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**Civilian Radioactive Waste Management System
Management & Operating Contractor**

**Data Qualification Report: Major Ion and pH Data for Use on the
Yucca Mountain Project**

TDR-NBS-GS-000013 REV 00

August 2000

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8/23/00
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EXECUTIVE SUMMARY

This data qualification report uses technical assessment and corroborating data methods according to Attachment 2 of AP-SIII.2Q, Rev. 0, ICN 2, *Qualification of Unqualified Data and the Documentation of Rationale for Accepted Data*, to qualify major ion and pH data. This report was prepared in accordance with Data Qualification Plan TDP-NBS-GS-000031, Revision 2. Additional reports will be prepared to address isotopic and precipitation-related data.

Most of the data considered in this report were acquired and developed by the U.S. Geological Survey (USGS). The data qualification team considers the sampling and analytical protocols employed by the USGS over the time period of data acquisition to be state-of-the-art. The sample collection methodologies have evolved with no significant change that could affect the quality of the data considered in this report into the currently used Hydrologic Procedures that support the Yucca Mountain Project-approved USGS Quality Assurance Program Plan. Consequently, for USGS data, the data collection methods, documentation, and results are reasonable and appropriate in view of standard practice at the time the data were collected.

A small number of data sets were collected by organizations other than the USGS and were reviewed along with the other major ion and pH data using corroborating data methods. Hydrochemical studies reviewed in this qualification report indicate that the extent and quality of corroborating data are sufficient to support qualification of both USGS and non-USGS major ion and pH data for generalized hydrochemical studies. The corroborating data included other major ion and pH data, isotope data, and independent hydrological data. Additionally, the analytical adequacy of the major ion data was supported by a study of anion-cation charge balances. Charge balance errors for USGS and non-USGS data were under 10% and acceptable for all data.

This qualification report addresses the specific major ion data sets selected to support the hydrochemical studies in Analysis/Model Report (AMR) S0040 and pH data used in AMRs U0100 and U0085. Based on a preponderance of evidence, these data are recommended to be qualified for inclusion in technical products in support of the Site Recommendation for generalized uses as described in this report.

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ACRONYMS AND ABBREVIATIONS

AMR	Analysis/Model Report
CAR	Corrective Action Request
CMB	Chloride Mass Balance
DCNR	Department of Conservation and Natural Resources
DIRS	Document Input Reference Sheet
DOE	U.S. Department of Energy
DR	Deficiency Report
DRI	Desert Research Institute
DTN	Data Tracking Number
HP	Hydrologic Procedure
MPV	Most Probable Value
NWQL	National Water Quality Laboratory
QAPP	Quality Assurance Program Plan
QARD	Quality Assurance Requirements and Description
QSL	Qualified Supplier List
SNL	Sandia National Laboratory
SRWS	Standard Reference Water Sample
TDMS	Technical Data Management System
TWRI	Techniques of Water Resources Investigations
USBR	U.S. Bureau of Reclamation
USGS	U.S. Geological Survey
WATSTORE	National Water Data Storage and Retrieval System
WIPP	Waste Isolation Pilot Project
WT	Water Table
YMP	Yucca Mountain Project

1. INTRODUCTION

1.1 PURPOSE

The data addressed in this qualification report have been cited in analysis/model reports (AMRs) to support the Site Recommendation in determining the suitability of Yucca Mountain as a repository for high level nuclear waste. The AMRs refer to both qualified and unqualified hydrochemical data. Within the context of this report, the word *hydrochemical* is used as a general term encompassing both chemical and isotopic data. This report evaluates the unqualified data based on the pedigree of the data to support Yucca Mountain Project (YMP) studies. The unqualified data considered in this report were directly used in the following AMR:

- *AMR S0040, Geochemical and Isotopic Constraints on Ground water Flow Directions, Mixing and Recharge at Yucca Mountain (ANL-NBS-HS-000021)* - an analysis of ground water recharge rates, flow directions and velocities, and mixing proportions of water from different source areas based on ground water chemical and isotopic data.

Although pH data are included in the data sets considered for qualification in AMR S0040, these data are primarily used in the following two AMRs:

- *AMR U0100, Unsaturated Zone and Saturated Zone Transport Properties (ANL-NBS-HS-000019)* - data are presented in the context of pH values that lie outside values of pH assumed for performance assessment. These pH data are evaluated in this qualification report.
- *AMR U0085, Analysis of Geochemical Data for the Unsaturated Zone (ANL-NBS-HS-000017)* - the ambient geochemistry analysis emphasizes refinement of the range of infiltration rates and percolation fluxes to the repository considered in performance assessment.

AMR S0045, Calibration of the Site-Scale Saturated Zone Flow Model (MDL-NBS-HS-000011), cites several of the Data Tracking Numbers (DTNs) addressed in this qualification report. These DTNs are listed in the Document Input Reference Sheets (DIRS) for AMR S0045 as "N/A - Reference Only." Finally, AMR S0030, Probability Distribution for Flowing Interval Spacing (ANL-NBS-MD-000003), cites a single DTN addressed by this qualification report. The flowmeter survey data from this DTN are addressed in a separate qualification report.

The purpose of this report is to recommend data that can be cited as qualified for use in technical products to support the Site Recommendation and that may also be used to support the License Application. The qualified data may either be retained in the original DTN or placed in new DTNs generated as a result of the evaluation. The appropriateness and limitations (if any) of the data with respect to intended use are addressed in this report.

1.2 SCOPE

This report evaluates a subset of data identified in Data Qualification Plan TDP-NBS-GS-000031 (Revision 2). The Data Qualification Plan identifies unqualified DTNs containing acquired and developed concentrations of ground water constituents measured by the U.S. Geological Survey (USGS) or other sources cited in the USGS literature. The DTNs cited in the plan include the following hydrochemical data:

- pH
- Major ions
- Carbon isotopes
- Deuterium
- Tritium
- Oxygen isotopes
- Total uranium and uranium isotopes

This report evaluates the major ion and pH data using the methodology and evaluation criteria described in the qualification plan. Other qualification reports prepared pursuant to Data Qualification Plan TDP-NBS-GS-000031 (Revision 2) address isotopic and precipitation-related data.

The major ion data cited in AMR S0040 are based on the following unqualified DTNs identified by the author of the AMR:

AMR	Unqualified DTN
S0040 S0045	GS931100121347.007. Selected Ground-Water Data for Yucca Mountain Region, Southern Nevada and Eastern California, Through December 1992.
S0040 S0045 U0085 U0100	GS990608312133.001. Ground-Water Quality Data
S0040 S0045 U0085 U0100	GS980908312322.008. Field, Chemical, and Isotopic Data from Precipitation Sample Collected Behind Service Station in Area 25 and Ground Water Samples Collected at Boreholes UE-25 C #2, UE-25 C #3, USW UZ-14, UE-25 WT #3, UE-25 WT #17, and USW WT-24, 10/06/97 to 07/01/98
S0040 S0045 U0085	GS991299992271.001. Preliminary Unsaturated Zone Borehole Hydrochemistry Data.
S0030 S0040 S0045	GS920408312314.009. Geohydrology of Rocks Penetrated by Test Well UE-25p#1 (UE-25 p#1), Yucca Mountain Area, Nye County, Nevada
S0040	GS990208312272.001. Analysis for Chemical Composition of Pore Water

S0045	from Borehole USW UZ-14 and USW UZ-16 and Groundwater from USW UZ-16.
S0040 S0045	GS000308312322.003. Preliminary Release of Field, Chemical, and Isotopic Data from the Nye County Early Warning Drilling Program (EWDP) Wells in Amargosa Valley, Nevada Collected Between 12/11/98 and 11/15/99.
S0040 S0045	GS000308312322.004. Preliminary Release of Chemical Data From Borehole TW-5 Collected 7/5/94 and Borehole NDOT Collected 5/17/95.
S0040	GS000308312144.001. Hydrochemical Data from Unpublished, Non-YMP Sources.
S0040 S0045	GS940308312322.001. Hydrochemical database for the Death Valley Region. USGS OFR 94-305.
S0040 S0045	GS930508312322.001. Sources and Mechanisms of Recharge for Groundwater in the West-central Amargosa Desert, Nevada
S0040 S0045 U0085 U0100	GS930308312323.001. Chemical Composition of Groundwater and the Locations of Permeable Zones in the Yucca Mountain Area. USGS OFR 83-854
S0040	GS920508312321.004. Chemical Analyses of Water from Selected Wells and Springs in the Yucca Mountain area, Nevada, and Southeastern California. USGS OFR 90-355.
S0040 U0100	GS920408312321.003. Chemical Composition of Ground Water in the Yucca Mountain Area, Nevada 1971-1984.
S0040 U0085	GS000508312322.005. Chemical and Isotopic Data from Boreholes USW WT-7, USW WT-10, UE-25 WT#12, UE-25 WT#14 and UE-25 WT#15 Collected between 3/26/88 and 6/4/88.

The foregoing DTNs include specific data sets in the Technical Data Management System (TDMS) and/or tables within USGS reports. These data sets contain a wide variety of hydrochemical data collected according to general water chemistry sampling and analytical protocols or sampling plans developed for the activities at the time of data acquisition. Calcium, magnesium, sodium, potassium, chloride, sulfate, total alkalinity (as bicarbonate) and pH are addressed in this report. Field measurements of total alkalinity were preferentially used in AMR S0040; however, laboratory measurements were used when field measurements were not available. Some of the data in the DTNs were not directly used in the AMRs addressed in this report, and are not within the scope of this qualification activity (e.g. temperature, specific conductance, total dissolved solids, depth-to-water).

This qualification report focuses on the specific data points selected to support the hydrochemical studies in the AMRs addressed in this report. To the extent that only subsets of data within a specific DTN are used in the AMRs, only those data are evaluated for qualification. Table 3 of AMR S0040 presents a summary of the saturated ground water chemical and isotopic data that were used. Perched water major ion data are included in Table 7 of AMR S0040. For purposes of this report, the "source DTNs" or

"original DTNs" are the DTNs that were identified by the author of AMR S0040 as the sources of the major ion and pH data.

1.3 DATA QUALIFICATION TEAM

The Responsible Manager for this data qualification task is Robert Wemheuer.

The Chairperson for this data qualification team is Charles Wilson. Dr. Wilson has a Ph.D. (1970) in civil engineering with emphasis in ground water hydrology. He has 20 years of experience in site characterization for nuclear facilities and served on the data qualification independent Peer Review Panel for the U.S. Department of Energy's (DOE's) Waste Isolation Pilot Project (WIPP) site license application. Dr. Wilson has had no involvement with the collection or processing of these data.

