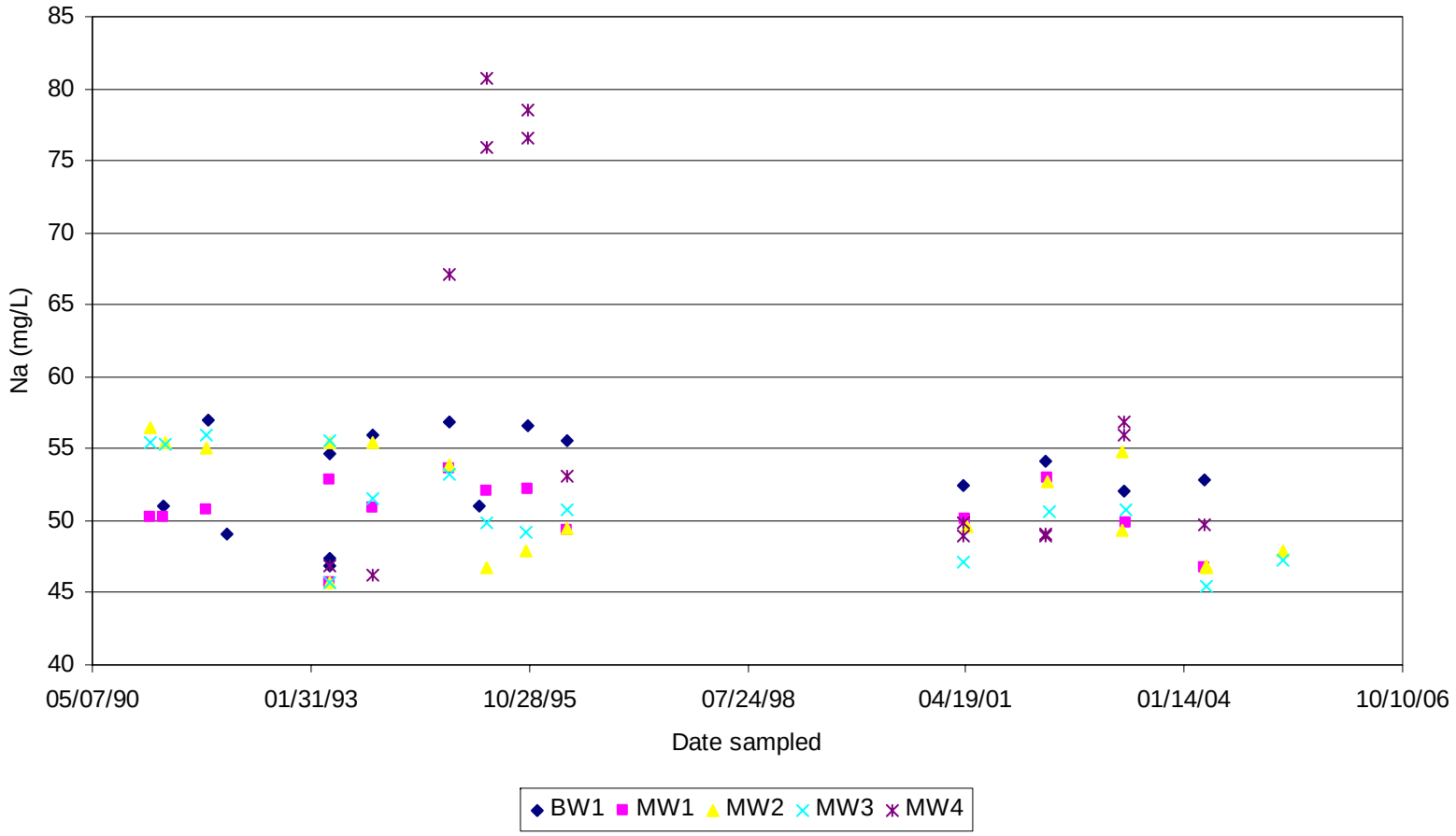
MWL--NO_3 concentrations



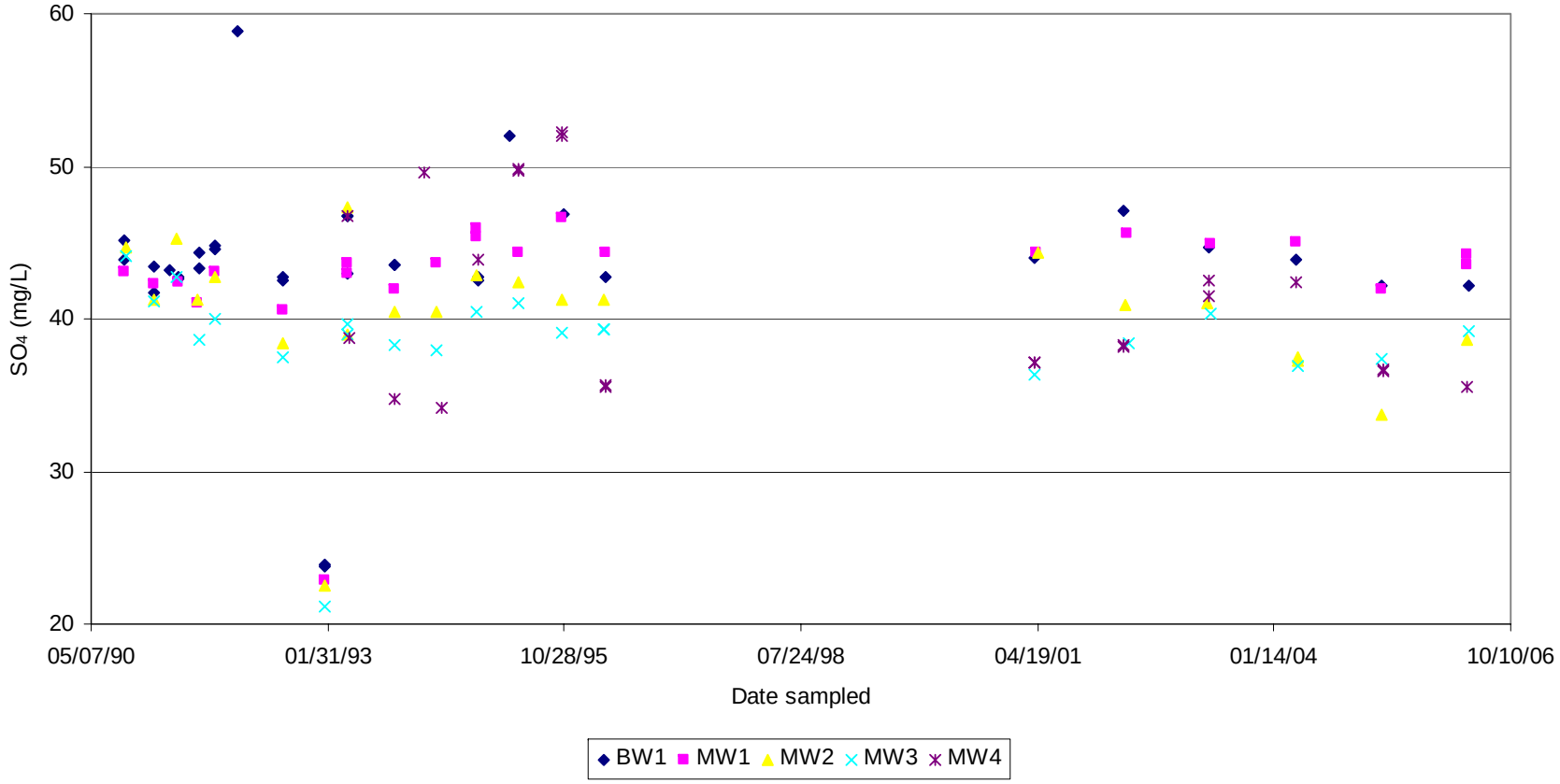
MWL--pH


8.4
8.2
8
7.8
7.6
7.4
7.2
7
6.8
pH
05/07/90
01/31/93
10/28/95
07/24/98
04/19/01
01/14/04
10/10/06
Date sampled
BW1
MW1
MW2
MW3
MW4

