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**ESTIMATION OF GROUNDWATER VELOCITIES
FROM YUCCA FLAT TO THE
AMARGOSA DESERT USING GEOCHEMISTRY AND
ENVIRONMENTAL ISOTOPES**

prepared by

Ronald L. Hershey and Steve Y. Acheampong

MASTER

submitted to

Nevada Operations Office
U.S. Department of Energy

June 1997

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Las Vegas, Nevada

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ABSTRACT

Geochemical modeling techniques were applied to groundwater flowpaths from Yucca Flat on the Nevada Test Site (NTS) to the Amargosa Desert, south of the NTS to estimate groundwater flow velocities for independent comparison to velocities calculated by other methods. The groundwater flowpaths examined considered flow in the carbonate aquifer beneath Yucca and Frenchman flats mixing with flow from carbonate aquifers east and southeast of the NTS and discharging at wells south of the NTS border. The approach used the computer codes WATEQ4F and NETPATH to calculate chemical speciation, determine the saturation state of mineral phases, and simulate mixing and the possible chemical reactions along the flowpath. The reactions were used to predict the $\delta^{13}\text{C}$ and ^{14}C values of the final downgradient water. These calculated carbon isotopic values were then compared to data to test the validity of the modeled geochemical reactions. Travel times produced by the modeling were used to calculate groundwater velocities for the various flowpaths.

Fifty-six different groundwater mixing and geochemical evolution scenarios were considered. All simulations used Ca, Mg, HCO_3 , and SO_4 to constrain each simulation; reactive mineral phases were calcite, dolomite, gypsum, Ca-montmorillonite, and Mg-montmorillonite, along with cation exchange between Ca and Na. Mixing proportions for each simulation were calculated two different ways using Cl concentrations or $\delta^{18}\text{O}$ values. Running the 56 different mixing and groundwater geochemical evolution scenarios with two different mixing proportions for each scenario resulted in a total of 99 simulations evaluated. Resultant models from each simulation were considered valid if the precipitation and dissolution constraints applied to the mineral phases were not ignored by NETPATH and if the modeled $\delta^{13}\text{C}$ value was within $\pm 1.0\text{‰}$ of the measured $\delta^{13}\text{C}$ value of the final groundwater.

The results of the geochemical and isotopic modeling suggest that only a few mixing scenarios from Yucca Flat to Army #1 Water Well and Amargosa Tracer Well #2 are possible. These scenarios required mixing of carbonate aquifer water represented by Water Well C-1 with Spring Mountain water represented by Cold Creek Spring and/or a component of overlying volcanic aquifer groundwater represented by UE-5e PW-3. None of the mixing scenarios using either UE-1q or ER-6-1 groundwater to represent Yucca Flat groundwater were successful. Also, none of the mixing scenarios using USGS HTH #3 representing groundwater flow from east of the NTS were successful. This suggests that either the flowpath is not valid or that USGS HTH #3 is not representative of eastward flowing groundwater.

For the successful mixing scenarios, additional NETPATH modeling simulations with Si, Na, and K added as constraints and several major volcanic minerals added as phases were conducted to account for the possible interaction of groundwater with volcanic-rock aquifers in the geologically complex NTS flow system. The additional mineral phases included anorthite, Na-montmorillonite, K-montmorillonite, albite, potassium feldspar, and Mg/Na exchange. The increased complexity of the modeling simulations provided better constraint on the total chemical mass balance and tested the variability of travel times originally calculated with the simpler simulations.

The successful geochemical and isotopic mixing models suggest that the proportion of groundwater flowing from Yucca Flat to Frenchman Flat is larger (20 to 57 percent), the groundwater flow from the east (USGS HTH #3 representing flow from the Sheep Range) and

southeast (Cold Creek Spring representing from the Spring Mountains) to Frenchman Flat is smaller (0 to 54 percent), and the flow from the overlying volcanic aquifer into the carbonate aquifer is larger (8 to 60 percent) than the present conceptual model. Only one geochemical evolution model evolving Army #1 Water Well to Amargosa Tracer Well #2 had non-changing conservative tracers (Cl and $\delta^{18}\text{O}$) from initial to final groundwater.

A mixing zone for the three valid mixing simulations was delineated by evaluating the potentiometric map of the NTS and vicinity. The mixing zone delineated is roughly southwest of Frenchman Lake in Frenchman Flat. Distances measured from the mixing zone were divided by the range of travel times developed during geochemical and isotopic modeling to produce groundwater velocities. Groundwater velocities from Yucca Flat to Army #1 Water Well and Amargosa Tracer Well #2 ranged from 0.9 m/yr to 10.0 m/yr. Calculated velocities from Yucca Flat are slower (0.9 to 1.3 m/yr) when overlying volcanic waters are not included in the simulations (Water Well C-1 plus Cold Creek Spring to Army #1 Water Well); calculated velocities from Yucca Flat including overlying volcanic waters are somewhat faster (1.0 to 5.8 m/yr for Water Well C-1, Cold Creek Spring, and UE-5e PW5 to Army #1 Water Well and 1.6 to 2.6 m/yr to Amargosa Tracer Well #2). The fastest velocities are from the geochemical evolution simulation from Army #1 Water Well and Amargosa Tracer Well #2 (5.6 to 10.0 m/yr). These groundwater velocities fall at the lower end of groundwater velocities for the area reported by others (1.8 to 18,288 m/yr).

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INTRODUCTION

Geochemical and isotopic data from groundwater sampling locations can be used to estimate groundwater flow velocities for independent comparison to velocities calculated by other methods. In this study, geochemical modeling techniques were applied to groundwater flowpaths from Yucca Flat on the Nevada Test Site (NTS) to the Amargosa Desert, south of the NTS. The flowpaths, previously delineated by other investigations (Winograd and Thordarson, 1975; Waddell *et al.*, 1984; Lacznia *et al.*, 1996), include groundwater flow in the carbonate aquifer beneath Yucca and Frenchman flats mixing with flow from east and southeast of the NTS and discharging at wells south of the NTS (Figure 1). Available groundwater geochemical and environmental isotopic data were used to evaluate groundwater mixing ratios and calculate groundwater velocities. However, groundwater flowpath simulations from models are not unique; any number of different simulations can provide the same end result. In the chemical and isotopic models in this report, knowledge of the hydrology, mineralogy, and groundwater geochemistry was combined to constrain feasible groundwater geochemical mixing and flowpath evolution simulations.

OBJECTIVE

The objective of this study was to calculate groundwater flow velocities using geochemistry and environmental isotopes from the southern end of Yucca Flat to the Amargosa Desert, considering mixing of different groundwater inputs from sources east and southeast of the NTS.

APPROACH

The approach used to accomplish the objective of this study consisted of five steps: 1) reviewing and selecting locations where carbon isotopic groundwater analyses, reliable ionic analysis, and well completion information are available; 2) calculating chemical speciation with the computer code WATEQ4F (Ball and Nordstrom, 1991) to determine the saturation state of mineral phases for each groundwater location; 3) grouping wells into reasonable flowpaths and mixing scenarios from different groundwater sources; 4) using the computer code NETPATH (Plummer *et al.*, 1991) to simulate mixing and the possible chemical reactions along the flowpath, and to calculate the changes in carbon-13/carbon-12 isotopic ratios ($\delta^{13}\text{C}$) as a result of these reactions; and, 5) using carbon-14 (^{14}C) data to calculate velocity.

BACKGROUND INFORMATION

Available Chemical and Carbon Isotopic Data

A considerable number of wells have been drilled at the NTS, but the number of wells with reliable carbon isotopic data are quite few. Groundwaters from eight wells and one spring which met the criteria outlined in the study approach were selected for use in this study. The groundwater locations are shown in Figure 1 and the chemical compositions used for simulations are listed in Table 1. Trilinear and Stiff diagrams (Figures 2 and 3) show graphically the differences in major-ion composition of each groundwater.

Figure 1. Groundwater locations and general flow directions used to calculate groundwater velocities at the Nevada Test Site.

TABLE 1. CHEMICAL DATA USED FOR MODELING GROUNDWATER MIXING AND CALCULATING GROUNDWATER VELOCITIES AT THE NEVADA TEST SITE (units are milligrams/liter unless otherwise noted).

Ground-water	Army #1 Water Well	UE-1q	ER-6-1	Water Well C-1	Amargosa Tracer Well #2	Cold Creek Spring	USGS HTH #3	UE-5e PW-3
Source	Winograd and Pearson	DRI Files	DRI Files	Boughton	Winograd and Pearson	Hershey	Lyles <i>et al.</i>	DRI Files
Temp, °C	31	31.0	43.7	36.4	31	10.0	34.5	17
pH	7.4	7.73	7.31	6.58	7.4	7.77	7.4	8.4
SiO ₂	19	50.5	34.3	30.0	22	7.0	17.4	39.1
Ca	45.1	28.8	33.4	75.4	44.5	69.1	48.8	18.3
Mg	21.6	14.8	12.2	29.7	19.6	17.0	19.7	5.58
Na	37.7	29.5	47.0	127.0	64.6	1.9	79.6	56.7
K	5.47	5.0	8.32	14.0	7.8	0.58	9.18	6.15
Cl	16.3	6.3	11.8	33.6	19.9	1.6	23.2	9.2
HCO ₃	275.2	205	228	587	291.0	272	323	140
SO ₄	54.3	22.1	32.1	65.5	70.1	8.5	66.8	35.3
F	0.95	0.47	0.68	1.2	1.71	0.1		
NO ₃		4.21	0.58			0.7	<0.004	14.7
Al	0.019*	<0.02	<0.02	0.024*				
Ba	0.11*	0.058	0.134	0.14*				
B	0.184*			0.538*				
Cu	0.007*	0.022	0.034	0.03*			0.12	
Fe	0.018*	0.01	0.06	0.038*		0.03		
Li	0.07	0.021	0.035	0.3*	0.08		0.11	
Mn	0.007*	<0.005	0.009	0.0007 [†]				
Sr	0.75			0.077*	0.77	0.21	0.89	

Sources: Boughton (1986), Desert Research Institute files, Hershey (1989), Lyles *et al.* (1991), Winograd and Pearson (1976).

*Average of trace data from Claassen (1973)

[†]Davisson *et al.* (1994)

All available isotopic data for each groundwater are listed in Table 2. As seen in Table 2, there is a wide range of carbon isotopic values for several groundwaters where sample collection has spanned many years. For example, $\delta^{13}\text{C}$ values for Army #1 Water Well spanning from 1965 through 1993 range from -11.99 to -5.6 per mil (‰) and the percent modern carbon (pmc) ranges from 2.8 to 10.6. These variations may be the result of different sampling procedures (*e.g.*, pumping versus bailing), different sample preparation (*e.g.*, field precipitation of carbonate versus laboratory precipitation), different analytical techniques (scintillation counting versus accelerator mass spectrometry), and/or the time of sampling (*e.g.*, collected during drilling versus collected after 10 years of continuous water-supply pumping). Geochemical and isotopic models that will produce reliable results must use the best and the most consistent data set possible.

- A UE-1q
- B ER-6-1
- C Water Well C-1
- D UE-5e PW-3
- E USGS HTH #3
- F Cold Creek Spring
- G Army #1 Water Well
- H Amargosa Tracer Well #2

Figure 2. Trilinear diagram showing major-ion chemistry of groundwaters used to model mixing and calculate velocities at the Nevada Test Site.