Qualification Team Members include:

Terry Steinborn: Dr. Steinborn has a BA (1968) in Chemistry with emphasis on inorganic and radiochemistry, and an MS (1972) and PhD (1976) in Geology with emphasis in geochemistry and volcanology, and is a Professional Hydrogeologist, certified by the American Institute of Hydrology. He has 24 years of experience, most of it in activities related to nuclear and hazardous waste environmental issues. He served on the DOE-HQ Independent Review Team for WIPP, and worked with Sandia National Laboratory (SNL) on WIPP, the Greater Confinement Disposal Program, and SNL Site Environmental Restoration. He has had no involvement with the collection or processing of any YMP data

Gary Patterson (USGS) is listed as a Technical Representative in the Data Qualification Plan (TDP-NBS-GS-00031, Rev. 2). However, because of his involvement with several of the DTNs addressed in this report, he has not provided any input regarding qualification of data associated with this qualification report.

1.4 BACKGROUND

The quality issues associated with the data in the cited DTNs include:

- Data collected prior to implementation of the YMP-approved USGS Quality Assurance Program Plan (QAPP)
- Data collected from non-YMP sources and cited in USGS documents or USGS database
- Data collected under the current Quality Assurance Requirements and Description (QARD) document (e.g., DTN GS991299992271.001) but cited as preliminary and unqualified until administrative USGS review and/or approval are complete.

Data obtained prior to approval of the USGS YMP QAPP in May 1989 are unqualified. In general, data collected by the USGS after May 1989 are qualified. After May 1989, USGS *Hydrologic Procedures* (HPs) became the approved implementation procedures

for USGS data collection activities. The USGS began developing and implementing these HPs as early as 1983 but they were not formally adopted by the survey until 1986.

The data considered in this report were collected between 1958 and 1999 (Table 1). For the earliest data, descriptions of the collection and analytical methodologies can be found in published USGS literature (Rainwater and Thatcher 1960). Between 1967 and 1985, USGS *Techniques of Water Resources Investigations* (TWRIs) are cited as the source for hydrochemical sampling and analytical protocols. Major ion data were also collected by other agencies and provided to and published by the USGS. These agencies include the Nevada Department of Conservation and Natural Resources (DCNR), U.S. Bureau of Reclamation (USBR), and the University of Nevada's Desert Research Institute (DRI). Derived from multiple qualified and unqualified sources, the data addressed in this report are used in regional hydrochemical analyses to establish meaningful inferences about the hydrologic system near Yucca Mountain. In this context, the data are used to define general and regional qualitative trends, such that outliers, if present, can be distinguished from the general sample population.

2. QUALIFICATION METHODS

Qualification methods of *technical assessment* and *corroboration* are used. Technical assessment is applied to determine the appropriateness of data acquisition and analysis methodologies and their application through a technical review of procedures and protocols. The corroborating data method is used in making cross comparisons to evaluate the internal consistency of independently acquired data within the hydrochemical database. The corroborating data method is also used to compare ground water flow rates and directions determined from the hydrochemical database with those determined from independent hydrological databases.

Technical Assessment. As stated previously, USGS sampling and analytical protocols are documented in USGS literature and water resource investigation procedures (TWRIs and HPs). Similarities existing between the TWRIs and the HPs (available before May 1989 and approved in May 1989) are used to establish the technical adequacy of the procedures as an indicator of the quality of information obtained. This assessment is performed in a general review of the USGS procedures. The adequacy of sampling and analytical protocols is further substantiated through evaluation of quality checks of the selected data being used in the hydrochemical studies. Technical assessment methods identified in the evaluation criteria in Section 2.1 are used as needed to further support the review of data acquisition and analysis methodologies that are not as well documented. Technical assessments were conducted by subject matter experts in accordance with the requirements of procedure AP-SIII.2Q, Rev. 0, ICN 2 Attachment 2.

Corroborating Data. As stated in procedure AP-SIII.2Q Attachment 2, the corroborating data approach may include comparisons of unqualified to unqualified data as well as unqualified to qualified data. The corroborating data methods are used to show that the hydrochemical data set provides internally consistent information on the major ion characteristics of the ground waters near Yucca Mountain. The corroborating data methods are also used to show that information on the characteristics of ground water flow near Yucca Mountain obtained from the hydrochemical data set are generally consistent with information on the characteristics of ground water flow obtained from independent hydrological data sets. Although these two data sets are based on different types of information, they can be shown to be mutually corroborative in that they provide similar results.

For non-USGS data, procedures and sampling and analytical protocols are not evaluated. These data represent only a small portion of the sample population and are reviewed using corroborating data.

2.1 EVALUATION CRITERIA

The criteria considered in evaluating the qualification status of the USGS hydrochemical data are identified below. These criteria were selected to incorporate the considerations in procedure AP-SIII.2Q Attachment 2 and the applicable qualification process attributes listed in procedure AP-SIII.2Q Attachment 3.

1. Are data collection and analysis methods comparable to those used under the YMP-approved USGS QAPP, or are the data collection and analytical methods reasonable in view of standard measurement and instrumentation practice at the time the data were collected?
2. Are the data the best available?
3. Are these data or similarly collected data generally accepted by the technical community for use in non-project applications?
4. Does evaluation of comparable qualified and unqualified data sets suggest the same conclusions regarding the saturated zone flow conceptual model?
5. Are the conclusions reached regarding ground water flow rates and directions near Yucca Mountain consistent with conclusions reached based on independent, hydrological data sources?

2.2 RECOMMENDATION CRITERIA

The following recommendation criteria were considered in determining whether the status of the data should be changed to *qualified*. However, the final recommendations of the data qualification team subject matter experts were based on a preponderance of evidence, and not all of the recommendation criteria were necessarily applied.

1. The data collection methods, documentation, and results were reasonable and appropriate in view of standard practice at the time the data were collected.
2. The data were required for the study and the best available data were used.
3. These data or similarly collected data are generally accepted by the technical community for use in non-project applications.
4. The extent and quality of the corroborating data are sufficient and no additional data sources were identified that should have been considered.
5. The data are corroborated by comparison of data sets and/or the conclusion reached regarding ground water flow rates and directions near Yucca Mountain from hydrochemistry are consistent with conclusions reached based on independent hydrological data sources.

A finding that the data are qualified means that the data are adequate for generalized use and can be appropriately used in a wide variety of applications, so long as consideration is given to accuracy, precision and representativeness of the data for an intended use in a technical product.

Although precise definition of the accuracy and precision of a data point is often not possible, particularly with older data, the team recognizes that even qualified hydrochemical data have an inherent variability. This variability can result from natural

fluctuations in the field as well as from minor changes in sampling and analysis techniques and should be expected. A generalized use of data is therefore a use wherein conclusions are not based on the precise value of a single data point or on minor differences among a small number of data points but are rather based on the cumulative evidence of many corroborating data points. Such use tends to be self-correcting, it simplifies identification of significant errors and outliers, and it focuses on general trends and ranges of values. A generalized use of data is therefore most appropriate for data points with mixed origin and pedigree.

3. EVALUATION RESULTS

The evaluation results are described in several subsections each reflecting a qualification method previously described:

- Section 3.1 provides a review of the USGS sampling and analytical protocols documented in the historical literature for the time periods of data acquisition.
- Section 3.2 provides a technical assessment of the sample collection and analysis methodologies used for the data addressed in this report to substantiate application of appropriate sampling and analytical protocols.
- Section 3.3 provides a combination of technical assessment and corroboration focusing on the consistency of the data within the context of several studies. These studies include an evaluation of the areal distribution of major ion data to determine regional flow in the saturated zone, a chloride mass balance study, a local recharge study and an evaluation of the mixing of waters from carbonate and volcanic rocks.

3.1 REVIEW OF SAMPLE COLLECTION AND ANALYSIS METHODOLOGIES

The validity of a laboratory chemical analysis can be strongly influenced by the sample collection and handling techniques used in the field. For example, samples should be stored in clean, uncontaminated bottles. Samples to be analyzed for dissolved cations (metals) should be filtered and stabilized with acid to avoid precipitation. For samples intended to be representative of formation water, indicator parameters such as temperature, specific conductance and pH should be measured during pumping to determine when stable conditions are reached. For samples intended to be analyzed for dissolved carbon, sampling should be conducted with a minimum of agitation and exposure to air to minimize CO₂ offgassing or absorption. Downhole packers may be used to obtain samples from specific well depths and time-series sampling may be conducted to determine the influence of drilling fluids on the sample. It is important that the conditions under which the samples were collected are documented so that the data user can determine whether the sample is appropriate for a particular use.

Data quality is often more sensitive to sampling methods than to analysis methods. This is due in part to the fact that some properties or constituents may change dramatically within a few minutes or hours after sample collection, and thus may be affected by field collection and storage techniques. Analysis methods on the other hand, are generally easier to control, both in the field and in the laboratory. Replicate samples can be analyzed to assess the reproducibility of analysis results. This provides assurance that analytical methods are providing consistent results. Furthermore, when standard reference water samples are available, data from these standards provide information on the accuracy and precision of analytical procedures. It is therefore important to examine

the USGS collection methodologies as documented in USGS reports, manuals and procedures over the collection period of interest for the data presented in AMR S0040.

Ground water sample collection and analysis methods have been documented in the following USGS reports, manuals and procedures:

- USGS Water Supply Paper 1454, *Methods of Collection and Analysis of Water Samples*, 1960 (TIC: 247508) (Rainwater and Thatcher 1960)
- TWRI Book 5, Chapter A1, *Methods for Collection and Analysis of Water Samples for Dissolved Minerals and Gases*, 1970 (TIC: 236364) (Brown et al. 1970)
- Hydrologic Procedure HP-23, *Collection and Field Analysis of Saturated Zone Ground Water Samples*
 - R0, 11/04/83 (ACC: NNA.19930526.0014)
 - R1, 10/03/84 (ACC: MOL.19960926.0200)
 - R2, 10/30/91 (ACC: NNA.19911219.0027)
 - R3, 6/11/93 (ACC: NNA.19930701.0089)
 - R4, 8/28/95 (ACC: MOL.19960715.0046)
 - R5, 5/22/98 (ACC: MOL.19980608.0227)
- Hydrologic Procedure HP-200, *Collection of Ground Water Samples from Wells*
 - R0, 12/16/91 (ACC: NNA.19920318.0024)
 - R1, 7/20/95 (ACC: MOL.19960129.0386)
- Hydrologic Procedure HP-202, *Analysis of Water Samples for Anion and Cation Concentrations by Ion Chromatography*
 - R0, 5/7/92 (ACC: NNA.19920817.0084)
 - R0-M3, 1/8/99 (ACC: MOL.19990201.0039)

The USGS procedures in effect from 1960 to the present indicate an evolution and elaboration of the methodology for water sample collection. This methodology includes ensuring the cleanliness of the sample containers, filtering of the samples, acidification to preclude precipitation of metals, tightly sealed caps and stoppers for sample bottles, and timeliness of conducting analysis of the obtained samples. The evolution of the methodology is reviewed in the following subsections.