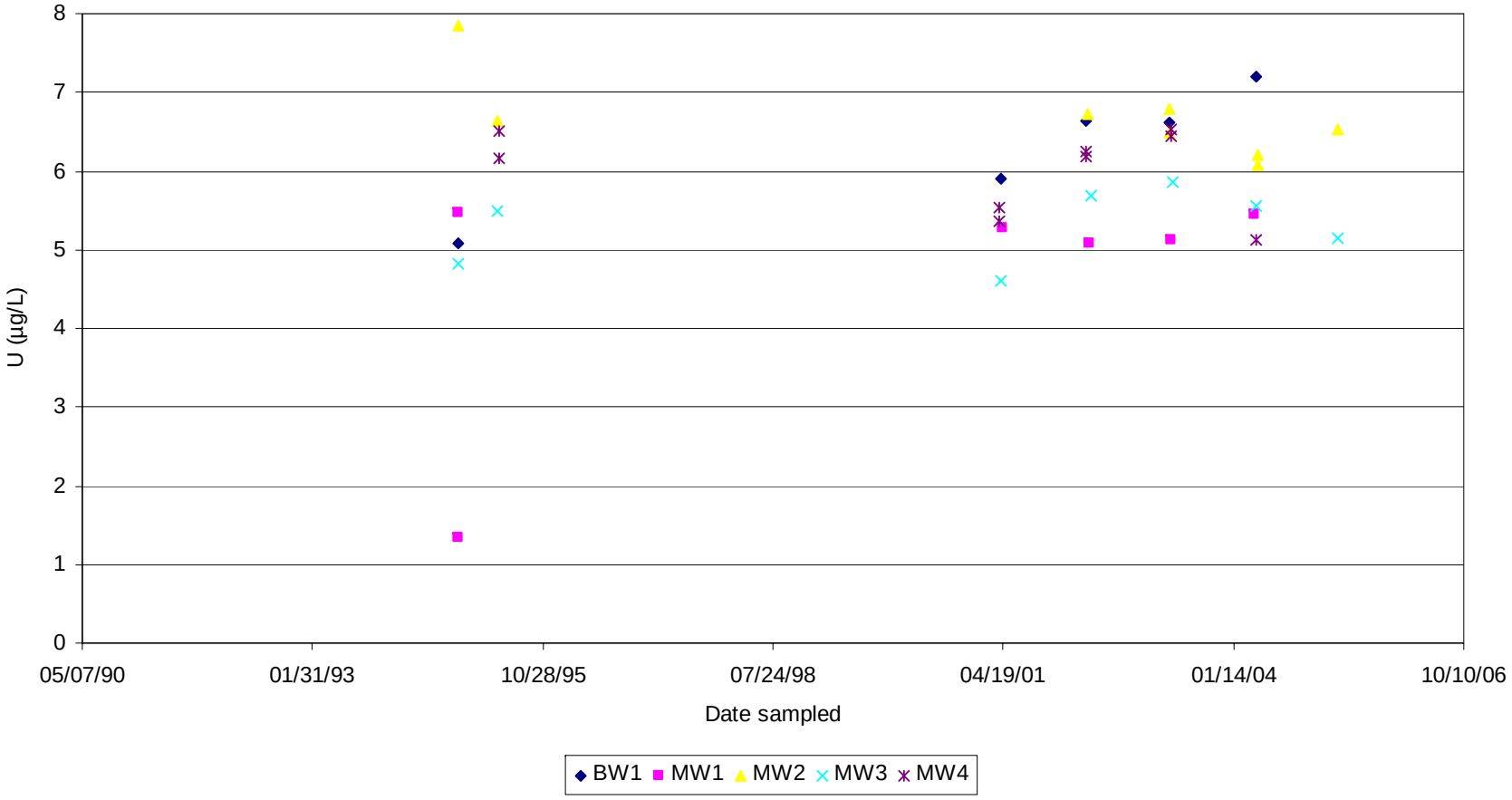
MWL--Na concentrations



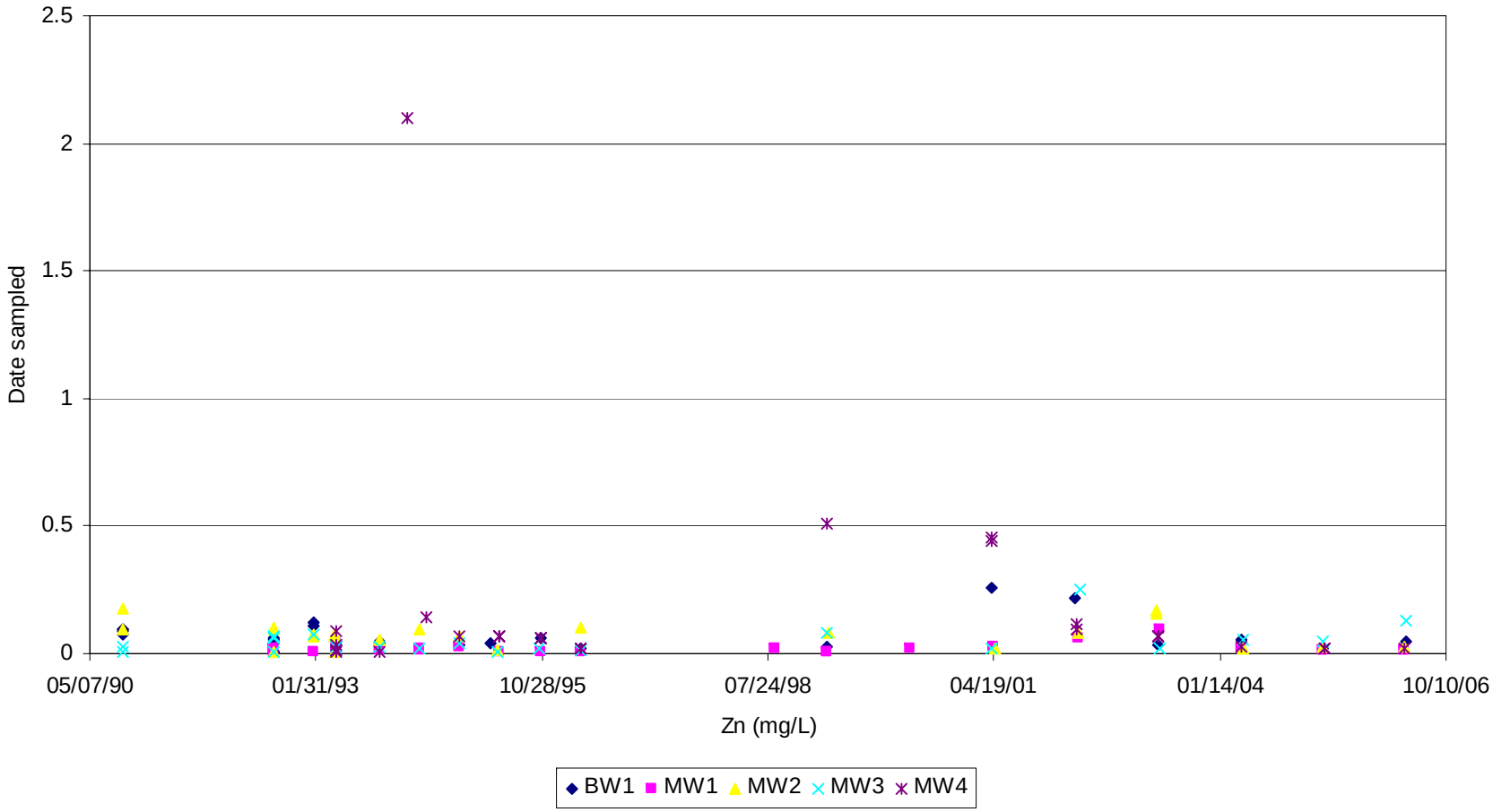
MWL--SO_4 concentrations



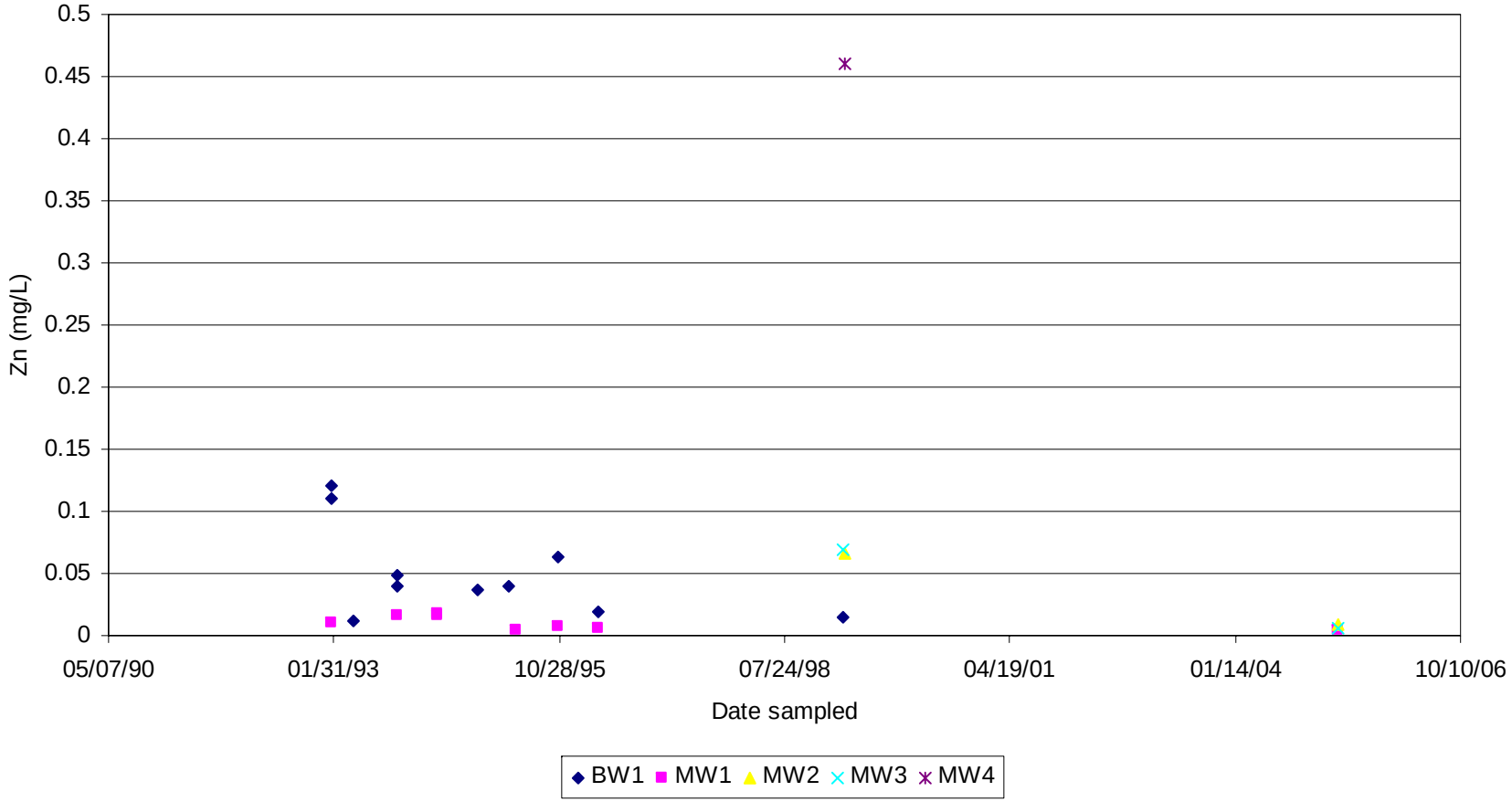
MWL--total U concentrations



MWL--total Zn concentrations



MWL--dissolved Zn concentrations



Appendix C: Groundwater monitoring data for MW5

Groundwater Monitoring Data for MW5