To produce the most consistent isotopic data set possible for the simulations in this study, as many data as possible were selected from the same laboratory. The majority of the isotopic data used were produced by the Desert Research Institute (DRI). The DRI data were selected (where possible) because of the internal consistency of the DRI sampling procedures and analytical techniques over time, the relatively recent sample collection dates (1980s and 1990s for the DRI versus 1960s and 1970s for the U. S. Geological Survey (USGS)), and the authors' familiarity with the DRI sampling procedures and analytical techniques. Table 3 lists the isotopic data used for simulations in this study. USGS carbon isotopic data were selected for Amargosa Tracer Well #2 and Army #1 Water Well; all other data were generated by DRI. Since a deuterium/hydrogen isotopic ratio (δD) was not available for Amargosa Tracer Well #2, oxygen-18/oxygen-16 ratios ($\delta^{18}O$) were used to calculate mixing proportions.

Figure 3. Stiff diagrams comparing major-ion chemistry of groundwaters used to model Nevada Test Site groundwater mixing and calculating groundwater velocities.

TABLE 2. AVAILABLE ISOTOPIC DATA FOR NEVADA TEST SITE GROUNDWATERS.

Groundwater	Collect Date	$\delta^{13}\text{C}$ (‰)	^{13}C Laboratory	^{14}C (pmc)	$\delta^{14}\text{C}$ (‰)	Age (yrs)	^{14}C Laboratory	δD (‰)	$\delta^{18}\text{O}$ (‰)	δD and $\delta^{18}\text{O}$ Laboratory	Source	Report Date
Amargosa Tracer Well #2	02/14/68	-7.4	TI	7.3	-	21,000	USGS	-	-	-	Schroder <i>et al.</i>	1973
	09/09/69	-	-	20.1	-	12,900	USGS	-	-	-	Schroder <i>et al.</i>	1978
	09/28/69	-	-	35.6	-	8,300	USGS	-	-	-	Schroder <i>et al.</i>	1978
	11/08/69	-6.0	TI	5.1	-	24,600	USGS	-	-	-	Schroder <i>et al.</i>	1978
	11/17/73	-	-	1.8	-	-	USGS	-	-13.6	USGS	Winograd and Pearson	1976
	03/07/75	-4.6	USGS	-	-	-	-	-	-	-	Winograd and Pearson	1976
Army #1 Water Well	-	-11.99	USGS	6.5	-935	22,000	USGS	-	-	-	Grove <i>et al.</i>	1969
	02/09/65	-9.9	USGS	10.6	-	18,000	USGS	-	-	-	Schroder <i>et al.</i>	1978
	02/09/65	-7.1	TI	10.0	-	18,500	USGS	-	-	-	Schroder <i>et al.</i>	1978
	11/16/67	-	-	4.4	-	25,100	USGS	-	-	-	Schroder <i>et al.</i>	1973
	01/-/69	-	-	-	-	-	-	-107	-	-	Winograd and Friedman	1972
	03/-/70	-	-	-	-	-	-	-106	-	-	Winograd and Friedman	1972
	12/11/74	-5.6	USGS	-	-	-	-	-	-	-	Winograd and Pearson	1976
	03/07/75	-5.6	USGS	2.8	-	-	USGS	-	-	-	Winograd and Pearson	1976
	06/21/82	-	-	-	-	-	-	-99	-13.1	DRI	Boughton	1986
	04/16/90	-5.9	DRI	-	-	-	-	-99	-14.1	DRI	DRI Files	-
	05/12/93	-	-	5.4	-	24,129	LLNL	-	-	-	Davisson <i>et al.</i>	1994
	-	-20.14	USGS	83.6	-164	1,400	USGS	-	-	-	Grove <i>et al.</i>	1969
	02/17/65	-11.6	TI	95.7	-	350	USGS	-	-	-	Schroder <i>et al.</i>	1978
Cold Creek Spring	12/12/66	-11.6	TI	82.9	-	1,500	USGS	-	-	-	Schroder <i>et al.</i>	1973
	08/-/68	-	-	-	-	-	-	-100	-	-	Winograd and Friedman	1972
	01/-/69	-	-	-	-	-	-	-105	-	-	Winograd and Friedman	1972
	03/-/70	-	-	-	-	-	-	-106	-	-	Winograd and Friedman	1972
	05/31/73	-10.3	USGS	-	-	-	-	-	-	-	Winograd and Pearson	1976
	11/13/73	-9.7	USGS	-	-	-	-	-	-	-	Winograd and Pearson	1976
	12/09/74	-9.3	USGS	-	-	-	-	-	-	-	Winograd and Pearson	1976
	11/10/75	-9.4	USGS	69.3	-	-	USGS	-	-	-	Winograd and Pearson	1976
	01/21/87	-	-	-	-	-	-	-100	-13.7	DRI	Hershey	1989
	03/31/87	-9.3	DRI	66.7	-333	-	TI	-99	-13.8	DRI	DRI Files	-

TABLE 2. AVAILABLE ISOTOPIC DATA FOR NEVADA TEST SITE GROUNDWATERS (Continued).

Groundwater	Collect Date	$\delta^{13}\text{C}$ (‰)	^{13}C Laboratory	^{14}C (pmc)	$\delta^{14}\text{C}$ (‰)	Age (yrs)	^{14}C Laboratory	δD (‰)	$\delta^{18}\text{O}$ (‰)	δD and $\delta^{18}\text{O}$ Laboratory	Source	Report Date
Cold Creek Spring	05/07/87	-10.9	TI	68.0	-320	-	TI	-	-	-	DRI Files	-
	10/20/95	-9.6	DRI	-	-	-	-	-	-	-	DRI Files	-
ER-6-1	10/09/92	-	-	-	-	-	-	-108	-	DRI	DRI Files	-
	10/09/92	-6.3	DRI	2.4	-	-	Krueger	-107	-14.0	DRI	DRI Files	-
	10/09/92	-0.7	LLNL	2.1	-	31,900	LLNL	-	-	-	Davisson <i>et al.</i>	1994
UE-5c PW-3	1991	-7.9	Krueger	17.1	-	-	Krueger	-	-	-	DRI Files	-
	01/20/93	-7.4	DRI	-	-	-	-	-103	-13.3	DRI	DRI Files	-
	05/26/93	-7.4	LLNL	21.0	-	12,897	LLNL	-	-	-	Davisson <i>et al.</i>	1994
UE-1q	08/20/91	-10.1	DRI	-	-	-	-	-109	-14.6	DRI	DRI Files	-
	07/10/92	-8.5	DRI	3.8	-	-	Krueger	-107	-14.8	DRI	DRI Files	-
	07/10/92	-2.4	LLNL	7.7	-	20,650	LLNL	-	-	-	Davisson <i>et al.</i>	1994
USGS HTH #3	06/09/90	-	-	-	-	-	-	-104	-14.2	DRI	DRI Files	-
	06/16/90	-	-	-	-	-	-	-103	-14.2	DRI	DRI Files	-
	1991	-9.2	DRI	36.9	-	8,010	UA	-	-	-	DRI Files	-
Water Well C-1	-	-13.84	USGS	3.0	-970	28,000	USGS	-	-	-	Grove <i>et al.</i>	1969
	02/09/65	-5.5	TI	10.4	-	18,200	USGS	-	-	-	Schroder <i>et al.</i>	1978
	09/27/83	-3.8	DRI	0.8	<-992	>39,920	TI	-102	-12.8	DRI	Boughton	1986
	09/11/89	-	-	-	-	-	-	-108	-13.7	DRI	Sadler	1990
	04/16/90	-	-	-	-	-	-	-108	-14.6	DRI	DRI Files	-
	09/11/90	-	-	-	-	-	-	-109	-14.4	DRI	DRI Files	-
	05/19/93	-	-	1.0	-	37,827	LLNL	-	-	-	Davisson <i>et al.</i>	1994

Laboratory: DRI - Desert Research Institute; Krueger - Krueger Enterprises Inc.; LLNL - Lawrence Livermore National Laboratory; TI - Teledyne Isotopes; UA - University of Arizona; USGS - U.S. Geological Survey

TABLE 3. ISOTOPIC DATA USED TO SIMULATE GROUNDWATER MIXING AND FLOWPATH EVOLUTION AT THE NEVADA TEST SITE.

Groundwater	$\delta^{13}\text{C}$ (‰)	^{14}C (pmc)	δD (‰)	$\delta^{18}\text{O}$ (‰)
Amargosa Tracer Well #2	-4.6	1.8	-	-13.6
Army #1 Water Well	-5.6	2.8	-99	-14.1
Cold Creek Spring	-9.3	66.7	-100	-13.7
ER-6-1	-6.3	2.4	-107	-14.0
UE-1q	-8.5	3.8	-107	-14.8
UE-5e PW-3	-7.4	17.1	-103	-13.3
USGS HTH #3	-9.2	36.9	-103	-14.2
Water Well C-1	-3.8	0.8	-109	-14.4

Spatial Distribution of Groundwater Chemical and Isotopic Data

Each groundwater location and the chemical and isotopic data used for simulations are described below.

Amargosa Tracer Well #2. This well was completed in 1966 for a tracer study 25 kilometers (km) southwest of the NTS. The well was drilled to a total depth of 252.4 meters (m). The well penetrates Cenozoic-age lake clays and sands, cemented alluvial gravels, a thin basalt flow, and tuffaceous sands. Beneath the Cenozoic rocks, the well penetrates approximately 52.7 m of Paleozoic-age brecciated dolomite of the Bonanza King Formation and limestone with some interbedded shale of the Carrara Formation (Johnson, 1968). The water level on November 21, 1966, was 11.97 m (719.6 m above mean sea level). The water chemistry data used in this study were an average of five water samples from Winograd and Pearson (1976). The carbon isotopic values are individual analyses also from Winograd and Pearson (1976).

Army #1 Water Well. This water-supply well was drilled in 1962 and was drilled to a total depth of 593.1 m. The well penetrates sand and gravel, and bedded and reworked tuff. Beneath these rocks, the well penetrates 407.2 m of carbonate rocks (Claassen, 1973). Winograd and Thordarson (1975) identified these rocks as Paleozoic in age with 116.7 m of saturated dolomite and limestone of the Nopah Formation (?) overlying 186.8 m of interbedded shale and limestone, and brecciated and calcified limestone and dolomite of the Bonanza King Formation (?). The water level on November 7, 1963, was 239.3 m (722.1 m above mean sea level) (Young, 1965). There is a wide range of carbon isotopic values for this well as stated previously. For consistency between the $\delta^{13}\text{C}$ and ^{14}C values, the USGS sample from 1975 with a $\delta^{13}\text{C}$ of -5.6 ‰ and a ^{14}C of 2.8 pmc (Winograd and Pearson, 1976) was used in this study.

Cold Creek Spring. This spring is located on an alluvial fan on the northeast side of the Spring Mountains, approximately 30 km southeast of the NTS. The spring issues at the head of an erosional

cut in the alluvium at an elevation of 1930 m. Hughes (1966) suggested that the large spring discharge (over 400 liters/minute) originates from a buried karst system. This spring was used to represent the groundwater chemistry of water from the Spring Mountains that flows towards the NTS and the Amargosa Desert. Recent carbon isotopic data are in good agreement; however, older isotopic data from the 1960s have lighter $\delta^{13}\text{C}$ values and younger ^{14}C values. Samples collected in 1987 by DRI were selected for this study.

ER-6-1. This well was drilled in 1992 to a total depth of 648.9 m. The well penetrates Quaternary alluvium, Tertiary volcanic tuffs and Paleozoic Simonson Dolomite (?). The well is completed in the Simonson Dolomite (?). The water level on August 21, 1991, was 471.2 m (729.7 m above mean sea level) (Gillespie, 1993). The well is located on the southeastern edge of Yucca Flat. Only one chemical analysis is available and was sampled by pumping after aquifer tests were conducted. Duplicate carbon isotopic analyses were conducted by Lawrence Livermore National Laboratory (LLNL) and DRI. There is good agreement between two ^{14}C values; however, there is poor agreement between the $\delta^{13}\text{C}$ values. The DRI generated $\delta^{13}\text{C}$ value of -6.3 ‰ was selected for modeling.