3.1.1 USGS Water Supply Paper 1454 (1960)

Standard sample collection and analysis methodologies were documented by the USGS as early as 1960 in USGS Water Supply Paper 1454, *Methods of Collection and Analysis of Water Samples* (Rainwater and Thatcher 1960). The report stated that although no comprehensive study had been made of factors affecting sample containers, hard rubber, polyethylene and other plastics, and some types of borosilicate glass were believed to be suitable on the basis of experience within the USGS. A limited investigation, conducted by the USGS, of the relative merits of four common type bottles showed that storage in Pyrex and polyethylene did not significantly alter the silica, sodium, total alkalinity, chloride and boron content, or the specific conductance, pH, or hardness of the water during a storage period of about five months. However, some investigators avoided Pyrex because of suspected contamination from the boron in the glass. The report cautioned

that before use, all new bottles must be thoroughly cleansed, filled with water, and allowed to soak for several days to remove water-soluble material from the container surface. A standard biochemical-oxygen demand bottle with pointed stopper should be used to collect samples that are to be analyzed for dissolved oxygen, carbon dioxide, sulfides, and oxygen consumed. The closures for sample containers should be glass, well washed rubber, tin wrapped cork, or inert plastics. The report stated that no practical, completely gas-tight closure had been developed. The report stated that all bottles should be rinsed with the water to be sampled prior to sample collection. A pH meter was cited as the method for determining the pH of a sample. This method was applicable to field and laboratory analysis. The meter measured the electrical potential between two suitable electrodes, a reference electrode and an indicating electrode. A mercury-calomel electrode was typically used as the reference electrode while a glass electrode was normally used as the indicating electrode.

Filtration of samples was accomplished using a 0.5 micrometer cellulose acetate membrane to remove solids. Filtering was performed prior to any acidification. To minimize the precipitation of metals (e.g., aluminum, chromium, copper, iron, lead, manganese and zinc) in the water sample, USGS Water Supply Paper 1454 recommended that the sample collected for metals analysis should be acidified to a pH of about 3.5 with glacial acetic acid at the time of collection. However, inasmuch as acetic acid stimulates the growth of molds, the report stated that it may be necessary to add a small amount of formaldehyde to retard growth. The report also gave recommended sample treatments for analysis of ammonia nitrogen, chlorine residual, dissolved oxygen, nitrate nitrogen, oils and waxes, orthophosphate, phenolic material, selenium and sulfate. Acidification does not have an appreciable affect on the cations of interest in this qualification report (Ca, Mg, Na, K). Samples analyzed for anions are not acidified. The anions of interest in this report are Cl, SO₄ and HCO₃.

Detailed laboratory analysis procedures were presented in USGS Water Supply Paper 1454 for determination of major ion concentrations in water samples. Methods for determining ion concentration varied depending on the ion of interest. Most methods involved titration or gravimetric methods.

3.1.2 USGS TWRI Book 5, Chapter A1 (1970)

A series of TWRI manuals was later published by the USGS to provide procedures for the collection and analysis of water samples. TWRI Book 5, Chapter A1, published in 1970, is titled "Methods for Collection and Analysis of Water Samples for Dissolved Minerals and Gases" (Brown et al. 1970). This manual stated that although a great number of glass bottles were still in use, the trend in USGS laboratories was toward polyethylene, teflon, or other plastic containers.

A pH meter was cited as the method for determining the pH of a sample. This method was applicable to field and laboratory analysis. The meter measured the electrical potential between two suitable electrodes, a reference electrode and an indicating

electrode. A mercury-calomel electrode was typically used as the reference electrode while a glass electrode was normally used as the indicating electrode.

TWRI Book 5, Chapter A1 stated that before use, all new bottles were to be thoroughly cleansed, filled with water, and allowed to soak for several days. Field filtration of untreated water samples was accomplished through a 0.45 micrometer filter. Acidified samples were first filtered through a 0.45 micrometer membrane filter, and then acidified with double-distilled, reagent grade HNO_3 to a pH of 3.0 or less. The samples were to be stored in a tightly capped polyethylene bottle.

Detailed laboratory analysis procedures were presented in TWRI Book 5, Chapter A1 for determination of major ion concentrations in water samples. Methods for determining ion concentration varied depending on the ion of interest. These methods were generally consistent with those presented in USGS Water Supply Paper 1454. Atomic absorption spectrophotometry was added as a method of determining ion concentration in USGS TWRI, Book 5, Chapter A1.

3.1.3 USGS Hydrologic Procedures HP-23 and HP-200 (1983 to present)

USGS procedure NWM-USGS-HP-23, R0, *Collection and Field Analysis of Saturated Zone Ground Water Samples* (NNA.19930526.0014), was issued in November 1983. This procedure provided more detailed guidance on collection methodologies. In addition to the standard 0.45 micrometer membrane filter, the procedure recommended use of a 0.1 to 0.2 micrometer filter for trace metal samples (Al, Fe, Mn, As). Equipment needed for sample collection included several 500 ml sample bottles and one 250 ml sample bottle with polyseal or polypropylene caps. Bottles and caps were to be washed twice with double-distilled, reagent grade nitric acid and rinsed with deionized water before use.

The procedure stated that ultra pure nitric or hydrochloric acid was added to freshly collected samples to lower the pH to a value of 2.0 or less to minimize precipitation and sorption of dissolved constituents. Acidification was required for samples to be analyzed for major cations and trace metals (Ca, Mg, Na, K, Sr, Li, U, Fe, Mn, Al).

Revision 2 of NWM-USGS-HP-23, dated 10/31/91 (NNA.19911219.0027), was the first revision of the procedure under the approved USGS YMP QAPP, and added a table to the procedure titled "Table 1. Sample Descriptions Summary." The table described the type of container, cap and filter pore size to use for various elements as well as isotopes. This table was an expanded version of the Rev. 0 and Rev. 1 table titled "Summary of Large Volume Sample Requirements." Revision 5, dated 5/22/98 (MOL.19980608.0227), is the current revision of NWM-USGS-HP-23.

Measurement of pH was accomplished using a pH meter with a glass hydrogen ion membrane electrode compared against a reference electrode of known potential. It was cautioned that high sodium content would give an anomalous pH reading. Also, since the measurement of pH is temperature sensitive, the procedure stated that standard buffers

should be within one degree centigrade of the sample solution. Revision 3 of NWM-USGS-HP-23, dated 6/11/93 (NNA.19930701.0089) required that the measurement of pH be repeated until three consecutive readings differed by no more than 0.02 pH units. It was cautioned that equilibrium might not be attained if CO₂ outgassing was occurring. This could be minimized by inserting the electrode through a tightly fitting stopper into a sample-filled flask or bottle.

NWM-USGS-HP-200, R1, *Collection of Ground Water Samples from Wells*, dated 7/20/95 (MOL.19960129.0386), interfaces with NWM-USGS-HP-23. The procedure describes several methods that may be used to obtain ground water samples from wells. Among these are purging the well to draw water into a well directly from an aquifer to collect a representative sample. The procedure recommends that four to ten well volumes of water should be evacuated. Controlled pumping is also used to obtain representative samples. In this case physical water parameters such as pH, temperature and specific conductance are monitored until their values stabilize. At this point a representative water sample can be collected. The procedure also discusses the rate of pumping. The rate of pumping must be set carefully to prevent volatilization of dissolved gases.

In addition, procedure NWM-USGS-HP-200 discusses the various types of devices that can be used to withdraw water samples from wells:

- Submersible water bottle
- Bailer
- Bladder pump
- Peristaltic pump
- Multi-layer sampler
- Electric submersible pump
- Single acting piston pump
- Wireline sampler
- Airlift pump

NWM-USGS-HP-200 references NWM-USGS-HP-23 as the procedure to provide instruction on preserving the integrity of samples. NWM-USGS-HP-200 addresses cleanliness of equipment by stating that samplers should be steam cleaned or washed and decontaminated prior to deployment, and/or rinsed with deionized water prior to use at each well.

Measurement of pH should take place immediately after collection in those cases where the pH is not actually measured in the well prior to sample collection. Samples are taken repeatedly until temperature, electrical conductance and/or pH readings are constant for three consecutive samples. NWM-USGS-HP-200 cautions that sampling devices designed with a construction that causes abrupt changes of water velocity may readily change pH as a result of change in partial pressure of carbon dioxide in a water sample. NWM-USGS-HP-200 was first issued as Rev. 0 on 12/16/91 (NNA.19920318.0024).

3.1.4 USGS Hydrologic Procedure HP-202

USGS procedure YMP-USGS-HP-202, applicable to recent water chemical analyses, provides instruction for analyzing water samples by ion chromatography. This technique simplifies earlier laboratory analysis procedures. Water samples are injected onto an ion exchange column where the ions of interest are separated. Ionic affinity for column exchange sites is largely determined by ionic radius and valence. Since different ions have different affinities and migration rates, each species is identified by its retention time within the exchange column. These are recorded as peaks on a chromatogram and are compared to a calibration curve prepared from a suite of standard solutions to determine ion concentration. The ion chromatography method of analysis is not applicable to the measurement of pH. YMP-USGS-HP-202 was first issued as Revision 0 in May 1992. The current revision of the procedure is Rev. 0-M3, dated January 1999.

The various laboratory analysis methods in USGS Water Supply Paper 1454, TWRI Book 5, Chapter A1, and HP-202 are listed in the following table for the major ions of interest. Note that pH meters were employed throughout the procedural evolution process.

MAJOR ION LABORATORY ANALYSIS METHODS

Major Ion	USGS WATER SUPPLY PAPER 1454	USGS TWRI BOOK 5, CHAPTER A1	YMP-USGS-HP-202
Ca	Complexometric Method Permanganitmetric Method Gravimetric Method Turbidimetric Method	Complexometric Method Atomic-absorption Method-direct	Ion Chromatography
Mg	Calculation Method Pyrophosphate Method Eriochrome Black T Method	Calculation Method Atomic-absorption Method-direct	Ion Chromatography
Na	Flame-photometric Method Zinc Uranyl Acetate Method	Atomic-absorption Method-direct	Ion Chromatography
K	Flame-photometric Method	Atomic-absorption Method-direct	Ion Chromatography
Cl	Volumetric Method Gravimetric Method	Mohr Method Mercurimetric Method	Ion Chromatography
SO ₄	Visual Thorin Method Spectrophotometric Thorin Method Gravimetric Method Turbidimetric Method	Thorin Method	Ion Chromatography
HCO ₃	Residue-on-Evaporation Method	Residue-on-Evaporation Method	Ion Chromatography
SiO ₂	Molybdate Blue Method Gravimetric Method	Molybdate Blue Method Atomic-absorp. Method-direct	Ion Chromatography

The analytical techniques employed by the USGS since 1960 are accepted by the technical community as being appropriate for the analysis of large numbers of water samples. The techniques give results with good precision and accuracy, and are the best available techniques suited to analysis of large numbers of samples available at the time they were employed. The use of newer techniques as they became available improves the precision and accuracy of the analyses while increasing the sample throughput. The chemical analyses are considered to be of high quality and appropriate for generalized use on the Yucca Mountain Project.