Sample Date	Calcium mg/L	Aluminum (total) mg/L	Sulfate mg/L	Barium (Total) mg/L	Uranium (Total) mg/L	Zinc (Total) mg/L
01/17/01		0.136	56.8	0.133		0.0092
01/17/01						
04/16/01		0.0766	52.0	0.134	9.23	0.00577
04/16/01		0.0911	52.4		9.03	0.00632
07/24/01		0.0172		0.133		0.00572
07/24/01		0.0172				0.0051
10/08/01	77.7	0.063	50.6	0.146	9.53	0.0124
01/30/02	73.3	0.0509	55.8	0.149	9.56	0.00839
01/30/02	72.7	0.0562	55.2	0.151	9.91	0.00774
04/17/02	84.1	0.0172	56.8	0.141	9.37	0.00392
07/23/02	79.5	0.0239	52.5	0.132	8.86	0.00362
07/23/02	78.9	0.0344	54.2	0.130	8.86	0.00366
10/15/02	84.6	0.00454	57.0	0.134	9.44	0.00525
04/09/03	88	0.0111	56.8	0.129	9.53	0.00513
04/21/04	86.8	0.00454	54.3	0.133	9.58	0.00514
04/06/05		0.0413	46.7			0.0173
04/14/06		0.0244	54.7			0.0077