UE-1q. This well was originally drilled in 1980 and was deepened in 1992 to 792.5 m. The well penetrates Quaternary alluvium, Tertiary volcanic tuffs, and Paleozoic carbonates. The well is completed in the Paleozoic carbonates (DOE, 1996). The water level on May 27, 1992, was 503.5 m (740.6 m above mean sea level). UE-1q is located in the central part of Yucca Flat and lies west of the Yucca fault which has been interpreted as a major hydraulic barrier preventing east-west flow in the carbonates. Only one chemical analysis is available since the well was recompleted in the carbonate aquifer. The well was sampled by pumping after aquifer tests were conducted. Duplicate carbon isotopic analyses were conducted by LLNL and DRI. There is poor agreement between the ^{14}C and $\delta^{13}\text{C}$ values. The DRI generated $\delta^{13}\text{C}$ value of -8.5 ‰ and the ^{14}C value of 3.8 pmc were selected for modeling.

UE-5e PW-3. This well penetrates sandy textured alluvium and volcanic tuffs on an alluvial fan surface in eastern Frenchman Flat. The well is completed at the unconfined water table. A water sample was collected with a discrete bailer by DRI on January 20, 1993, for chemistry and isotopic analysis. A sample for ^{14}C analysis was collected by pumping by DRI approximately one year later. There is good agreement between the carbon isotopic data generated by DRI and an LLNL sample collected the same year (Davission *et al.*, 1994). The DRI data were used for modeling.

USGS HTH #3. This well was drilled in 1962 to a total depth 565 m and is located east of Frenchman Flat beyond the NTS boundary within the Nellis Air Force Range. The well is on the flank of the Ranger Mountains at an elevation of 1,060 m and penetrates Quaternary/Tertiary-age alluvium and limestone, dolomite, and shale of Paleozoic age (Lyles *et al.*, 1991). The water level on June 9, 1990, was 337 m (723 m above mean sea level). Currently, sampling of USGS HTH#3 is possible only through a 7.3-cm tube. One water sample was collected by bailing for chemical and isotopic analysis on this date. During sampling, oil was encountered at the top of the water column.

The well was visited approximately one year later and a water sample was bailed for carbon isotopic analysis. These samples were used for modeling in this study.

Water Well C-1. This water-supply well was drilled in 1962 to a total depth of 502.9 m. The well penetrates sand and gravel, zeolitized bedded and reworked tuff, and limestone of the Cambrian Carrara Formation (Winograd and Thordarson, 1975). The well is completed in the Carrara Formation. The water level on October 10, 1963, was 470.6 m (724.6 m above mean sea level) (Young, 1965). The well was used for a tritium tracer experiment in 1965 and tritium in this well continues to be above normal background levels; however, this should not affect other isotopic data. Carbon isotopic data are in poor agreement; the DRI ^{14}C value of 0.8 pmc and $\delta^{13}\text{C}$ value of -3.8 ‰ were selected for modeling.

RESULTS

The aqueous chemical composition of the eight groundwaters above were analyzed by the equilibrium thermodynamic chemical speciation computer program WATEQ4F to calculate the saturation state of important minerals for each groundwater. Various groundwater mixing and flowpath geochemical evolution scenarios were developed. These scenarios were then simulated with the net geochemical mass-balance reaction computer program NETPATH. The results of the groundwater speciation, mixing simulations, and chemical evolution simulations are listed below.

Mineral Saturation States Calculated by WATEQ4F

Table 4 lists the partial pressure of dissolved carbon dioxide (P_{CO_2}) and the saturation state of important minerals as calculated by WATEQ4F. Limited trace-ion data were only available for ER-6-1, UE-1q, Army #1 Water Well, and Water Well C-1; therefore, these wells have saturation states calculated for minerals having trace ions in their chemical formula. Detectable aluminum (Al) concentrations were only available for Army #1 Water Well and Water Well C-1; therefore, these wells have calculated saturation states for important Al-bearing, igneous minerals and weathering-product clay and zeolite minerals.

The saturation state of a mineral is indicated by the saturation index (SI) which is equal to the $\log \text{IAP}/K_T$ where IAP is the ion-activity product of the mineral-water reaction and K_T is the thermodynamic equilibrium constant. Saturation for a mineral is indicated when the SI is between -1.0 and +1.0; undersaturation is $\text{SI} < -1.0$ and oversaturation is $\text{SI} > +1.0$. All groundwaters are saturated with respect to the minerals aragonite, calcite, dolomite, and quartz. All groundwaters are undersaturated with respect to gypsum. Army #1 Water Well and Water Well C-1 are undersaturated with respect to the Al-bearing igneous minerals albite, anorthite, chlorite, enstatite, diopside, phlogopite, and tremolite; saturated with respect to the Al-bearing minerals adularia, boehmite, gibbsite, and phillipsite; and supersaturated with respect to the Al-bearing clay and zeolite minerals, beidellite, illite, kaolinite, laumontite, leonhardite, calcium montmorillonite, and pyrophyllite.

Modeling Simulations Using NETPATH

Fifty-six different groundwater mixing and geochemical evolution scenarios were considered. All simulations used measured concentrations of calcium (Ca), magnesium (Mg), bicarbonate

TABLE 4. WATEQ4F CALCULATED CARBON DIOXIDE PARTIAL PRESSURE (P_{CO_2}) AND MINERAL SATURATION INDICES (SI) FOR NEVADA TEST SITE GROUNDWATERS.

		ER-6-1	UE-1q	Army #1 Water Well	Water Well C-1	Amargosa Tracer Well #2	Cold Creek Spring	USGS HTH #3	UE-5e PW-3
log P_{CO_2}		-1.84	-2.40	-1.94	-0.77	-1.92	-2.44	-1.85	-3.32
Mineral	Elements	SI	SI	SI	SI	SI	SI	SI	SI
Adularia	K Al Si			-0.48	0.04				
Albite	Na Al Si			-1.91	-1.22				
Analcime	Na Al Si			-3.59	-3.01				
Anorthite	Ca Al Si			-3.01	-2.80				
Aragonite	Ca C	-0.15	0.00	-0.05	-0.31	-0.04	0.21	0.08	0.10
Beidellite	Ca Na Mg K Al Si			1.77	3.18				
Boehmite	Al			0.28	0.82				
Calcite	Ca C	-0.02	0.14	0.09	-0.18	0.10	0.37	0.22	0.25
Chalcedony	Si	0.10	0.40	-0.02	0.12	0.05	-0.20	-0.10	0.45
Chlorite 14A	Mg Al Si			-2.05	-6.99				
Chlorite 7A	Mg Al Si			-5.36	-10.26				
Chrysotile	Mg Si	-3.09	-1.38	-3.83	-7.48	-3.87	-5.36	-3.67	-0.58
Clinoenstatite	Mg Si	-2.58	-2.05	-3.00	-4.12	-3.00	-3.83	-2.94	-0.94
Cristobalite	Si	0.10	0.43	0.01	0.14	0.07	-0.13	-0.08	0.50
Diaspore	Al			1.93	2.43				
Diopside	Ca Mg Si	-2.49	-1.35	-3.23	-5.46	-3.18	-4.19	-3.09	-0.63
Dolomite (d)	Ca Mg C	-0.45	-0.12	-0.25	-0.81	-0.28	-0.37	0.03	-0.37
Dolomite (c)	Ca Mg C	0.03	0.40	0.27	-0.30	0.24	0.24	0.48	0.22
Fosterite	Mg Si	-7.18	-6.51	-8.01	-10.32	-8.06	-9.69	-7.77	-6.47
Gibbsite	Al			0.67	1.14				
Gypsum	Ca S	-2.35	-2.56	-2.06	-1.89	-1.97	-2.62	-1.96	-2.50
Halloysite	Al Si			-2.02	-0.74				
Illite	K Mg Al Si			0.93	1.94				

TABLE 4. WATEQ4F CALCULATED CARBON DIOXIDE PARTIAL PRESSURE (P_{CO_2}) AND MINERAL SATURATION INDICES (SI) FOR NEVADA TEST SITE GROUNDWATERS (Continued).

Mineral	Elements	ER-6-1	UE-1q	Army #1 Water Well	Water Well C-1	Amargosa Tracer Well #2	Cold Creek Spring	USGS HTH #3	UE-5e PW-3
		SI	SI	SI	SI	SI	SI	SI	SI
Kaolinite	Al Si			2.98	4.19				
Kmica	K Al Si			6.51	7.99				
Laumontite	Ca Al Si			0.83	1.09				
Leonhardite	Ca Al Si			9.34	9.72				
Magnesite	Mg C	-0.55	-0.33	-0.41	-0.72	-0.57	-0.65	-0.33	-0.58
Montmorillonite	Ca Al Si			1.56	2.98				
Phillipsite	K Na Al Si			-0.20	0.76				
Phlogopite	K Mg Al Si			-28.64	-31.91				
Prehnite	Ca Al Si			-2.86	-3.92				
Pyrophyllite	Al Si			7.10	9.34				
Quartz	Si	0.47	0.81	0.39	0.52	0.54	0.28	-0.31	0.90
Spiolite	Mg Si	-2.76	-0.68	-3.01	-5.40	-2.93	-3.54	-3.16	0.45
Silica gel	Si	-0.42	-0.13	-0.55	-0.40	-0.48	-0.74	-0.62	-0.09
SiO ₂	Si	-0.68	-0.42	-0.84	-0.68	-0.77	-1.09	-0.90	0.42
Talc	Mg Si	1.04	3.21	-0.09	-3.39	0.00	-2.28	-0.05	3.90
Tremolite	Ca Mg Si	0.06	4.92	-2.13	-10.08	-1.95	-5.48	-1.93	7.54

(c), (d) indicate different thermodynamic data used to calculate saturation index.

(HCO₃), and sulfate (SO₄) to constrain each simulation. The mineral phases allowed to react with groundwaters were calcite, dolomite, gypsum, Ca-montmorillonite, and Mg-montmorillonite. WATEQ4F calculations suggest that precipitation of Ca- and Mg-bearing secondary minerals may be occurring. Beidellite, illite, laumontite, leonhardtite, and Ca-montmorillonite are supersaturated at Water Well C-1 and Army #1 Water Well (only wells with detectable Al) and are considered possible precipitating phases in the carbonate aquifer. Also, clay minerals and zeolites are abundant in the overlying volcanic rocks. Because NETPATH does not include most of these minerals in its database, Ca- and Mg-montmorillonites are used as sinks for excess Ca and Mg in the simulations. Cation exchange between Ca and sodium (Na) was also included as a phase in each simulation. Because of the great depth to groundwater and the large thickness of overlying saturated volcanic rock at the NTS, the hydrologic system is considered closed to any carbon dioxide reservoir; therefore, carbon dioxide gas was not used as a mineral phase.

The chemical simulations were further constrained by allowing dolomite and gypsum to only dissolve, and allowing Ca- and Mg-montmorillonite to only precipitate. Mixing proportions for each simulation were calculated two different ways based on measured chloride (Cl) concentrations, or $\delta^{18}\text{O}$. Running the 43 different mixing scenarios with two different mixing proportions for each scenario resulted in a total of 86 mixing simulations plus 13 different groundwater geochemical evolution scenarios for a total of 99 simulations evaluated.