3.1.5 USGS Analytical Laboratory Standard Reference Water Sample Program

Standard Reference Water Samples (SRWS) (Schroder et al. 1980) are used as the principal component of the quality assurance program at the USGS National Water Quality Laboratory (NWQL). The SRWS are diluted with deionized water, mixed in varying proportions with other SRWS, or used undiluted. A large range of concentrations of chemical constituents is thereby achieved, increasing the number of unique samples available for quality assurance purposes. This increase, in turn, decreases the probability that quality assurance samples will be recognized in the laboratory due to frequency of analyses or unique sample behavior.

In addition to the SRWS, ampules obtained from the U.S. Environmental Protection Agency that contain known concentrations of various constituents and synthetic samples made from reagent-grade chemicals are used in preparing reference samples. All samples are made to appear as much like real samples as possible. This effort is coordinated with USGS offices that will be shipping the samples during any given calendar month. When the samples are prepared and appropriate forms are completed to assure that appropriate constituents have been requested for the sample, they are shipped to selected USGS offices across the country. These offices then ship the quality assurance samples to the laboratories daily, along with their regular samples.

The analyses requested reflect the frequency of analyses for each chemical constituent in the laboratory. The program goal is to have at least one quality assurance sample analyzed daily for those constituents that are analyzed daily and, similarly, an appropriate number of quality assurance samples analyzed for those constituents that are analyzed less frequently.

All constituents in the reference samples are in the dissolved phase. Those constituents that are designated as "total recoverable" are from reference samples that have undergone a digestion process (Skougstad et al. 1979) during analysis, rather than from unfiltered or "whole-water" samples.

Quality assurance samples pass through each laboratory as routine samples including the application of laboratory quality control and quality assurance procedures. The data are then stored in the USGS's National Water Data Storage and Retrieval System (WATSTORE). Having passed through the laboratories in this manner, these quality

assurance samples should reflect the quality of the analytical data for environmental samples that the laboratories produce. Laboratory errors other than those related to analytical chemistry also will be reflected in these data. These errors include logging the sample into the laboratory, transcription errors by the analyst, and keypunching errors. No effort is made to correct nonanalytical errors of this type even when it is quite obvious which corrective measures were appropriate, in order to preserve the laboratories' data as they produce it, regardless of the source of error.

The SRWS initially are analyzed by many other laboratories throughout the United States, using several different analytical methods. These results are compiled by calculating the means, standard deviations, 95-percent confidence limits, and applying a rejection routine (American Society for Testing and Materials, 1980). Resultant means are the values most probably correct or the "most probable values" (MPVs). These MPVs are used in this quality assurance program for comparison with laboratory data. For reference samples composed of a mixture of two SRWS or an SRWS and deionized water, MPVs for each constituent are averaged according to their respective percentage contribution to determine a new set of MPVs for the mixture.

For non-SRWS based samples, for example, ampules provided by the U.S. Environmental Protection Agency, "true" or "most probable" values were supplied by the respective agency, with corresponding standard deviations. These values were used in determining whether or not the data from the USGS laboratories were acceptable.

There have been several Corrective Action Requests (CARs) and Deficiency Reports (DRs) associated with the National Water Quality Laboratory. These deficiencies are:

- USGS-99-C-002 (MOL.19991029.0072)
- USGS-97-D-007 (MOL.19981209.0323)
- USGS-98-D-012 (MOL.19980422.0326)
- USGS-97-D-004 (MOL.19971014.0587)
- YM-94-050 (MOL.19960313.0296)
- LVMO-98-C-002 (MOL.20000427.0125)

The deficiencies were primarily related to procurement issues related to NWQL services, placement on the Qualified Supplier List (QSL), and the transfer of QARD requirements to the subcontract labs. None of these deficiencies involved concerns regarding the quality of NWQL analyses, and all are now closed.

3.2 TECHNICAL ASSESSMENT OF SAMPLE COLLECTION AND ANALYSIS METHODOLOGIES

This section presents evidence of procedural implementation and an assessment of sample collection and analysis results for the specific data (samples) addressed in this report. Issues specific to the actual data collection are discussed. Table 1 of this report provides sampling dates, a cross correlation of samples to data sources, and specific

information used to document the quality of the data. The data in Table 1 come from the sources listed in Section 1.2 of this report:

- Benson and McKinley 1985 (DTN GS920408312321.003),
- Claassen 1985 (DTN GS930508312322.001),
- Perfect et al. 1994 (DTN GS940308312322.001).
- McKinley, Long and Benson 1991 (DTN GS920508312321.004)
- Benson, Robison, Blankennagel, and Ogard 1983 (DTN GS930308312323.001)
- Yang 1999 (DTN GS991299992271.001)
- La Camera and Westenburg 1993 (DTN GS93110121347.007)
- Patterson 2000a (DTN GS000308312322.003)
- Patterson 2000b (DTN GS000308312322.004)
- Yang 2000 (DTN GS990208312272.001)
- Patterson 1998 (DTN GS980908312322.008)
- Oliver 2000 (DTN GS000508312322.005)
- Savard 1997 (DTN GS990608312133.001)
- Craig and Robison 1984 (DTN GS920408312314.009)
- Perfect, D.L. 1996 (DTN GS000308312144.001)

Collection dates for unqualified major ion samples addressed in this report are presented in Table 1. A sample collected in 1958 (AMR S0040 sample 52) is the earliest in the data set. Six samples were collected in the 1960s and the remaining 98 samples were collected in the 1970s, 1980s and 1990s. Collection methodologies for samples acquired prior to 1980 are generally not identified in contemporaneous data sources. Many of these earlier data, including the aforementioned 1958 sample, were compiled in 1991 by McKinley, Long and Benson who provided the following statement (McKinley, Long and Benson 1991, p. 4).

“The data source, sampling method, filtration information, name of the analyzing laboratory and anion-cation balance of the analysis are included to aid the user in assessing the quality of the data. Most of the data presented are taken from U.S. Geological Survey sources, and techniques are documented in “Techniques of Water-Resources Investigations” manuals.”

Reports prepared during the 1980s provided additional documentation of data collection methodologies. In a 1983 report, Benson et al. (1983 p. 3) provide a summary of methods and procedures for sample collection and analysis for the 17 data sets described in their report. Although most of these data sets were for samples collected in the 1980s, two were for samples collected in 1971. Benson et al. (1983 p. 3) cite the aforementioned 1970 TWRI document as describing the laboratory procedures used.

Benson et al. (1983 p. 3) purged the sampled wells by pumping for 2 to 13 days and monitored routinely for temperature, specific conductance, pH, and lithium concentration (an indicator of drilling fluid contamination) before water samples were taken. An effort was made to sample after these parameters became relatively stable and the lithium

concentration had decreased to a value near that considered typical of natural formation water. Water samples were filtered onsite with a 0.45 μ m membrane and collected in polyethylene bottles that had been previously washed with nitric acid and rinsed with distilled-deionized water. Samples to be analyzed for cations were acidified with nitric acid to a pH of about 1.

Procedures required sample collection techniques and wellbore collection zones to be recorded to help the data user determine the representativeness of the analytical results. For example, Benson et al. identified that the samples were taken relative to the stabilization of field-measured hydrochemical indicators (1983, p. 3) and provided information on the sampled intervals (1983, Table 1). They also reported that the samples were handled to minimize contamination prior to shipment. The sampled interval is particularly important to analyzing the data and was identified in detail. Additional information such as pumping times and rates were also often identified at the time of sampling, and are reported by McKinley, Long and Benson (1991 Table 5) for many of the samples used in AMR S0040.

From 1960 to the present, the procedures used by the USGS for collecting samples for major ions adhered to state-of-the-art practices or the data were collected under technically adequate procedures. Of the 105 unqualified samples shown in Table 1, 13 samples were collected by an organization other than the USGS. These organizations are the University of Nevada's DRI (6 samples), the USBR (4 samples), and the Nevada DCNR (3 samples). Of these 13 samples, seven were analyzed in USGS laboratories. These data are evaluated by other technical assessment methods in Section 3.3.

3.2.1 Evaluation of Field Sampling Practices

Previously cited documentation indicates that the USGS procedures available at the time of sampling were generally followed by USGS personnel during the period when the unqualified samples addressed in this report were collected. The data qualification team contacted several USGS personnel who were directly involved in the sampling during this period to obtain personal observations. These individuals included Zell Peterman, Pat McKinley, and Jim Paces (all USGS Denver, Colorado), Larry Benson (USGS Boulder, Colorado), and Bill Steinkampf (USGS Tucson, Arizona). Relevant issues identified by these individuals are discussed below.

In general, the data qualification team found that the techniques used by the USGS to sample saturated zone ground water were adequate for the major ions. The accuracy of the aforementioned documentation regarding well purging and sample handling practices was discussed with original authors, particularly for the samples collected in the vicinity of Yucca Mountain which are of primary interest in the AMRs addressed in this report. Well purging was found to be the most significant sample collection issue because of its direct bearing on the extent to which the sample is representative of in situ conditions. Samples of saturated zone ground water were considered generally acceptable because the large available volume of water allowed extensive purging which minimized the influence of drilling fluids and borehole casing.

Some YMP wells were drilled with a lithium tracer added to the drilling fluid to provide an indication of the adequacy of purging (Benson et al. 1983 p. 3). Although most of those wells were pumped until the lithium concentration had dropped to less than one percent of its concentration in the drilling fluid (Benson et al. 1983 p. 16), the effects of lithium sorption-desorption kinetics add uncertainty to its value as an indicator of residual drilling fluid contamination. However, the wells were pumped for 2 to 13 days before the samples were taken (Benson et al. 1983 p. 3) and although the effects of drilling fluid were still present at the time of sampling, its volume percent was undoubtedly low. The data qualification team believes that the sampling results were not strongly influenced by drilling fluid and that the major ion data are appropriate for generalized use.