Resultant models from each simulation were considered valid if the precipitation and dissolution constraints applied to the minerals dolomite, gypsum, Ca-montmorillonite, and Mg-montmorillonite were not ignored by NETPATH and if the modeled $\delta^{13}\text{C}$ value was within $\pm 1.0\text{‰}$ of the measured $\delta^{13}\text{C}$ value of the final groundwater (Army #1 Water Well and Amargosa Tracer Well #2). The total number of models and the number of valid $\delta^{13}\text{C}$ models of each mixing and groundwater evolution simulation are listed in Tables 5, 6, 7, 8, 9, and 10. The models that met the criteria for chemical and isotopic validation are described below.

Yucca Flat to Army #1 Water Well

Mixing Water Well C-1 with Cold Creek Spring to produce Army #1 Water Well. This scenario produced a total of two possible chemical models. The Cl mixing simulation produced one model with a $\delta^{13}\text{C}$ value 0.8 ‰ less than the measured $\delta^{13}\text{C}$ value of Army #1 Water Well and the $\delta^{18}\text{O}$ mixing simulation produced one model with a $\delta^{13}\text{C}$ value 0.6 ‰ less than the measured $\delta^{13}\text{C}$. The Cl mixture and the $\delta^{18}\text{O}$ mixture are in good agreement on mixing ratios and precipitated/dissolved minerals (Table 11). Chloride produced a mixture of 46 percent Water Well C-1 and 56 percent Cold Creek Spring, while the $\delta^{18}\text{O}$ produced a mixture of 57 percent Water Well C-1 and 43 percent Cold Creek Spring. These two models produced a range of calculated ^{14}C travel times from 13,200 to 15,900 years (yrs).

TABLE 5. TOTAL NUMBER OF MODELS AND THE NUMBER OF VALID $\delta^{13}\text{C}$ MODELS FOR EACH NETPATH MIXING SIMULATION TO PRODUCE ARMY #1 WATER WELL.

Mixture Simulation	Total Number of Models	Modeled $\delta^{13}\text{C} \pm 1.0\text{‰}$	
		C1	$\delta^{18}\text{O}$
ER-6-1 + Cold Creek Spring	0	0	0
ER-6-1 + UE-5e PW-3	0	0	0
ER-6-1 + USGS HTH #3	2	0	0
UE-1q + Cold Creek Spring	5	0	1
UE-1q + UE-5e PW-3	5	0	4
UE-1q + USGS HTH #3	1	0	0
UE-5e PW-3 + Cold Creek Spring	0	0	0
USGS HTH #3 + Cold Creek Spring	1	0	0
USGS HTH #3 + UE-5e PW-3	5	0	0
Water Well C-1 + Cold Creek Spring	2	1	1
Water Well C-1 + UE-5e PW-3	1	1	0
Water Well C-1 + USGS HTH #3	0	0	0
ER-6-1 + UE-5e PW-3 + Cold Creek Spring	0	0	0
ER-6-1 + USGS HTH #3 + Cold Creek Spring	3	0	0
ER-6-1 + USGS HTH #3 + UE-5e PW-3	8	0	0
UE-1q + UE-5e PW-3 + Cold Creek Spring	0	0	0
UE-1q + USGS HTH #3 + Cold Creek Spring	8	0	0
UE-1q + USGS HTH #3 + UE-5e PW-3	12	0	0
Water Well C-1 + UE-5e PW-3 + Cold Creek Spring	2	1	1
Water Well C-1 + USGS HTH #3 + Cold Creek Spring	4	0	0
Water Well C-1 + USGS HTH #3 + UE-5e PW-3	6	0	0

TABLE 6. TOTAL NUMBER OF MODELS AND THE NUMBER OF VALID $\delta^{13}\text{C}$ MODELS FOR EACH NETPATH GROUNDWATER EVOLUTION SIMULATION TO PRODUCE ARMY #1 WATER WELL.

Evolution Simulation	Total Number of Models	Modeled $\delta^{13}\text{C} \pm 1.0\text{‰}$
Cold Creek Spring	3	1
ER-6-1	5	5
UE-1q	5	5
UE-5e PW-3	5	0
USGS HTH #3	0	0
Water Well C-1	0	0

TABLE 7. TOTAL NUMBER OF MODELS AND THE NUMBER OF VALID $\delta^{13}\text{C}$ MODELS FOR EACH NETPATH MIXING SIMULATION TO PRODUCE AMARGOSA TRACER WELL #2.

Mixture Simulation	Total Number of Models	Modeled $\delta^{13}\text{C} \pm 1.0\text{‰}$	
		C1	$\delta^{18}\text{O}$
ER-6-1 + Cold Creek Spring	0	0	0
ER-6-1 + UE-5e PW3	5	0	4
ER-6-1 + USGS HTH #3	1	0	0
UE-1q + Cold Creek Spring	0	0	0
UE-1q + UE-5e PW3	5	0	4
UE-1q + USGS HTH #3	1	0	0
UE-5e PW-3 + Cold Creek Spring	5	0	1
USGS HTH #3 + Cold Creek Spring	1	0	0
USGS HTH #3 + UE-5e PW-3	8	0	5
Water Well C-1 + Cold Creek Spring	1	0	0
Water Well C-1 + UE-5e PW3	2	1	1
Water Well C-1 + USGS HTH #3	0	0	0
ER-6-1 + UE-5e PW-3 + Cold Creek Spring	0	0	0
ER-6-1 + USGS HTH #3 + Cold Creek Spring	1	0	0
ER-6-1 + USGS HTH #3 + UE-5e PW-3	3	0	1
UE-1q + UE-5e PW-3 + Cold Creek Spring	0	0	0
UE-1q + USGS HTH #3 + Cold Creek Spring	0	0	0
UE-1q + USGS HTH #3 + UE-5e PW-3	3	0	0
Water Well C-1 + UE-5e PW-3 + Cold Creek Spring	6	1	3
Water Well C-1 + USGS HTH #3 + Cold Creek Spring	1	0	0
Water Well C-1 + USGS HTH #3 + UE-5e PW-3	9	0	6

TABLE 8. TOTAL NUMBER OF MODELS AND THE NUMBER OF VALID $\delta^{13}\text{C}$ MODELS FOR EACH NETPATH GROUNDWATER EVOLUTION SIMULATION TO PRODUCE AMARGOSA TRACER WELL #2.

Evolution Simulation	Total Number of Models	Modeled $\delta^{13}\text{C} \pm 1.0 \%$
Cold Creek Spring	5	1
ER-6-1	5	5
UE-1q	5	1
UE-5e PW-3	5	0
USGS HTH #3	1	0
Water Well C-1	1	1

TABLE 9. TOTAL NUMBER OF MODELS AND THE NUMBER OF VALID $\delta^{13}\text{C}$ MODELS FOR NETPATH SIMULATION MIXING ARMY #1 WATER WELL WITH COLD CREEK SPRING TO PRODUCE AMARGOSA TRACER WELL #2.

Mixture Simulation	Total Number of Models	Modeled $\delta^{13}\text{C} \pm 1.0\text{‰}$	
		Cl	$\delta^{18}\text{O}$
Army #1 Water Well + Cold Creek Spring	0	0	0

TABLE 10. TOTAL NUMBER OF MODELS AND THE NUMBER OF VALID $\delta^{13}\text{C}$ MODELS FOR NETPATH GROUNDWATER EVOLUTION SIMULATION FROM ARMY #1 WATER WELL TO AMARGOSA TRACER WELL #2.

Evolution Simulation	Total Number of Models	Modeled $\delta^{13}\text{C} \pm 1.0\text{‰}$
Army #1 Water Well	5	5

TABLE 11. NETPATH SIMULATION RESULTS FOR MIXING SCENARIO WATER WELL C-1 AND COLD CREEK SPRING TO PRODUCE ARMY #1 WATER WELL.

Parameter	Mixing Proportion	
	Cl	$\delta^{18}\text{O}$
Water Well C-1 (%)	46	57
Cold Creek Spring (%)	54	43
Difference in $\delta^{13}\text{C}$ (‰)	-0.8	-0.6
^{14}C Travel time (yrs)	15,919	13,211
Calcite (mmoles)*	-4.1	-5.2
Dolomite (mmoles)*	-	-
Gypsum (mmoles)*	0.2	0.1
Ca-Montmorillonite (mmoles)*	-	-
Mg-Montmorillonite (mmoles)*	-0.3	-0.7
Ca/Na Exchange (mmoles)†	-3.2	-4.3

*For minerals, negative number indicates precipitation, positive number indicates dissolution.

†For exchange, negative number indicates Ca released into solution, positive number indicates sodium released into solution.

Mixing Water Well C-1 with UE-5e PW-3 and Cold Creek Spring to produce Army #1 Water Well. This scenario produced a total of two possible chemical models. The Cl mixing simulation produced one model with a $\delta^{13}\text{C}$ value 0.7 ‰ less than the measured $\delta^{13}\text{C}$ value of Army #1 Water Well and the $\delta^{18}\text{O}$ mixing simulation produced one model with a $\delta^{13}\text{C}$ value that matched the measured $\delta^{13}\text{C}$ exactly. The Cl mixture and the $\delta^{18}\text{O}$ mixture are in poor agreement on mixing ratios and precipitated/dissolved minerals (Table 12). Chloride produced mixtures of 44 percent Water Well C-1, 8 percent UE-5e PW-3, and 48 percent Cold Creek Spring, while the $\delta^{18}\text{O}$ produced a mixture of 69 percent Water Well C-1, 22 percent UE-5e PW-3, and 8 percent Cold Creek Spring. These two models produced a range of calculated ^{14}C travel times from 2,600 to 15,400 yrs.

TABLE 12. NETPATH SIMULATION RESULTS FOR MIXING SCENARIO WATER WELL C-1, UE-5e PW-3 AND COLD CREEK SPRING TO PRODUCE ARMY #1 WATER WELL.

Parameter	Mixing Proportion	
	Cl	$\delta^{18}\text{O}$
Water Well C-1 (%)	44	69
UE-5e PW-3 (%)	8	22
Cold Creek Spring (%)	48	8
Difference in $\delta^{13}\text{C}$ (‰)	-0.7	0
^{14}C Travel time (yrs)	15,429	2,560
Calcite (mmoles)*	-3.7	-5.8
Dolomite (mmoles)*	-	-
Gypsum (mmoles)*	0.2	-
Ca-Montmorillonite (mmoles)*	0.0	0.0
Mg-Montmorillonite (mmoles)*	-	-0.4
Ca/Na Exchange (mmoles)†	-3.0	-5.4

*For minerals, negative number indicates precipitation, positive number indicates dissolution.

†For exchange, negative number indicates Ca released into solution, positive number indicates Na released into solution.

Evolve Cold Creek Spring to Army #1 Well Water. Evolution simulations do not mix different waters so the simulations are not constrained by either Cl or $\delta^{18}\text{O}$, they are only constrained by the chemical mass balance. This scenario produced three possible chemical models but only one model with a $\delta^{13}\text{C}$ value within 1.0 ‰ of the measured $\delta^{13}\text{C}$ value of Army #1 Water Well. This model produced a $\delta^{13}\text{C}$ value 0.5 ‰ less than the measured $\delta^{13}\text{C}$ and a ^{14}C travel time of 21,700 yrs. The simulation precipitated 2.3 millimoles (mmoles) of calcite, dissolved 1.3 mmoles of dolomite and 0.5 mmoles of gypsum, and precipitated 6.5 mmoles of Mg-montmorillonite (Table 13).

TABLE 13. NETPATH SIMULATION RESULTS FOR GROUNDWATER CHEMICAL EVOLUTION SCENARIO FROM COLD CREEK SPRING TO ARMY #1 WATER WELL.

Parameter	Model 1
Difference in $\delta^{13}\text{C}$ (‰)	-0.5
^{14}C Travel Time (yrs)	21,746
Calcite (mmoles)*	-2.3
Dolomite (mmoles)*	1.3
Gypsum (mmoles)*	0.5
Ca-Montmorillonite (mmoles)*	-
Mg-Montmorillonite (mmoles)*	-6.5
Ca/Na Exchange (mmoles)†	-

*For minerals, negative number indicates precipitation, positive number indicates dissolution.

†For exchange, negative number indicates Ca released into solution, positive number indicates Na released into solution.

Evolve ER-6-1 to Army #1 Well Water. This scenario produced five possible chemical models. Four of the models produced a $\delta^{13}\text{C}$ value 0.3 ‰ more than the measured $\delta^{13}\text{C}$ value of Army #1 Water Well and one model produced a $\delta^{13}\text{C}$ value 0.8 ‰ more than the measured $\delta^{13}\text{C}$ value; however, all models produced negative ^{14}C travel times. The five models with acceptable $\delta^{13}\text{C}$ values dissolved dolomite and gypsum with variations between calcite dissolution and precipitation, Ca-montmorillonite precipitation, Mg-montmorillonite dissolution and precipitation, and release of Na into solution by Ca/Na exchange (Table 14).

TABLE 14. NETPATH SIMULATION RESULTS FOR GROUNDWATER CHEMICAL EVOLUTION SCENARIO FROM ER-6-1 TO ARMY #1 WATER WELL.

Parameter	Model 1	Model 2	Model 3	Model 4	Model 5
Difference in $\delta^{13}\text{C}$ (‰)	0.3	0.3	0.8	0.3	0.3
^{14}C Travel Time (yrs)	-2,741	-2,741	-3,985	-2,741	-2,741
Calcite (mmoles)*	0.01	0.01	-0.7	-	-
Dolomite (mmoles)*	0.4	0.4	0.7	0.4	0.4
Gypsum (mmoles)*	0.2	0.2	0.2	0.2	0.2
Ca-Montmorillonite (mmoles)*	-	-2.0	-	-	-2.0
Mg-Montmorillonite (mmoles)*	-	-	-2.0	0.2	-0.03
Ca/Na Exchange (mmoles)†	0.3	-	-	0.3	-

*For minerals, negative number indicates precipitation, positive number indicates dissolution.

†For exchange, negative number indicates Ca released into solution, positive number indicates Na released into solution.

Evolve UE-1q to Army #1 Well Water. This scenario produced five possible chemical models. Four of the models produced a $\delta^{13}\text{C}$ value 0.5 ‰ less than the measured $\delta^{13}\text{C}$ value of Army #1 Water Well and one model produced a $\delta^{13}\text{C}$ value 0.7 ‰ more than the measured $\delta^{13}\text{C}$ value; however, all models produced negative ^{14}C travel times. All five models dissolved dolomite and gypsum with variations between calcite dissolution and precipitation, Ca and Mg-montmorillonite precipitation, and release of Na into solution by Ca/Na exchange (Table 15).

TABLE 15. NETPATH SIMULATION RESULTS FOR GROUNDWATER CHEMICAL EVOLUTION SCENARIO FROM UE-1q TO ARMY #1 WATER WELL.

Parameter	Model 1	Model 2	Model 3	Model 4	Model 5
Difference in $\delta^{13}\text{C}$ (‰)	-0.5	-0.5	0.7	-0.5	-0.5
^{14}C Travel Time (yrs)	-258	-258	-2,760	-258	-258
Calcite (mmoles)*	0.8	-0.8	-1.2	-	-
Dolomite (mmoles)*	0.3	0.3	1.3	0.7	0.7
Gypsum (mmoles)*	0.3	0.3	0.3	0.3	0.3
Ca-Montmorillonite (mmoles)*	-	-6.2	-	-	-3.7
Mg-Montmorillonite (mmoles)*	-	-	-6.2	-2.5	-2.5
Ca/Na Exchange (mmoles)†	1.0	-	-	0.6	-

*For minerals, negative number indicates precipitation, positive number indicates dissolution.

†For exchange, negative number indicates Ca released into solution, positive number indicates Na released into solution.

Yucca Flat to Amargosa Tracer Well #2

Mixing Water Well C-1 with UE-5e PW-3 to Produce Amargosa Tracer Well #2. This scenario produced a total of two possible chemical models. The Cl mixing simulation produced one model with a $\delta^{13}\text{C}$ value 0.3 ‰ less than the measured $\delta^{13}\text{C}$ value of Amargosa Tracer Well #2 and the $\delta^{18}\text{O}$ mixing simulation produced one model with a $\delta^{13}\text{C}$ value 0.1 ‰ less than the measured $\delta^{13}\text{C}$. The Cl mixture and the $\delta^{18}\text{O}$ mixture were in moderate agreement on mixing ratios and precipitated/dissolved minerals (Table 16). Chloride produced a mixture of 44 percent Water Well C-1 and 56 percent UE-5e PW-3, while $\delta^{18}\text{O}$ produced a mixture of 27 percent Water Well C-1 and 73 percent UE-5e PW-3. These models produced a range of calculated ^{14}C travel times from 5,300 to 8,500 yrs.

TABLE 16. NETPATH SIMULATION RESULTS FOR MIXING SCENARIO WATER WELL C-1 WITH UE-5e PW-3 TO PRODUCE AMARGOSA TRACER WELL #2.

Parameter	Mixing Proportion	
	$\delta^{18}\text{O}$	$\delta^{18}\text{O}$
Water Well C-1 (%)	44	27
UE-5e PW-3 (%)	56	73
Difference in $\delta^{13}\text{C}$ (‰)	-0.3	-0.1
^{14}C Travel time (yrs)	5307	8,555
Calcite (mmoles)*	-2.6	-1.0
Dolomite (mmoles)*	0.1	0.3
Gypsum (mmoles)*	0.2	0.3
Ca-Montmorillonite (mmoles)*	-	-
Mg-Montmorillonite (mmoles)*	-	-
Ca/Na Exchange (mmoles)†	-2.3	-0.7

*For minerals, negative number indicates precipitation, positive number indicates dissolution.

†For exchange, negative number indicates Ca released into solution, positive number indicates Na released into solution.

Mixing Water Well C-1 with UE-5e PW-3 and Cold Creek Spring to Produce Amargosa Tracer Well #2. This scenario produced a total of six possible chemical models but only four models with a $\delta^{13}\text{C}$ value within 1.0 ‰ of the measured value of Amargosa Tracer Well #2. The Cl mixing simulation produced one model with a $\delta^{13}\text{C}$ value 1.0 ‰ less than the measured $\delta^{13}\text{C}$ value and the $\delta^{18}\text{O}$ mixing simulation produced three models with a $\delta^{13}\text{C}$ value 0.8 ‰ less than the measured $\delta^{13}\text{C}$. The Cl mixture and the $\delta^{18}\text{O}$ mixtures were in fair agreement on mixing ratios and precipitated/dissolved minerals (Table 17). Chloride produced a mixture of 49 percent Water Well C-1, 32 percent UE-5e PW-3, and 18 percent Cold Creek Spring, while $\delta^{18}\text{O}$ produced a mixture of 20 percent Water Well C-1, 60 percent UE-5e PW-3, and 21 percent Cold Creek Spring. These models produced a range of calculated ^{14}C travel times from 13,00 to 17,900 yrs.

TABLE 17. NETPATH SIMULATION RESULTS FOR MIXING SCENARIO WATER WELL C-1, UE-5e PW-3, AND COLD CREEK SPRING TO PRODUCE AMARGOSA TRACER WELL #2.

Parameter	Cl	Mixing Proportion		
		$\delta^{18}\text{O}$	$\delta^{18}\text{O}$	$\delta^{18}\text{O}$
Water Well C-1 (%)	50	20	20	20
UE-5e PW-3 (%)	32	60	60	60
Cold Creek Spring (%)	18	20	20	20
Difference in $\delta^{13}\text{C}$ (‰)	-1.0	-0.8	-0.8	-0.8
^{14}C Travel Time (yrs)	13,024	17,922	17,922	17,922
Calcite (mmoles)*	-3.4	-0.5	-0.5	-0.5
Dolomite (mmoles)*	-	0.3	0.3	0.3
Gypsum (mmoles)*	0.3	0.4	0.4	0.4
Ca-Montmorillonite (mmoles)*	0.0	0.0	-	-
Mg-Montmorillonite (mmoles)*	-	-	0.0	-
Ca/Na Exchange (mmoles)†	-2.9	-	-	0.0

*For minerals, negative number indicates precipitation, positive number indicates dissolution.

†For exchange, negative number indicates Ca released into solution, positive number indicates Na released into solution.

Evolve Cold Creek Spring to Amargosa Tracer Well #2. This scenario produced five possible chemical models but only one model with a $\delta^{13}\text{C}$ value within 1.0 ‰ of the measured $\delta^{13}\text{C}$ value of Amargosa Tracer Well #2. This model produced a $\delta^{13}\text{C}$ value 0.7 ‰ less than the measured $\delta^{13}\text{C}$ value and a ^{14}C travel time of 24,000 yrs. The simulation precipitated 3.0 mmoles of calcite, dissolved 1.7 mmoles of dolomite and 0.6 mmoles of gypsum, and precipitated 9.7 mmoles of Mg-montmorillonite (Table 18).

TABLE 18. NETPATH SIMULATION RESULTS FOR GROUNDWATER CHEMICAL EVOLUTION SCENARIO FROM COLD CREEK SPRING TO AMARGOSA TRACER WELL #2.

Parameter	Model 1
Difference in $\delta^{13}\text{C}$ (‰)	-0.7
^{14}C Travel Time (yrs)	23,958
Calcite (mmoles)*	-3.0
Dolomite (mmoles)*	1.7
Gypsum (mmoles)*	0.6
Ca-Montmorillonite (mmoles)*	-
Mg-Montmorillonite (mmoles)*	-9.7
Ca/Na Exchange (mmoles)†	-

*For minerals, negative number indicates precipitation, positive number indicates dissolution.

†For exchange, negative number indicates Ca released into solution, positive number indicates Na released into solution.

Evolve ER-6-1 to Amargosa Tracer Well #2. This scenario produced five possible chemical models. Four of the models produced a $\delta^{13}\text{C}$ value 0.4 ‰ less than the measured $\delta^{13}\text{C}$ value of Amargosa Tracer Well #2 and a ^{14}C travel time of 445 yrs. One simulation produced a $\delta^{13}\text{C}$ value 0.5 ‰ more than the measured $\delta^{13}\text{C}$ value; however, this simulation produced a negative ^{14}C travel time. All five models dissolved dolomite and gypsum with variations between calcite dissolution and precipitation, Ca- and Mg-montmorillonite precipitation, and release of Na into solution by Ca/Na exchange (Table 19).

TABLE 19. NETPATH SIMULATION RESULTS FOR GROUNDWATER CHEMICAL EVOLUTION SCENARIO FROM ER-6-1 TO AMARGOSA TRACER WELL #2.

Parameter	Model 1	Model 2	Model 3	Model 4	Model 5
Difference in $\delta^{13}\text{C}$ (‰)	-0.4	-0.4	0.5	-0.4	-0.4
^{14}C Travel Time (yrs)	445	445	-1,928	445	445
Calcite (mmoles)*	0.5	0.5	-1.3	-	-
Dolomite (mmoles)*	0.3	0.3	1.2	0.5	0.5
Gypsum (mmoles)*	0.4	0.4	0.4	0.4	0.4
Ca-Montmorillonite (mmoles)*	-	-5.3	-	-	-3.9
Mg-Montmorillonite (mmoles)*	-	-	-5.3	-1.4	-1.4
Ca/Na Exchange (mmoles)†	0.9	-	-	0.7	-

*For minerals, negative number indicates precipitation, positive number indicates dissolution.