Some YMP wells were identified as not having been developed at the time of drilling, in part due to low flow conditions. However, some of these wells were developed and resampled in the 1990s. The earlier samples from these wells were often taken without extensive purging and were likely contaminated by drilling fluids and not representative of in situ conditions. This is particularly true for the water table (WT) wells. In addition, it is noted in AMR S0040 that the chloride concentration in well WT-15 (AMR S0040 Sample 7) was probably affected by NaCl used during water level measurements (AMR S0040 Section 6.5.5.2). AMR S0040 samples 6, 7, 27, 28, 29, 33 and 34 were taken from WT wells. The effect of an inability to adequately purge a well does not appear to be significant for generalized uses of the data. For example, the ground water flow paths are inferred in AMR S0040 based on multiple point sources of data (wells) and multiple chemical and isotopic species and corroborate major ion data from the WT wells.

Perched water data collection practices were specifically reviewed by the data qualification team because of the increased difficulty of purging large volumes of water. Problems in obtaining representative samples of perched water were related to low well yields and contamination by drilling fluids from nearby saturated zone ground water wells. All perched zone samples were taken in wells drilled with air and organic tracers, which minimized drilling contamination issues for the major ion constituents addressed in this report.

Contamination by drilling fluid losses from nearby wells was identified as a significant problem for perched water sampling only in well USW UZ-14 where the perched water was contaminated by extensive fluid losses from nearby well USW G-1. This contamination was successfully addressed by pumping the perched zone from well USW UZ-14 for approximately one month and monitoring the declining influence of the drilling fluids. Major ion data from this time-series sampling are tabulated in AMR S0040 Table 7.

3.2.2 Review of Laboratory Analytical Adequacy

Examples of USGS laboratory analytical sheets are cited in DTNs GS920408312321.003 and GS920508312321.004. These sheets are copies of the original laboratory reports issued by the USGS. They were reviewed to confirm the data values and evaluate the accuracy and precision of the results. Sheets from the 1960s and 1970s provide

information on the sampling location, sample collection techniques, analytical results, and charge balance information as a check of analytical accuracy. Non-detects are presented as "less than" values to provide information on analytical detection limits. Sheets from the 1980s provide additional information on the sample collection techniques and analysis methods used. The information presented on the analytical sheets was standard practice at the time and provided data that were widely used and considered adequate by both government agencies and private organizations. The laboratory analytical sheets indicate that the analysis techniques and precision of the analytical results were adequate for generalized use.

The major ion charge balances calculated from the results of the laboratory analyses were used to evaluate the accuracy of those analyses. In an aqueous solution, the total charge of the positive cations must equal the total charge of the negative anions. The degree of balance is calculated in milliequivalents per liter (meq/L) as the difference between the calculated equivalence of anions and cations divided by the sum of these values and expressed as a percentage of the total equivalence. If all anions and cations were included, the net charge would be balanced and the theoretical calculated result should be zero. However, error is introduced because trace ions are normally not included and because of limitations in the analytical results. Low charge balance errors are not necessarily indicative of good analytical results if the charge balance is dominated by one or two ionic species; however, high charge balance errors are indicative of problems with the data set. For the Yucca Mountain data, sodium tends to dominate the positive charges and total alkalinity (as bicarbonate) tends to dominate the negative charges. For this reason, the charge balance errors were considered indicative but not definitive indicators of good laboratory standards. In practice, charge balance errors between zero and 5% are considered good and errors between 5% and 10% are considered acceptable for general use. Charge balance errors greater than 10% indicate the data should be used with caution.

Charge balance data for the unqualified major ion samples are shown in Table 1. For samples without analytical laboratory data sheets, the charge balance was calculated by the data qualification team as shown in Appendix A to this report. These calculations were based on the data presented in AMR S0040 Table 3, and do not include minor ion data such as fluoride and nitrogen that were sometimes included in the laboratory data sheet calculation. This omission is conservative because ignoring minor constituents would tend to increase the calculated charge balance.

Charge balance calculations were checked for errors greater than 10% and against the original laboratory data sheets where available. All samples were found to lie within the acceptable range. The charge balance error for USGS data was found to range from 0.0 to 8.2%, and the result for most samples was less than 5%. In addition, each of the four samples not analyzed in USGS laboratories had a charge balance error of less than 5%. The low charge balance errors support the adequacy of the laboratory analyses for unqualified major ion data from both USGS and non-USGS sources for generalized use.

In reviewing the data sources, it was noted that some data values represent the average of two or more samples. Those data values are footnoted in AMR S0040 Table 3. The data values were checked and all were found to be consistent with the values used in AMR S0040 except for the value for well USW H-3 (see ACC: NNA.19940323.0239). In this well the actual chloride concentration of 9.5 mg/L was erroneously reported as 5.5 mg/L by Benson and McKinley (1985, Table 1), and the error was carried over to AMR S0040 Tables 4 and 10. The chloride concentration for this well is correctly reported as 9.5 mg/L by McKinley et al (1991, Table 6). The data qualification team reported this error to the author of AMR S0040.

3.2.3 Review of Sample Collection Adequacy

A general discussion of the adequacy of sample collection techniques is presented in Section 3.1. To specifically evaluate the adequacy of these techniques for major ion data, a comparison of the results of replicate samples was made. Replicate samples are independent samples collected from the same water source. A comparison of replicate results provides information on the consistency of sample collection techniques as well as the adequacy of the laboratory analyses. For samples of the same water source taken at different times, a difference in analytical results may be due to an actual change in water chemistry; however, a similarity in analytical results would indicate consistency in the water chemistry as well as in the sample collection and analysis techniques. For samples from the same source taken at the same time, a difference in analytical results would be likely due to problems in sample collection or analysis; however, a similarity in results would indicate consistency in the sample collection and analysis techniques.

Eleven sets of replicate samples taken by the USGS are shown in Table 2. Although the total population of USGS replicate samples is not represented in Table 2, the samples presented were collected between 1966 and 1998 and provide comparisons between recent and older data as well as between qualified and unqualified data. The data are shown in the table in order of increasing age. The first six data sets were collected in the mid to late 1990s. Two of these data sets are qualified. The next three data sets were collected in the 1980s and are unqualified. These data sets show analytical results that are again either identical or very similar and are comparable in quality to the aforementioned qualified data sets.

The last two data sets are from the 1960s and 1970s. During this period written procedures were also in existence, but published documentation of their use is limited. However, a comparison of these two data sets, which were the only two replicate analytical results identified by the data qualification team from this period, indicates that the results of replicate analyses were again either identical or very similar and are comparable in quality to the qualified results from the 1990s. These early samples appear to have been carefully collected and analyzed. The quality of the results supports the aforementioned statement by McKinley, Long and Benson (1991, p. 4) that the sample collection and analysis methodologies used by the USGS during that period were those documented in the TWRI manuals.

Although a comparison of replicate sampling results does not rule out a systematic bias in sample collection, a bias resulting from sampling error is unlikely to persist over a period of years and the involvement of different personnel. The principal precautions to be taken in collecting samples for major ion analysis were recognized in the USGS procedures prepared for use by USGS personnel. Samples collected for cation analysis were acidified to stabilize against precipitation. Samples collected for dissolved constituent analysis were filtered to remove particulates and colloids. Samples collected for analysis of carbon and other potentially volatile constituents were processed to minimize offgassing. The data qualification team considers the sample collection procedures available at the time the unqualified samples were taken to be adequate for pH and major ion analysis for generalized use.

3.3 CORROBORATION OF MAJOR ION DATA THROUGH HYDROCHEMICAL STUDIES

3.3.1 Areal Distribution and Regional Flow

Major ion data are plotted on regional maps in Figures 5 through 11 and in Figure 17 of AMR S0040 to interpret regional ground water flow patterns and compare with the flow patterns inferred from purely hydrologic data. The assumptions identified in Table 4 of AMR S0040 relative to this use of hydrochemical data include the following: "regional flow paths can be traced by linking areas with similar chemical and isotopic compositions in a downgradient direction;" and "...once in the saturated zone ground water system, delta deuterium, delta oxygen-18, Cl^- , SO_4^{2-} , Na^+ , and Ca^{2+} are sufficiently conservative to identify likely flow paths."

The areal distribution study was based on both qualified and unqualified data. The unqualified data include data collected by organizations other than the USGS. The results of the study are described in Section 6.5.1 of AMR S0040. The observed spatial variability in the data was found to be generally explained by changes in mineralogical environments (for example, water from volcanic as compared with carbonate aquifers; water from desert playas) and the resultant mixing of waters with different compositions. As discussed below, the more conservative major ions otherwise retained similar concentrations in directions that generally coincided with the flow paths based on purely hydrologic data.

The study of probable regional flow paths inferred from hydrochemical data is described in Section 6.5.2 of AMR S0040. This is considered a generalized use of the data that provided corroboration for the unqualified data in each of these data sets. Although multiple chemical and isotopic species were used to construct the flow paths, primary reliance was placed on the more conservative chemical and isotopic species described above. Six regional flow paths were inferred from the hydrochemical data and are shown in Figure 17 of AMR S0040. These flow paths indicate that on a regional scale ground water moves from the mountains in the north to the playas in the south. The flow paths are generally consistent with those inferred from purely hydrologic data (see Figure 4 of AMR S0040), but have a stronger north-south component in the northern part of the

study area. However, both the hydrochemical and hydrological data sets support the conclusion that ground water beneath the potential repository area flows across rather than along the south-trending faults in the southern part of Yucca Mountain. Although differences in detail should be expected, the general agreement on a regional scale between the ground water flow directions inferred from two entirely different sets of data (hydrochemical and hydrological) provides additional corroborative evidence for the adequacy of the hydrochemical data used in this study. Furthermore, the study substantiates the quality of non-USGS sources in such applications.

3.3.2 Chloride Mass Balance Study

Chloride data used in chloride mass balance (CMB) calculations are presented in AMR S0040 Table 10. All samples were collected from saturated zone ground water and analyzed by the USGS. Of the 18 chloride data points used in these calculations, 11 were taken from the unqualified data sources listed in Section 1.2 of this report. All of these unqualified samples (identified as AMR S0040 sample numbers 11, 13, 15, 16, 17, 19, 20, and 22 through 25) are included in Table 1 and were subjected to the same data qualification review as the other samples presented in the table. All 11 samples were collected and analyzed during a period when available documentation indicates that the aforementioned USGS procedures for sample collection and analysis were both available and applied. The chloride concentrations presented in Table 10 of AMR S0040 were used in a generalized way to determine a range of average ground water recharge rates. As previously discussed, the data qualification team has determined that the techniques employed by the USGS for collecting and analyzing ground water samples for major ions have been appropriate for generalized use since at least the 1960s. The narrow range of recharge rate estimates resulting from this study (7 ± 1 mm/yr for one calculation method and 14 ± 2 mm/yr for a second calculation) provides corroborative evidence supporting qualification of the unqualified chloride data for generalized use (AMR S0040 Section 6.5.6).