†For exchange, negative number indicates Ca released into solution, positive number indicates Na released into solution.

Evolve UE-1q to Amargosa Tracer Well #2. This scenario produced five possible chemical models but only one model with a $\delta^{13}\text{C}$ value within 1.0 ‰ of the measured $\delta^{13}\text{C}$ value of Amargosa Tracer Well #2. This model produced a $\delta^{13}\text{C}$ value 0.4 ‰ more than the measured $\delta^{13}\text{C}$ value but a negative ^{14}C travel time (Table 20). The simulation precipitated 1.9 mmols of calcite, dissolved 1.8 mmols of dolomite and 0.5 mmols of gypsum, and precipitated 9.4 mmols of Mg-montmorillonite.

TABLE 20. NETPATH SIMULATION RESULTS FOR GROUNDWATER CHEMICAL EVOLUTION SCENARIO FROM UE-1q TO AMARGOSA TRACER WELL #2.

Parameter	Model 1
Difference in $\delta^{13}\text{C}$ (‰)	0.4
^{14}C Travel Time (yrs)	-756
Calcite (mmoles)*	-1.9
Dolomite (mmoles)*	1.8
Gypsum (mmoles)*	0.5
Ca-Montmorillonite (mmoles)*	-
Mg-Montmorillonite (mmoles)*	-9.4
Ca/Na Exchange (mmoles)†	-

*For minerals, negative number indicates precipitation, positive number indicates dissolution.

†For exchange, negative number indicates Ca released into solution, positive number indicates Na released into solution.

Evolve Water Well C-1 to Amargosa Tracer Well #2. This scenario produced one possible chemical model with a $\delta^{13}\text{C}$ value 1.0 ‰ less than the measured $\delta^{13}\text{C}$ value of Amargosa Tracer Well #2 but a negative ^{14}C travel time. The model precipitated 8.9 mmoles of calcite, dissolved 0.05 mmoles of gypsum, precipitated 2.5 mmoles of Mg-montmorillonite, and released 8.1 mmoles of Ca into solution by Ca/Na exchange (Table 21).

TABLE 21. NETPATH SIMULATION RESULTS FOR GROUNDWATER CHEMICAL EVOLUTION SCENARIO FROM WATER WELL C-1 TO AMARGOSA TRACER WELL #2.

Parameter	Model 1
Difference in $\delta^{13}\text{C}$ (‰)	-1.0
^{14}C Travel time (yrs)	-6,733
Calcite (mmoles)*	-8.9
Dolomite (mmoles)*	-
Gypsum (mmoles)*	0.05
Ca-Montmorillonite (mmoles)*	-
Mg-Montmorillonite (mmoles)*	-2.5
Ca/Na Exchange (mmoles)†	-8.1

*For minerals, negative number indicates precipitation, positive number indicates dissolution.

†For exchange, negative number indicates Ca released into solution, positive number indicates Na released into solution.

Army #1 Water Well to Amargosa Tracer Well #2

Evolve Army #1 Water Well to Amargosa Tracer Well #2. This scenario produced five possible chemical models. Four of the models produced a $\delta^{13}\text{C}$ value 0.7 ‰ less than the measured $\delta^{13}\text{C}$ value of Amargosa Tracer Well #2 and a ^{14}C travel time of 3200 yrs. One model produced a $\delta^{13}\text{C}$ value 0.3 ‰ less than the measured $\delta^{13}\text{C}$ value and a ^{14}C travel time of 2100 yrs. All five models dissolved gypsum; one simulation precipitated 0.6 mmoles of calcite and 3.2 mmoles Mg-montmorillonite, while dissolving 0.5 mmoles of dolomite; two models dissolved 0.3 mmoles of calcite and precipitated 0.5 mmoles of Mg-montmorillonite with variations between Ca-montmorillonite precipitation and release of Na into solution by Ca/Na exchange; and, two models dissolved 0.1 mmoles of dolomite and precipitated 1.3 mmoles of Mg-montmorillonite with variations between Ca-montmorillonite precipitation and release of Na into solution by Ca/Na exchange (Table 22).

TABLE 22. NETPATH SIMULATION RESULTS FOR GROUNDWATER CHEMICAL EVOLUTION SCENARIO FROM ARMY WATER WELL #1 TO AMARGOSA TRACER WELL #2.

Parameter	Model 1	Model 2	Model 3	Model 4	Model 5
Difference in $\delta^{13}\text{C}$ (‰)	-0.3	-0.7	-0.7	-0.7	-0.7
^{14}C Travel Time (yrs)	2,118	3,186	3,186	3,186	3,190
Calcite (mmoles)*	-0.6	0.3	0.3	-	-
Dolomite (mmoles)*	0.5	-	-	0.1	0.1
Gypsum (mmoles)*	0.2	0.2	0.2	0.2	0.2
Ca-Montmorillonite (mmoles)*	-	-	-2.8	-	-1.9
Mg-Montmorillonite (mmoles)*	-3.2	-0.5	-0.5	-1.3	-1.3
Ca/Na Exchange (mmoles)†	-	0.5	-	0.3	-

*For minerals, negative number indicates precipitation, positive number indicates dissolution.

†For exchange, negative number indicates Ca released into solution, positive number indicates Na released into solution.

DISCUSSION

Geochemical and isotopic modeling shows that only a few mixing scenarios from Yucca Flat to Army #1 Water Well and Amargosa Tracer Well #2 are possible. These scenarios require mixing of Yucca Flat carbonate aquifer groundwater represented by Water Well C-1 with Spring Mountain water represented by Cold Creek Spring and/or a component of overlying volcanic aquifer groundwater represented by UE-5e PW-3. Modeling also shows that the geochemical evolution along a flowpath of either Yucca Flat or Spring Mountain groundwater can produce the geochemical and isotopic characteristics of Army #1 Water Well and Amargosa Tracer Well #2.

An important outcome of this study is the lack of a valid simulation that includes groundwater flow from east of the NTS represented by USGS HTH #3. Lacznia *et al.* (1996) suggest that most of the spring discharge observed at Ash Meadows (southwest of Amargosa Tracer Well #2) is derived from flow east and southeast of the NTS, principally from the Sheep Range and the Spring Mountains. They suggest that Sheep Range groundwater mixes with NTS groundwater in the area of Frenchman Flat, and Spring Mountains groundwater mixes with NTS groundwater in the area of Mercury Valley. However, no valid model simulations were produced by mixing USGS HTH #3 groundwater with Yucca Flat groundwater. Yucca Flat groundwater is represented by a range of different groundwater geochemistries from wells UE-1q (mostly carbonate groundwater), ER-6-1 (mixed volcanic and carbonate groundwater), and Water Well C-1 (mixed volcanic and carbonate groundwater with higher dissolved solids). In addition, groundwater from USGS HTH #3 could not be geochemically evolved to produce water at either Army #1 Water Well or Amargosa Tracer Well #2.

If groundwater from the east is flowing toward the NTS as suggested by Lacznia *et al.* (1996), then the geochemical and isotopic changes along the flowpath should be reproducible with modeling. However, since these geochemical changes could not be modeled using groundwater

from USGS HTH #3, it suggests that either the flowpath is not valid or that USGS HTH #3 is not representative of eastward-flowing groundwater. Unfortunately, USGS HTH #3 is the only well along the eastern edge of the NTS that penetrates the carbonate aquifer, and thus is the only groundwater analysis presently available for geochemical modeling.

Mixing Simulations

Two mixing scenarios were modeled successfully from Yucca Flat to Army #1 Water Well and two scenarios from Yucca Flat to the Amargosa Tracer Well #2. All of these mixing scenarios include Yucca Flat groundwater represented by Water Well C-1 mixed with Spring Mountain groundwater represented by Cold Creek Spring. None of the mixing scenarios using either UE-1q or ER-6-1 groundwater to represent Yucca Flat groundwater were successful. In general, these mixing scenarios do not work because either the initial Cl concentrations or $\delta^{18}\text{O}$ values cannot be mixed in any proportion to produce the final downgradient groundwater (*e.g.*, initial Cl concentrations of 23 and 33 mg/L cannot be mixed together to produce a final concentration of 16 mg/L), or the calculated final $\delta^{13}\text{C}$ values were not within $\pm 1.0\%$ of the measured value because either too much carbonate mineral dissolved or too little carbonate precipitated.

For the successful mixing scenarios, more detailed NETPATH modeling simulations with silica (Si), Na, and potassium (K) added as constraints and several major volcanic minerals added as phases were conducted to account for the possible interaction of groundwater with volcanic-rock aquifers in the geologically complex NTS flow system. The additional mineral phases included anorthite (Ca, Si; dissolve only), Na-montmorillonite (Na, Si; precipitate only), K-montmorillonite (K, Si; precipitate only), albite (Na, Si; dissolve or precipitate), potassium feldspar (K, Si; dissolve only), and Mg/Na exchange (release of Na into solution only). In addition, Ca/Na exchange was limited to the release of Na into solution. The increased complexity of the modeling simulations provided better constraint on the total chemical mass balance and tested the variability of travel times originally calculated with the simpler simulations. The results of these modeling simulations are located in the Appendix.

The mixing ratios for each simulation, as calculated with Cl and $\delta^{18}\text{O}$, did not change with the more detailed NETPATH modeling since the initial Cl concentrations and $\delta^{18}\text{O}$ values were the same from previous simulations. For the simulation mixing Water Well C-1 and Cold Creek Spring to produce Army #1 Water Well, the mixing proportions were 46 percent Water Well C-1 and 54 percent Cold Creek Spring calculated by Cl and 57 percent Water Well C-1 and 43 percent Cold Creek Spring calculated by $\delta^{18}\text{O}$ (Table 11 and Appendix). These mixing proportions are in good agreement and suggest roughly equal amounts of each water mixing to produce the downgradient water at Army #1 Water Well. The more detailed NETPATH modeling simulation produced a travel time range from 11,700 to 15,900 yrs, which is also in good agreement with the initial modeling results and shows that the more refined modeling of non-carbonate-bearing phases did not significantly affect the overall carbon isotopic signature of the mixture. The range of travel times resulted from small variations in the amount of calcite precipitated for different models.

For the Water Well C-1, Cold Creek Spring, and UE-5e PW-3 mixing simulation producing Army #1 Water Well, the mixing ratios calculated using Cl and $\delta^{18}\text{O}$ are in poor agreement (Table 12 and Appendix). Chloride produced a mixture where Water Well C-1 (44 percent) and Cold Creek Spring (48 percent) had approximately equal portions with UE-5e PW-3 accounting for the remainder (8 percent). $\delta^{18}\text{O}$ produced a mixture of 69 percent Water Well C-1, 22 percent UE-5e PW-3 and only 8 percent Cold Creek Spring. In the more detailed NETPATH modeling simulation, these large differences in mixing percentages required large variations in the amount of calcite precipitated, which affected the range of calculated travel times. The more detailed simulations produced a travel time range from 2,600 to 15,500 yrs, again, not significantly different from the initial modeling simulations.