3.3.3 Local Recharge Study

A trilinear diagram supporting a generalized comparison of the compositions of perched water samples and saturated zone ground water samples is presented in Figure 19 of AMR S0040. All of the perched water data in the figure lie within the ranges of the saturated zone waters and the AMR concluded that the proportions of major ions in perched and saturated zone water samples were similar (AMR S0040 Section 6.5.3.2). The unqualified saturated zone ground water data presented on the figure are from the same sources as used in the areal distribution study. AMR S0040 Table 7 contains the perched water pH and major ion data.

Saturated zone ground water data used in AMR S0040 Figure 19 are unqualified because they were collected and analyzed prior to YMP approval of the USGS QAPP. The samples were collected and analyzed during a period when available documentation indicates that the aforementioned USGS procedures for sample collection and analysis were both available and applied. As previously discussed, the data qualification team has

determined that the techniques employed by the USGS for collecting and analyzing ground water samples for major ions has been appropriate for generalized use since at least the 1960s. This study provides additional corroborative evidence supporting qualification of the unqualified major ion data for generalized use.

3.3.4 Carbonate and Volcanic Aquifer Mixing Study

Chloride data were plotted against delta deuterium data in Figure 24 of AMR S0040 to evaluate the upwelling of ground water from the carbonate aquifer into the overlying volcanic units. The evaluation of this plot in AMR S0040 focuses on the difference in chloride content between the water sample UE-25 p#1(c) and all other samples on the plot. The chloride concentration in sample UE-25 p#1(c) was approximately two times higher than the highest concentration in any of the other samples, which were taken from the volcanic aquifer. A higher chloride concentration in sample UE-25 p#1(c) would be expected because it was taken directly from the carbonate aquifer. AMR S0040 concludes from this information that ground waters from the volcanic aquifer contain, at most, only a minor amount of water from the carbonate aquifer.

The unqualified data used in Figure 24 of AMR S0040 are included in Table 1 of this report and were subjected to the same data qualification team review as the other data presented in the table. The samples were collected and analyzed during a period when available documentation indicates that the aforementioned USGS procedures for sample collection and analysis were both available and applied. The data in Figure 24 from the volcanic aquifer are corroborative and used in a generalized way to identify a range of chloride concentrations in the volcanic aquifer. However, the comparison made with the single unqualified data point UE-25 p#1(c) from the carbonate aquifer cannot be considered a generalized use because there is no corroboration presented on the figure for that data point. In recognizing this concern, corroboration for that data point was provided in AMR S0040 by comparing it with the chloride concentrations of major springs discharging from the carbonate aquifer at Ash Meadows (AMR S0040 Section 6.5.5.2). The chloride concentrations of those springs was in all cases higher than the highest chloride concentration of the volcanic aquifer samples shown in Figure 24. The Ash Meadows chloride contents were sufficiently different from the volcanic aquifer chloride contents that they can be considered corroborative of the chloride content in carbonate aquifer sample UE-25 p#1(c). These results support qualification of the data for generalized use by providing additional corroborative evidence for both the volcanic and carbonate aquifer samples.

3.4 SUMMARY OF MAJOR ION EVALUATION RESULTS

Most of the unqualified major ion data used in AMR 0040 were collected by the USGS. Sample collection and analysis methodologies for major ions were documented by the USGS in published reports as early as 1960. The early methodologies have evolved with little change into the currently used Hydrologic Procedures that support the YMP-approved USGS QAPP. Documentation of the use of those methodologies has also been provided in USGS reports. The USGS methodologies were reviewed by the data

qualification team and were found to be adequate to provide analytical results for generalized use as defined in Section 2.2. The major ion data sets developed using these methodologies were evaluated for sample collection adequacy by a review of sampling methodology and by corroboration of replicate samples. The data sets were evaluated for analytical adequacy by review of charge balance data. These approaches supported the adequacy of the sample collection and analysis methodologies. Based on this assessment approach, the data qualification team concluded that the data were qualified for generalized use.

AMR S0040 used major ion data in several studies that provided corroborative evidence to further support the data qualification team's conclusions. Major ion data were used to identify regional directions of ground water flow. In addition to providing mutual corroboration with other hydrochemical data, this generalized use was further corroborated by a favorable comparison to regional flowpaths identified using purely hydrologic information. Use of chloride data in chloride mass balance calculations and in an aquifer mixing study was also found to be a generalized use that provided corroborative support. Use of major ion data in a study of local recharge was also found to be corroborative. As a result, the data qualification team was able to qualify the USGS major ion data for generalized use in hydrochemical studies used to support the Site Recommendation.

Thirteen of the 105 unqualified major ion data sets used in AMR S0040 were collected by organizations other than the USGS. The analytical adequacy of these data was checked by a charge balance study and found to be acceptable. The non-USGS data were used in AMR S0040 to identify the regional directions of ground water flow. This is considered an adequately generalized use because it is corroborated by other hydrochemical data collected by the USGS, and was further corroborated by a favorable comparison to regional flowpaths identified using purely hydrologic information. Consequently, this data set is also qualified for generalized hydrochemical studies.

4. EVALUATION CONCLUSIONS

The conclusions of the data qualification team's review of major ion and pH data are presented below in terms of the five evaluation criteria presented in the controlling hydrochemical data qualification plan (TDP-NBS-GS-000031, Rev. 2).

1. Are data collection and analysis methods comparable to those used under the YMP-approved USGS QAPP, or are the data collection and analytical methods reasonable in view of standard measurement and instrumentation practice at the time the data were collected?

The majority of the data considered in this report were collected and analyzed by the USGS. The data qualification team considers the sampling and analytical protocols employed by the USGS over the time period of data acquisition to be state-of-the-art. The early sample collection methodologies have evolved without significant change into the currently used Hydrologic Procedures that support the YMP-approved USGS QAPP.

The data qualification team found that the techniques used by the USGS to collect hydrochemical samples ground water were generally adequate for the major ions and pH. Well purging was found to be the most significant sample collection issue because of its direct bearing on the extent to which the sample is representative of in situ conditions. Samples of saturated zone ground water were considered generally acceptable because the large available volume of water allowed extensive purging which minimized the influence of drilling fluids and borehole casing. Samples of perched zone water were considered generally acceptable because the boreholes were drilled with air. Specific instances where well purging was not considered to be adequate or drilling fluid contamination was present at the time of sampling are documented in USGS reports and in this report. These samples are also recommended for qualification for generalized use because the well purging issues are recognized, limitations in the representativeness of data from those samples are known and documented by the USGS, and such information is available to assist the data user in determining the appropriateness of the data for a particular application.

Consequently, for USGS data, the data collection methods, documentation, and results were found to be reasonable and appropriate in view of standard practice at the time the data were collected. The data qualification team considers the sample collection procedures available at the time the unqualified samples were taken to be adequate for major ion and pH evaluation for generalized use.

2. Are the data the best available?

The data evaluated in this report were selected to analyze the areal distribution of hydrochemical data to estimate regional flow directions in the saturated zone, to support a chloride mass balance study, and to support local recharge and carbonate and volcanic mixing studies in and around Yucca Mountain, Nevada. The literature sources cited are considered the best available and appropriate for such studies.

Data sets were evaluated for analytical adequacy by review of charge balance data. Charge balance errors were checked for outliers and against the original laboratory data sheets where available. Charge balance for USGS and non-USGS data were found to be under 10% for all data. This result supports the conclusion that the data are adequate for generalized use.

3. Are these data or similarly collected data generally accepted by the technical community for use in non-project applications?

Major ion and pH data are a standard component of general water chemistry studies used in environmental studies. These data would be acceptable for use in non-project applications in environmental studies in which large data sets are considered to describe baseline conditions (e.g. generalized use).

4. Does an evaluation of comparable qualified and unqualified data sets suggest the same conclusions regarding the saturated zone flow conceptual model?

Corroborating qualified and unqualified hydrochemical data define flow patterns on a regional scale that are consistent with a third qualified hydrological technical product – flow paths defined by the saturated zone potentiometric surface. In this context, the unqualified hydrochemical data used in the flow study are corroborated by both hydrochemical and hydrological data. Chloride mass balance calculations and an aquifer mixing study used qualified and unqualified chloride information and the data were found to be corroborative. Qualified and unqualified data used in an evaluation of local recharge were also found to be corroborative. As a result, the data qualification team found that the extent and quality of the corroborating data are sufficient to support generalized hydrochemical studies.

5. Are the conclusions reached regarding ground water flow rates and directions near Yucca Mountain consistent with conclusions reached based on independent, hydrological data sources?

There is general agreement on a regional scale between the ground water flow directions inferred from two entirely different sets of data (hydrochemical and hydrological). The regional flow paths constructed on the basis of the chemical and isotopic data are generally consistent with flow paths that could be inferred from potentiometric surface data.

5. RECOMMENDATIONS

Based on a preponderance of evidence, the major ion and pH data in AMR S0040 are recommended for qualification for generalized use as defined in Section 2.2 of this report. Because these data are subsets of larger data sets presented in unqualified source DTNs, they have been separately identified and assigned new DTNs. The qualification team recommends that the following new DTNs be qualified for inclusion in technical products in support of the Site Recommendation for generalized uses as described in this report.

Major ion and pH data cited in Tables 3 and 7 of AMR S0040 (ANL-NBS-HS-000021) have been compiled into discrete M&O DTNs and are recommended for qualification for generalized use. As previously mentioned, for purposes of this report the "source DTNs" or "original DTNs" are the DTNs that were identified by the author of the AMR as the sources of the major ion and pH data. The newly-compiled DTNs can be traced to each original DTN as follows:

<u>Original DTN</u>	<u>New DTN</u>
GS000308312144.001	MO0007MAJIONPH.002
GS990608312133.001	MO0007MAJIONPH.003
GS991299992271.001	MO0007MAJIONPH.004 MO0007MAJIONPH.016
GS980908312322.008	MO0007MAJIONPH.005
GS940308312322.001	MO0007MAJIONPH.006
GS990208312272.001	MO0007MAJIONPH.007
GS931100121347.007	MO0007MAJIONPH.008
GS000308312322.004	MO0007MAJIONPH.009
GS920408312314.009	MO0007MAJIONPH.010
GS920408312321.003	MO0007MAJIONPH.011
GS920508312321.004	MO0007MAJIONPH.012
GS930308312323.001	MO0007MAJIONPH.013
GS930508312322.001	MO0007MAJIONPH.014
GS000308312322.003	MO0007MAJIONPH.015
GS000508312322.005	MO0008MAJIONPH.017

The new DTNs were created to match the values tabulated in AMR S0040 including any unit conversions and averaging of data from the source DTNs. However, the data qualified in this report are ultimately based on the original source DTNs for these data as identified by the author of AMR S0040. The unit conversions and averaging of data do not impact the conclusion of this report that the data presented in the newly created DTNs can be qualified for generalized use.

As stated earlier in this report, AMRs U0085 and U0100 cite some of the same unqualified DTNs for major ion and pH data. The newly created DTNs listed above may be used in place of the unqualified DTNs provided that the data cited in the AMR are identical to those contained in the newly created DTNs. If data not addressed in this report are cited from the unqualified DTNs, the unqualified DTNs should be retained as references.

6. REFERENCES

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Table 1. Sampling Dates and Cross-Correlations for Unqualified Major Ion Data Sets
Used in AMR S0040

Well Identifier	Sample Collection Date	Sample I.D. Number in AMR S0040	Sample Collection Agency ¹	Sample Anion- Cation Balance ³ (%)
UE-29a#2(dp)	1/08/82	1	USGS	1.31 ⁶
UE-29a#2(sh)	1/15/82	2	USGS	0.63 ⁶
UE-25 J-12	3/26/71	3	USGS	0.75 ⁶
UE-25 J-13	3/26/71	4	USGS	0.2
UE-25 JF#3	3/5/92	5	USGS	2.70 ⁶
UE-25 WT#14	No date	6	DRI	Not available
UE-25 WT#15	No date	7	DRI	Not available
USW G-2	4/23/96	8	USGS	0.65
USW UZ-14 (sh)	2/25/98	9	USGS	0.6
USW UZ-14 (dp)	2/26/98	10	USGS	1.4
USW H-1(Tcp)	10/20/80	11	USGS	1.85 ⁶
USW H-1(Tcb)	12/08/80	12	USGS	0.33 ⁶
UE-25 b#1(bh)	8/07/81 9/01/81	13	USGS	2.18 ⁶
UE-25 b#1(Tcb)	7/20/82	14	USGS	3.41 ⁶
UE-25 c#1	9/30/83	15	USGS	1.14 ⁵
UE-25 c#2	3/13/84	16	USGS	3.45 ⁵
UE-25 c#3	5/09/84	17	USGS	2.80 ⁵
UE-25 ONC#1	12/15/94	19	USGS	8.23 ⁶
UE-25 p#1(v)	2/09/83	20	USGS	1.27 ⁵
UE-25 p#1(c)	5/12/83	21	USGS	2.29 ⁵
USW G-4	12/09/82	22	USGS	5.91 ⁶
USW H-3	3/14/84	23	USGS	3.72 ⁵
USW H-4	5/17/82	24	USGS	7.04 ⁶
USW H-5	7/03/82 7/26/82	25	USGS	3.41 ⁶
UE-25 UZ#16	2/24/93	26	USGS	Not available
UE-25 WT#12	No date	27	DRI	Not available
USW WT-17	7/1/98	28	USGS	4.0
UE-25 WT#3	6/22/98	29	USGS	2.6
USW H-6(bh)	10/16/82	30	USGS	2.35 ⁶
USW H-6(Tct)	6/20/84	31	USGS	4.26 ⁶
USW H-6(Tcb)	7/06/84	32	USGS	6.90 ⁶
USW WT-7	6/4/88	33	USGS	2.56 ⁶
USW WT-10	5/16/88	34	USGS	3.66 ⁶
USW VH-1	2/06/81, 2/08/81 and 2/11/81	35	USGS	2.61 ⁶
USW VH-2	9/6/92	36	USGS	0.37
Gexa Well 4	9/4/91 and 3/25/92	37	USGS	0.16 ⁶
NC-EWDP-2D	1/14/99	38	USGS	1.57 ⁶
NC-EWDP-5S	2/8/99	39	USGS	Not available

Table 1. Sampling Dates and Cross-Correlations for Unqualified Major Ion Data Sets
Used in AMR S0040 (continued)

Well Identifier	Sample Collection Date	Sample I.D. Number in AMR S0040	Sample Collection Agency ¹	Sample Anion-Cation Balance ³ (%)
NC-EWDP-3D	2/17/99, 2/18/99 and 2/20/99	40	USGS	1.78 ⁶
NC-EWDP-9S	1/14/99, 1/15/99 and 1/16/99	41	USGS	0.09 ⁶
NC-EWDP-ID	12/11/98	42	USGS	3.09 ⁶
CIND-R-LITE	9/16/92	43	USGS	7.07 ⁶
UE-25 J-11	12/16/58	44	USGS	1.02 ⁶
15S/50E-19b1	No date	45	USGS	2.11 ⁶
Airport Well	3/24/92	46	USGS	5.26 ⁶
15S/50E-18cdc	12/15/68	47	USGS	0.6
NDOT	9/3/91 and 4/27/92	48	USGS	0.54 ⁶
15S/50E-18ccc	11/17/72	49	USGS	0.8
16S/48E-23da	2/17/66	51	USBR ²	1.1
15S/49E-22a1	4/24/58	52	USGS	0.0
16S/49E-5acc	3/04/74	53	USGS	1.3
15S/49E-27acc	3/30/73	54	USGS	0.59 ⁶
15S/49E-22dcc	11/20/72	55	USGS	1.89 ⁶
15S/49E-22dc	11/20/72	56	USGS	1.2
16S/49E-8abb	11/17/72	57	USGS	1.4
16S/49E-8acc	4/01/71	58	USGS	0.7
16S/49E-9cda	11/18/72	59	USGS	2.4
16S/49E-9dcc	3/01/74	60	USGS	4.9
16S/49E-18dc	3/01/74	61	USGS	7.5
16S/49E-16ccc	6/26/79	62	USGS	0.7
16S/49E-19daa	3/05/74	63	USGS	7.8
16S/48E-24aaa	11/17/72	64	USGS	2.2
16S/48E-25aa	3/05/74	65	USGS	6.1
16S/48E-36aaa	3/04/74	66	USGS	7.1
17S/48E-1ab	3/05/74	67	USGS	6.3
17S/49E-7bb	3/01/74	68	USGS	5.6
17S/49E-8ddb	3/06/74	69	USGS	4.4
16S/49E-23add	6/25/79	70	USGS	7.3
16S/48E-23bdb	8/19/62	71	DCNR ²	1.7
16S/48E-36dcc	4/05/71	72	USGS	0.3
17S/49E-9aa	3/01/74	73	USGS	6.7
17S/49E-15bbd	3/06/74	74	USGS	1.3
17S/49E-35ddd	3/06/74	75	USGS	5.9
17S/49E-15bc	2/17/66	76	USBR	2.53 ^{4,6}
16S/48E-15dda	6/26/79	77	USGS	6.8
16S/48E-15aaa	3/31/71	78	USGS	0.4
16S/48E-10cba	3/31/71	79	USGS	2.2
16S/48E-15ba	6/24/71	80	USBR ²	0.3
TW-5	No date	81	USGS	0.68 ⁶

Table 1. Sampling Dates and Cross-Correlations for Unqualified Major Ion Data Sets
Used in AMR S0040 (continued)

Well Identifier	Sample Collection Date	Sample I.D. Number in AMR S0040	Sample Collection Agency ¹	Sample Anion- Cation Balance ³ (%)
16S/50E-7bcd	4/01/71	82	USGS	0.3
16S/49E-12ddd	6/26/79	83	USGS	1.6
16S/49E-15aaa	3/31/71	84	USGS	1.5
16S/49E-36aaa	6/24/79	85	USGS	3.53 ⁶
16S/49E-36aba	6/24/79	86	USGS	1.7
16S/49E-35aaa	6/24/79	87	USGS	4.3
16S/49E-35baa	6/24/79	88	USGS	0.7
17S/49E-11ba	3/07/74	89	USGS	0.0
18S/50E-6dac	2/12/72	90	DRI	3.4
17S/50E-19aab	12/27/71	91	DRI	0.4
18S/50E-7aa	12/28/71	92	DRI	1.64 ⁶
17S/49E-28bcd	6/23/79	93	USGS	1.8
18S/49E-1aba	4/06/71	94	USGS	1.7
18S/49E-2cbc	11/18/72	95	USGS	1.0
18S/49E-11bbb	6/23/79	96	USGS	4.4
17S/49E-29acc	6/23/79	97	USGS	4.3
16S/48E-8ba	6/24/71	98	USBR ²	1.5
16S/48E-7bba	3/30/71	99	USGS	0.1
16S/48E-7cbc	3/31/71	100	USGS	0.2
16S/48E-18bcc	6/24/79	101	USGS	1.8
16S/48E-17ccc	6/25/79	102	USGS	2.8
16S/48E-18dad	6/25/79	103	USGS	2.8
16S/48E-8cda	3/31/71	104	USGS	0.5
16S/48E-17abb	8/18/62	105	DCNR ²	0.9
27N/4E-27bbb	8/218/62	106	DCNR ²	0.2
Nucl. Eng. Co.	12/16/68	107	USGS	0.06 ⁶

1. USGS = U.S. Geological Survey; DCNR = Nevada Department of Conservation and Natural Resources; USBR = U.S. Bureau of Reclamation; DRI = University of Nevada Desert Research Institute.
2. Sample collected by others was analyzed in USGS laboratory.
3. The anion-cation balance is expressed as an absolute value in this table. Values taken from McKinley et al. 1991, Tables 1 and 5 (DTN GS920508312321.004) unless otherwise indicated.
4. Value erroneously given as 13% in McKinley et al. 1991, Table 2 (DTN GS920508312321.004)
5. Value taken from original laboratory data sheet (DTN GS920408312321.003)
6. Value calculated by data qualification team per Appendix A