For the Water Well C-1 and UE-5e PW-3 mixing simulation producing Amargosa Tracer Well #2, the mixing ratios calculated using Cl and $\delta^{18}\text{O}$ are in moderate agreement (Table 16). Chloride produced a mixture of 44 percent Water Well C-1 and 56 percent UE-5e PW-3 while the $\delta^{18}\text{O}$ mixture increased the amount of UE-5e PW-3 to 73 percent and Water Well C-1 was reduced to 27 percent. However, in the more detailed NETPATH modeling simulation, which limited Ca/Na exchange to one direction only (Ca uptake by the solid with corresponding release of Na into solution), the $\delta^{18}\text{O}$ simulation only produced models that ignored one of the mineral constraints. In the initial simulation, this would have invalidated the scenario. Because of this discrepancy, this mixing scenario will no longer be considered.

For the Water Well C-1, Cold Creek Spring, and UE-5e PW-3 mixing simulation producing Amargosa Tracer Well #2, the mixing ratios calculated using Cl and $\delta^{18}\text{O}$ are in fair agreement (Table 17 and Appendix). Chloride produced a mixture of 50 percent Water Well C-1, 32 percent UE-5e PW-3, and 18 percent Cold Creek Spring. $\delta^{18}\text{O}$ produced a mixture of 20 percent each Water Well C-1 and Cold Creek Spring, and 60 percent UE-5e PW-3. In the more detailed NETPATH modeling simulation, these differences in mixing percentages produced variations in the amount of calcite precipitated which affected the range of calculated travel times. The more detailed simulation produced a travel time range from 12,200 to 19,400 yrs.

Lazniack *et al.* (1996) state that "much of the groundwater flowing to Ash Meadows (17,000 acre-feet/yr) passes beneath Frenchman Flat or beneath the area just south of Frenchman Flat but originates primarily from outside these areas. More than 95 percent of the water passing beneath Frenchman Flat enters the lower carbonate aquifer from areas to the east and southeast." They also state that no more than 350 acre-feet/yr of groundwater flows from Yucca Flat to Frenchman Flat or less than 3 percent of the total outflow at the Ash Meadows discharge area. The authors do not attempt to distinguish the amount of flow from the Sheep Range vs. the amount from the Spring Mountains. Also, Lazniack *et al.* (1996) state that the range of annual downward recharge into Yucca Flat through the tuff confining units into the lower carbonate aquifer is only 25 to 65 acre-feet/yr. The geochemical and isotopic modeling conducted in this study suggested that the proportion of water flowing from Yucca Flat to Frenchman Flat is larger (20 to 57 percent), the groundwater flow from the east (USGS HTH #3 representing flow from the Sheep Range) and southeast (Cold Creek

Spring representing flow from the Spring Mountains) to Frenchman Flat is smaller (0 to 54 percent), and the flow from the overlying volcanic aquifer into the carbonate aquifer is larger (8 to 60 percent).

Flowpath Evolution Simulations

In addition to mixing scenarios, several groundwater geochemical evolution scenarios also produced reasonable geochemical and isotopic models. In all, a total of 11 valid models were produced excluding those that produced negative travel times. Negative groundwater travel times were produced when dissolution of too much calcite and dolomite was required for the carbon mass balance, which then made the evolved waters older than the end of the flowpath. Of the 11 valid models, one model evolved Cold Creek Spring to Army #1 Water Well, one evolved Cold Creek Spring to Amargosa Tracer Well #2, four models evolved ER-6-1 to Amargosa Tracer Well #2, and five models evolved Army #1 Water Well to Amargosa Tracer Well #2.

Chloride and $\delta^{18}\text{O}$ were considered conservative tracers in the NTS flow system. As such, Cl concentrations and $\delta^{18}\text{O}$ values should not change significantly from the initial to final water along a geochemical evolution flowpath unless mixing is occurring. The difference in Cl concentrations between the initial and final water should not be more than about three or four milligrams/liter (mg/L), while $\delta^{18}\text{O}$ values, with an analytical reporting error of ± 0.2 ‰, should not have a difference more than 0.4 ‰. Table 23 lists the Cl concentrations and $\delta^{18}\text{O}$ values of the initial and final waters for the valid evolution flowpath simulations and the differences between the initial and final waters. The flowpath from Army #1 Water Well to Amargosa Tracer Well #2 is the only flowpath with a small change in Cl concentrations (3.6 mg/L), but is also the only flowpath with a difference in $\delta^{18}\text{O}$ values greater than the range possible from analytical reporting errors (0.5 ‰). If the evolution flowpaths are valid, and no mixing is occurring, then both Cl and $\delta^{18}\text{O}$ should agree. Although none of the evolution flowpaths has both Cl and $\delta^{18}\text{O}$ in agreement, there is enough variability in the reported $\delta^{18}\text{O}$ values (Table 2) that the Army #1 Water Well to Amargosa Tracer Well #2 simulation is considered valid.

For the groundwater geochemical evolution flowpath from Army #1 Water Well to Amargosa Tracer Well #2, the more detailed NETPATH modeling simulation produced 27 possible models with a travel time range from 1,800 to 3,200 yrs, which is a slightly larger range than the initial modeling results. The increased range results from slightly faster travel times calculated for several models that have the largest amount of calcite precipitation. This occurs because the isotopically heavier ^{14}C is preferentially removed from the liquid phase as solid calcite precipitates. This process results in less ^{14}C in the final groundwater, making the modeled groundwater closer in age to the final, end of the flowpath groundwater, and thus, producing a faster travel time from the initial to final groundwater location.

TABLE 23. INITIAL AND FINAL CL AND $\delta^{18}\text{O}$ VALUES AND DIFFERENCES BETWEEN THE INITIAL AND FINAL VALUES FOR VALID GROUNDWATER EVOLUTION FLOWPATHS.

Flowpath	Initial Cl (mg/L)	Final Cl (mg/L)	Change Cl (mg/L)	Initial $\delta^{18}\text{O}$ (‰)	Final $\delta^{18}\text{O}$ (‰)	Change $\delta^{18}\text{O}$ (‰)
Cold Creek Spring to Army #1 Water Well	1.6	16.3	14.7	-13.7	-14.1	0.4
Cold Creek Spring to Amargosa Tracer Well #2	1.6	19.9	18.3	-13.7	-13.6	0.1
ER-6-1 to Amargosa Tracer Well #2	11.8	19.9	8.1	-14.0	-13.6	0.4
Army #1 Water Well to Amargosa Tracer Well #2	16.3	19.9	3.6	-14.1	-13.6	0.5

Groundwater Velocities

For the evolution flowpath, groundwater velocities were calculated using a distance from the initial to final groundwater location. However, calculating groundwater velocities for the mixing scenarios was more subjective. For the NETPATH simulations, two or three initial groundwaters were mixed together and then reacted with the mineral assemblage to produce the final, downgradient groundwater. Thus, an area of mixing must first be selected and then the distance from the mixing zone to the final groundwater location measured. This distance is then used to calculate a groundwater velocity. The uncertainty in selecting the location of the mixing zone resulted from the lack of groundwater sampling locations in the carbonate aquifer in the general area where mixing is thought to occur. Since the precise location of the mixing zone is unknown, the distances used to calculate groundwater velocities are uncertain. Nonetheless, a mixing zone was selected based on general hydrologic knowledge of the study area, distances measured, and groundwater velocities calculated for the valid mixing flowpaths.

A mixing zone for the three valid mixing simulations was delineated by evaluating Lacznia *et al.* (1996) potentiometric map of the NTS and vicinity. The mixing zone delineated is roughly southwest of Frenchman Lake in Frenchman Flat and results in a distance from the mixing zone to Army #1 Water Well of 15 km and to the Amargosa Tracer Well #2 of 31 km. An approximate distance between Army #1 Water Well and Amargosa Tracer Well #2 is 18 km. These distances were divided by the range of travel times developed during geochemical and isotopic modeling to produce groundwater velocities. Distances, travel times, and groundwater velocities are listed in Table 24. Groundwater velocities from Yucca Flat to Army #1 Water Well and Amargosa Tracer Well #2 ranged from 0.9 m/yr to 10.0 m/yr. Calculated velocities from Yucca Flat are slower (0.9 to 1.3 m/yr) when overlying volcanic waters are not included in the simulations (Water Well C-1 plus Cold Creek Spring to Army #1 Water Well); calculated velocities from Yucca Flat including overlying volcanic waters are somewhat faster (1.0 to 5.8 m/yr for Water Well C-1, Cold Creek Spring, and UE-5e PW5 to Army #1 Water Well and 1.6 to 2.6 m/yr to Amargosa Tracer Well #2). The fastest velocities are from the geochemical evolution simulation from Army #1 Water Well and Amargosa Tracer Well

#2 (5.6 to 10.0 m/yr). The groundwater velocities calculated in this study fall at the lower end of the range of groundwater velocities reported by Winograd and Thordarson (1975) (1.8 to 18,288 m/yr) and Laczniaik *et al.* (1996) (11.1 to 11,125 m/yr).

TABLE 24. TRAVEL TIMES, DISTANCES, AND GROUNDWATER VELOCITIES FOR THE VALID GROUNDWATER MIXING AND EVOLUTION FLOWPATHS FROM YUCCA FLAT TO ARMY #1 WATER WELL AND AMARGOSA TRACER WELL #2.

Flowpath	Travel Time (yrs)	Distance (m)	Velocity (m/yr)
Water Well C-1 and Cold Creek Spring to Army #1 Water Well	11,700 to 15,900	15,000	0.9 to 1.3
Water Well C-1, UE-5e PW3, and Cold Creek Spring to Army #1 Water Well	2,600 to 15,500	15,000	1.0 to 5.8
Water Well C-1, UE-5e PW3, and Cold Creek Spring to Amargosa Tracer Well #2	12,000 to 19,400	31,000	1.6 to 2.6
Army #1 Water Well to Amargosa Tracer Well #2	1,800 to 3,200	18,000	5.6 to 10.0

CONCLUSIONS

The results of the geochemical and isotopic modeling suggest that only a few mixing scenarios from Yucca Flat to Army #1 Water Well and Amargosa Tracer Well #2 are possible. These scenarios required mixing of carbonate aquifer water represented by Water Well C-1 with Spring Mountains water represented by Cold Creek Spring and/or a component of overlying volcanic aquifer groundwater represented by UE-5e PW-3. None of the mixing scenarios using either UE-1q or ER-6-1 groundwater to represent Yucca Flat groundwater was successful. In general, these mixing scenarios did not work because either the Cl concentrations or $\delta^{18}\text{O}$ values did not allow mixing, or calculated $\delta^{13}\text{C}$ values were not within 1.0 ‰ of measured values.

No valid simulations including groundwater flow from east of the NTS represented by USGS HTH #3 were produced. If groundwater from the east is flowing toward the NTS as suggested by Laczniaik *et al.* (1996), then the geochemical and isotopic changes along the flowpath should be reproducible with modeling, but these chemical changes were not successfully modeled in this study. This suggests that either the flowpath is not valid or that USGS HTH #3 is not representative of eastward-flowing groundwater.

The successful geochemical and isotopic models in this study suggest that the proportion of groundwater flowing from Yucca Flat to Frenchman Flat is larger (20 to 57 percent), the groundwater flow from the east (USGS HTH #3 representing flow from the Sheep Range) and southeast (Cold Creek Spring representing flow from the Spring Mountains) to Frenchman Flat is

smaller (0 to 54 percent), and the flow from the overlying volcanic aquifer into the carbonate aquifer is larger (8 to 60 percent).

A mixing zone for the three valid mixing simulations was delineated and is located southwest of Frenchman Lake in Frenchman Flat. The distances from the mixing zone were divided by the range of travel times developed during geochemical and isotopic modeling to produce groundwater velocities. Groundwater velocities from Yucca Flat to Army #1 Water Well and Amargosa Tracer Well #2 range from 0.9 m/yr to 10.0 m/yr. The fastest velocities are from the geochemical evolution simulation from Army #1 Water Well and Amargosa Tracer Well #2 (5.6 to 10.0 m/yr). The groundwater velocities calculated in this study fall at the lower end of the range of groundwater velocities reported by Winograd and Thordarson (1975) and Laczniaik *et al.* (1996) (1.8 to 18,288 m/yr).