Table 2. Replicate Major Ion Analyses

Well Name	Sample Collection Date	Data Source	Data Quality Status	Time Interval Between Samples	pH	Chemical Concentrations (mg/L)							
						Ca	Mg	Na	K	Cl	SO ₄	HCO ₃	SiO ₂
UE-25 WT-3	6/22/98	DTN GS980908312322.008	Q	1 hour	7.6	12	1.1	50	3.8	6.0	18	138	58
	6/22/98	DTN GS980908312322.008	Q	1.75 hours	7.7	11	1.0	49	3.8	6.0	19	134	55
	6/22/98	DTN GS980908312322.008	Q		7.7	11	1.0	48	3.8	6.0	18	135	55
USW WT-17	6/4/98	ACC: MOL.19981110.0103	UQ	2 hours	7.1	12	.93	56	3.1	15	9.6	--	31
USW WT-17	6/4/98	ACC: MOL.19981110.0103	UQ		7.1	12	1.1	55	2.9	15	11	--	31
USW UZ-14	2/25/98	ACC: MOL.19981110.0103	UQ	1 day	7.9	.48	.023	70	1.9	6.7	14	--	44
USW UZ-14	2/26/98	ACC: MOL.19981110.0103	UQ		7.4	.20	.030	74	1.9	7.7	14	--	47
UE-25 WT-3	2/05/98	DTN GS980908312322.008	Q	2 hours	7.6	11	.95	49	4.1	6.2	19	135	57
	2/05/98	DTN GS980908312322.008	Q		7.6	11	1.0	50	3.9	5.9	19	135	56
USW G-2	1/30/96	ACC: MOL.19980126.0713	UQ	9 days	7.6	8.6	.55	47	5.5	--	--	--	--
USW G-2	2/8/96	ACC: MOL.19980126.0713	UQ		7.5	8.1	.52	47	5.5	--	--	--	--
UE-25 WT-12	8/19/95	ACC: MOL.19980126.0711	UQ	2 days	--	14	.30	62	2.0	--	--	--	--
UE-25 WT-12	8/21/95	ACC: MOL.19980126.0711	UQ		--	14	.30	63	2.0	--	--	--	--
USW H-3	3/14/84	ACC: NNA.940323.0239	UQ		9.0	.80	.02	120	1.1	9.5	31	225 ¹	43
USW H-3	3/14/84	ACC: NNA.940323.0239	UQ	Laboratory Rerun	--	--	--	--	--	9.4	31	225 ¹	--
UE-25c #2	3/13/84	ACC: NNA.940323.0242	UQ	30 minutes	7.9	12	.30	53	2.0	7.0	22	117 ¹	53
	3/13/84	ACC: NNA.940323.0242	UQ		7.8	12	.40	54	2.1	7.1	22	117 ¹	54
UE-25c#1	9/30/83	ACC: NNA.940323.0241	UQ	1 minute	7.8	11	.34	56	2.1	7.2	20	140	56
	9/30/83	ACC: NNA.940323.0241	UQ		7.7	11	.34	56	2.0	7.4	23	138	56
UE-25 J-12	3/26/71	DTN GS920408312321.003	UQ	3.1 years	7.1	14	2.1	38	5.1	7.3	22	119	54
UE-25 J-12	5/01/74	ACC: MOL.19980406.1045	UQ		7.6	15	2.2	38	4.6	7.7	23	118	58
Point of Rocks Spring	11/21/66	ACC: MOL.19980406.1045	UQ	< 1 day	7.6	48	21	67	7.1	21	76	304	22
Point of Rocks Spring (small)	11/21/66	ACC: MOL.19980406.1045	UQ		7.7	46	21	68	7.5	21	78	304	22

1. Alkalinity reported as CaCO₃

APPENDIX A
ANION-CATION BALANCE FOR HYDROCHEMICAL DATA

APPENDIX A

ANION-CATION BALANCE FOR HYDROCHEMICAL DATA

Table A-1 contains examples of anion-cation balance calculations performed in an Excel spreadsheet based on information presented in Table 3 of AMR S0040. The balance is calculated as a percentage difference between the total meq/L for the cations and anions.

The meq/L for a given anion or cation is:

$$\text{meq/L} = [\text{sample concentration (mg/L)} \times \text{charge}] / \text{atomic weight}$$

The cation and anion atomic weights and charge are given below:

Cation (Anion)	Atomic Weight	Charge
Ca	40.1	+2
Mg	24.3	+2
Na	23.0	+1
K	39.1	+1
(Cl)	35.5	-1
(SO ₄)	96.1	-2
(HCO ₃)	61.0	-1

Atomic weights are based on the Periodic Table of the Elements (TIC: 245069).

For the first well identified on Table A-1 [UE-29 a#2 (dp)], the total meq/L for the cations is:

$$\text{meq/L} = [(10 \times 2)/40.1] + [(0.2 \times 2)/24.3] + [(44 \times 1)/23.0] + [(1.1 \times 1)/39.1] = 2.456 \quad (1)$$

For the anions:

$$\text{meq/L} = [(11 \times (-1))/35.5] + [(22 \times (-2))/96.1] + [(107 \times (-1))/61.0] = -2.522 \quad (2)$$

The absolute value of (2) is 2.522. (3)

The balance, expressed in percent, is equal to:

Balance % = absolute value of [(1) minus (3)] divided the sum of (1) and (3). The result is multiplied by 100. For this example:

$$\text{Balance \%} = \{[\text{ABS}(2.456 - 2.522)]/(2.456 + 2.522)\} \times 100 = 1.3 \%$$

Table A-1. Example Anion-Cation Balance Calculations

Well Identifier	Sample Collection Date	Sample I.D. in AMR S0040	Cations				Anions			Cation Sum (meq/L)	Anion Sum (meq/L)	Anion-Cation Balance (%)
			Ca	Mg	Na	K	Cl	SO ₄	HCO ₃			
UE-29 a#2 (dp)	01/08/82	1	10	0.2	44	1.1	11	22	107	2.456	2.522	1.31
US-29 a#2 (sh)	01/15/82	2	10	0.3	44	1.3	8.8	21	107	2.470	2.439	0.63
UE-25 J-12	03/26/71	3	14	2.1	38	5.1	7.3	22	119	2.654	2.614	0.75
UE-25 J-13	03/26/71	4	12	2.1	42	5	7.1	17	124	2.725	2.587	2.61
UE-25 JF#3	3/5/92	5	18	3.1	38	8.9	10	30	120	3.033	2.873	2.70
USW H-1 (Tcp)	10/20/80	11	4.5	0.1	51	2.4	5.7	18	115	2.511	2.420	1.85
USW H-1 (Tcb)	12/08/80	12	6.2	0.1	51	1.6	5.8	19	122	2.576	2.559	0.33
UE-25 b#1 (bh)	8/07/81& 9/01/81	13	18	0.66	49.5	3.6	10.75	23	156	3.196	3.339	2.18
UE-25 b#1(Tcb)	07/02/82	14	18	0.72	46	2.8	7.5	21	133	3.029	2.829	3.41
UE-25 c#1	09/30/83	15	11	0.34	56	2	7.4	23	151	3.063	3.163	1.61
UE-25 c#2	03/13/84	16	12	0.4	54	2.1	7.1	22	139	3.033	2.937	1.62
UE-25 c#3	05/09/84	17	11	0.4	55	1.9	7.2	22	137	3.021	2.907	1.94
UE-25 ONC#1	12/15/94	19	13	1.1	51	3.6	7.1	24	115	3.048	2.585	8.23
UE-25 p#1 (v)	02/09/83	20	37	10	92	5.6	13	38	282	6.812	5.780	8.19
UE-25 p#1 (c)	05/12/83	21	100	39	150	12	28	160	569	15.026	13.446	5.55
USW G-4	12/09/82	22	13	0.2	57	2.1	5.9	19	139	3.197	2.840	5.91
USW H-3	03/14/84	23	0.8	0.02	120	1.1	5.5	31	274	5.287	5.292	0.05
USW H-4	05/17/82	24	17	0.29	73	2.6	6.9	26	173	4.112	3.572	7.04
USW H-5	7/03/82 & 7/26/82	25	1.95	0.01	60	2.1	6.1	16	126.5	2.760	2.579	3.41
USW H-6 (bh)	10/16/82	30	4.1	0.09	86	1.3	7.6	29	182	3.984	3.801	2.35
USW H-6 (Tct)	06/20/84	31	1.4	0.02	88	1.3	7.2	25	217	3.931	4.280	4.26
USW H-6 (Tcb)	07/06/84	32	4.7	0.07	88	1.4	7.4	32	234	4.102	4.710	6.90
USW WT-7	6/4/88	33	2.6	0.18	97	2.1	13	7.2	252	4.416	4.647	2.56
USW WT-10	5/16/88	34	2.6	0.045	94.5	1	7.8	33.5	186	4.268	3.966	3.66
USW VH-1	2/6/81 & 2/8/81 & 2/11/81	35	10.3	1.53	79	1.9	10.33	44.33	164.7	4.123	3.914	2.61

Table A-1. Example Anion-Cation Balance Calculations (Continued)

Well Identifier	Sample Collection Date	Sample I.D. in AMR S0040	Cations				Anions			Cation Sum (meq/L)	Anion Sum (meq/L)	Anion-Cation Balance (%)
			Ca	Mg	Na	K	Cl	SO ₄	HCO ₃			
USW WT-10	5/16/88	34	2.6	0.045	94.5	1	7.8	33.5	186	4.268	3.966	3.66
USW VH-1	2/6/81 & 2/8/81 & 2/11/81	35	10.3	1.53	79	1.9	10.33	44.33	164.7	4.123	3.914	2.61
Gexa Well 4	9/4/91 and 3/25/92	37	11.5	0.37	71	3.25	13.5	45.5	150	3.774	3.786	0.16
NC-EWDP-2D	1/14/99	38	19	1.2	42	4.1	6.1	22	149	2.977	3.072	1.57
NC-EWDP-3D	2/17/99, 2/18/99, 2/20/99	40	0.51	0.07	113	3.0	9.0	45	223	5.021	4.846	1.78
NC-EWDP-9S	1/14/99, 1/15/99, 1/16/99	41	20.3	7.7	76	4.3	11.0	61.7	212	5.061	5.069	0.09
NC-EWDP-1D	12/11/98	42	55.5	31	73.5	10	16	136	369	8.771	9.330	3.09
CIND-R-LITE	9/16/92	43	12.33	6.17	71.7	3.97	9.23	46	193.7	4.342	3.768	7.07
UE-25 J-11	12/16/58	44	82	13	143	15	18	449	102	11.761	11.524	1.02
15S/50E-19b1	No date	45	20	3.9	107.5	6	17.5	127.5	167.5	6.146	5.892	2.11
Airport Well	3/24/92	46	5.6	0.23	70	1.5	10	46	110	3.380	3.042	5.26
NDOT	9/3/91, 4/27/92	48	16.33	0.813	101.3	3.83	14.67	110	160	5.384	5.325	0.54
15S/49E-27acc	3/30/73	54	22	1.6	48	2.9	7.3	36	151	3.390	3.430	0.59
15S/49E-22dcc	11/20/72	55	27	2.0	43	4.6	8.5	33	149	3.498	3.369	1.89
17S/49E-15bc	02/17/66	76	21.6	1	39.1	6.6	10.6	27.9	122	3.028	2.879	2.53
TW-5	No date	81	33	17	130	12	21	99	395	9.004	9.127	0.68
16S/49E-36aaa	06/24/79	85	52.1	22.1	120	18	26.9	168.1	314.2	10.095	9.407	3.53
18S/50E-7aa	12/28/71	92	25.7	9.5	140.9	19.2	37.6	147	261.2	8.681	8.400	1.64
Nucl. Eng. Co.	12/16/68	107	54.9	14.1	170.1	10.2	79.1	190.2	328.3	11.555	11.569	0.06