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APPENDIX

NETPATH MODELING SIMULATIONS

appendix

1

Initial Well 1 : Water Well C-1
Initial Well 2 : Cold Creek Spring
Final well : Army #1 Water Well

	Final	Initial 1	Initial 2
C	4.8251	14.0236	4.6291
S	0.5655	0.6825	0.0885
CA	1.1258	1.8831	1.7247
MG	0.8889	1.2228	0.6995
NA	1.6406	5.5295	0.0827
K	0.1400	0.3584	0.0148
CL	0.4600	0.9486	0.0452
SI	0.3164	0.4998	0.1166

CALCITE	CA	1.0000	C	1.0000	RS	4.0000	I1	0.0000	I2	0.0000
DOLOMITE	CA	1.0000	MG	1.0000	C	2.0000	RS	8.0000	I1	0.0000
	I2	0.0000								
GYPSUM	CA	1.0000	S	1.0000	RS	6.0000	I3	22.0000		
ANORTH	CA	1.0000	AL	2.0000	SI	2.0000				
Ca-MONT	CA	0.1670	AL	2.3300	SI	3.6700				
Mg-MONT	MG	0.1670	AL	2.3300	SI	3.6700				
Na-MONT	NA	0.3300	AL	2.3300	SI	3.6700				
K-MONT	K	0.3300	AL	2.3300	SI	3.6700				
ALBITE	NA	1.0000	AL	1.0000	SI	3.0000				
K-SPAR	K	1.0000	AL	1.0000	SI	3.0000				
EXCHANGE	CA	-1.0000	NA	2.0000	MG	0.0000				
Mg/Na EX	NA	2.0000	MG	-1.0000						

792 models checked
10 models found

MODEL 1	
Init 1	+ F 0.45914
Init 2	+ F 0.54086
CALCITE	-4.33259
DOLOMITE	+ 0.10760
GYPSUM	+ 0.20429
ANORTH	+ 3.34909
Mg-MONT	- -0.94903
K-MONT	- -0.09882
ALBITE	- -0.94289
	Computed Observed
Carbon-13	-6.2930 -5.6000
C-14 (% mod)	18.5971* 2.8000

Adjusted C-14 age in years: 15652.* * = based on Original Data

MODEL 2	
Init 1	+ F 0.45914
Init 2	+ F 0.54086
CALCITE	-5.59860
DOLOMITE	+ 0.74060
GYPSUM	+ 0.20429
ANORTH	+ 3.98209
K-MONT	- -0.09882
ALBITE	-2.52588
Mg/Na EX	+ 0.79150
	Computed Observed
Carbon-13	-5.5994 -5.6000
C-14 (% mod)	15.3732* 2.8000

Adjusted C-14 age in years: 14078.* * = based on Original Data

MODEL 3	
Init 1	+ F 0.45914
Init 2	+ F 0.54086
CALCITE	-4.11740
GYPSUM	+ 0.20429
ANORTH	+ 3.34909
Ca-MONT	- -0.64429
Mg-MONT	- -0.30474
K-MONT	- -0.09882
ALBITE	- -0.94289
	Computed Observed
Carbon-13	-6.4239 -5.6000
C-14 (% mod)	19.2088* 2.8000

Adjusted C-14 age in years: 15919.* * = based on Original Data

MODEL 4	
Init 1	+ F 0.45914
Init 2	+ F 0.54086
CALCITE	-4.11740
GYPSUM	+ 0.20429
ANORTH	+ 3.38979
Ca-MONT	- -0.88801
K-MONT	- -0.09882
ALBITE	-1.04467
Mg/Na EX	+ 0.05089
	Computed Observed
Carbon-13	-6.4239 -5.6000
C-14 (% mod)	19.2088* 2.8000

Adjusted C-14 age in years: 15919.* * = based on Original Data

MODEL 5	
Init 1	+ F 0.45914
Init 2	+ F 0.54086
CALCITE	-4.11740
GYPSUM	+ 0.20429
ANORTH	+ 3.24149
Mg-MONT	- -0.30474
Na-MONT	- -0.80200
K-MONT	- -0.09882
ALBITE	-0.67823
	Computed Observed
Carbon-13	-6.4239 -5.6000
C-14 (% mod)	19.2088* 2.8000

Adjusted C-14 age in years: 15919.* * = based on Original Data

MODEL 6	
Init 1	+ F 0.45914
Init 2	+ F 0.54086
CALCITE	-4.11740
GYPSUM	+ 0.20429
ANORTH	+ 3.24149
Mg-MONT	- -0.30474
K-MONT	- -0.90083
ALBITE	-0.94289
K-SPAR	+ 0.26466
	Computed Observed
Carbon-13	-6.4239 -5.6000
C-14 (% mod)	19.2088* 2.8000

Adjusted C-14 age in years: 15919.* * = based on Original Data

appendix

2

MODEL 7		
Init 1	+ F	0.45914
Init 2	+ F	0.54086
CALCITE		-4.11740
GYPSUM	+	0.20429
ANORTH	+	3.77883
Mg-MONT	-	-0.30474
K-MONT	-	-0.09882
ALBITE		-2.01757
EXCHANGE	+	0.53734
		Computed Observed
Carbon-13		-6.4239 -5.6000
C-14 (% mod)	19.2088*	2.8000

Adjusted C-14 age in years: 15919.* * = based on Original Data

MODEL 8		
Init 1	+ F	0.45914
Init 2	+ F	0.54086
CALCITE		-4.11740
GYPSUM	+	0.20429
ANORTH	+	3.24149
Na-MONT	-	-1.10538
K-MONT	-	-0.09882
ALBITE		-0.67990
Mg/Na EX	+	0.05089
		Computed Observed
Carbon-13		-6.4239 -5.6000
C-14 (% mod)	19.2088*	2.8000

Adjusted C-14 age in years: 15919.* * = based on Original Data

MODEL 9		
Init 1	+ F	0.45914
Init 2	+ F	0.54086
CALCITE		-4.11740
GYPSUM	+	0.20429
ANORTH	+	3.24149
K-MONT	-	-1.20420
ALBITE		-1.04467
K-SPAR	+	0.36477
Mg/Na EX	+	0.05089
		Computed Observed
Carbon-13		-6.4239 -5.6000
C-14 (% mod)	19.2088*	2.8000

Adjusted C-14 age in years: 15919.* * = based on Original Data

MODEL 10		
Init 1	+ F	0.45914
Init 2	+ F	0.54086
CALCITE		-4.11740
GYPSUM	+	0.20429
ANORTH	+	3.98209
K-MONT	-	-0.09882
ALBITE		-2.52588
EXCHANGE	+	0.74060
Mg/Na EX	+	0.05089
		Computed Observed
Carbon-13		-6.4239 -5.6000
C-14 (% mod)	19.2088*	2.8000

Adjusted C-14 age in years: 15919.* * = based on Original Data

Initial Well 1 : Water Well C-1
Initial Well 2 : Cold Creek Spring
Final well : Army #1 Water Well

	Final	Initial 1	Initial 2
C	4.8251	14.0236	4.6291
S	0.5655	0.6825	0.0885
CA	1.1258	1.8831	1.7247
MG	0.8889	1.2228	0.6995
NA	1.6406	5.5295	0.0827
K	0.1400	0.3584	0.0148
SI	0.3164	0.4998	0.1166
18	-14.1000	-14.4000	-13.7000

CALCITE	CA	1.0000	C	1.0000	RS	4.0000	I1	0.0000	I2	0.0000
DOLOMITE	CA	1.0000	MG	1.0000	C	2.0000	RS	8.0000	I1	0.0000
			I2	0.0000						
GYPSUM	CA	1.0000	S	1.0000	RS	6.0000	I3	22.0000		
ANORTH	CA	1.0000	AL	2.0000	SI	2.0000				
Ca-MONT	CA	0.1670	AL	2.3300	SI	3.6700				
Mg-MONT	MG	0.1670	AL	2.3300	SI	3.6700				
Na-MONT	NA	0.3300	AL	2.3300	SI	3.6700				
K-MONT	K	0.3300	AL	2.3300	SI	3.6700				
ALBITE	NA	1.0000	AL	1.0000	SI	3.0000				
K-SPAR	K	1.0000	AL	1.0000	SI	3.0000				
EXCHANGE	CA	-1.0000	NA	2.0000	MG	0.0000				
Mg/Na EX	NA	2.0000	MG	-1.0000						

792 models checked
10 models found

MODEL 1		
Init 1	+ F	0.57143
Init 2	+ F	0.42857
CALCITE		-5.25690
DOLOMITE	+	0.04229
GYPSUM	+	0.13759
ANORTH	+	4.38762
Mg-MONT	-	-0.90985
K-MONT	-	-0.21572
ALBITE		-1.55453
		Computed Observed
Carbon-13		-6.1271 -5.6000
C-14 (% mod)	13.6772*	2.8000

Adjusted C-14 age in years: 13112.* * = based on Original Data

MODEL 2		
Init 1	+ F	0.57143
Init 2	+ F	0.42857
CALCITE		-6.47064
DOLOMITE	+	0.64916
GYPSUM	+	0.13759
ANORTH	+	4.99449
K-MONT	-	-0.21572
ALBITE		-3.07215
Mg/Na EX	+	0.75881
		Computed Observed
Carbon-13		-5.5383 -5.6000
C-14 (% mod)	11.5210*	2.8000

Adjusted C-14 age in years: 11694.* * = based on Original Data

appendix

3

MODEL 3		
Init 1	+ F	0.57143
Init 2	+ F	0.42857
CALCITE		-5.17232
GYPSUM	+	0.13759
ANORTH	+	4.38762
Ca-MONT	-	-0.25324
Mg-MONT	-	-0.65660
K-MONT	-	-0.21572
ALBITE		-1.55453
		Computed Observed
Carbon-13		-6.1718 -5.6000

Adjusted C-14 age in years: 13211.* * = based on Original Data

MODEL 4		
Init 1	+ F	0.57143
Init 2	+ F	0.42857
CALCITE		-5.17232
GYPSUM	+	0.13759
ANORTH	+	4.47532
Ca-MONT	-	-0.77837
K-MONT	-	-0.21572
ALBITE		-1.77383
Mg/Na EX	+	0.10965
		Computed Observed
Carbon-13		-6.1718 -5.6000
C-14 (% mod)		13.8417* 2.8000

Adjusted C-14 age in years: 13211.* * = based on Original Data

MODEL 5		
Init 1	+ F	0.57143
Init 2	+ F	0.42857
CALCITE		-5.17232
GYPSUM	+	0.13759
ANORTH	+	4.34533
Mg-MONT	-	-0.65660
Na-MONT	-	-0.31523
K-MONT	-	-0.21572
ALBITE		-1.45050
		Computed Observed
Carbon-13		-6.1718 -5.6000
C-14 (% mod)		13.8417* 2.8000

Adjusted C-14 age in years: 13211.* * = based on Original Data

MODEL 6		
Init 1	+ F	0.57143
Init 2	+ F	0.42857
CALCITE		-5.17232
GYPSUM	+	0.13759
ANORTH	+	4.34533
Mg-MONT	-	-0.65660
K-MONT	-	-0.53095
ALBITE		-1.55453
K-SPAR	+	0.10403
		Computed Observed
Carbon-13		-6.1718 -5.6000
C-14 (% mod)		13.8417* 2.8000

Adjusted C-14 age in years: 13211.* * = based on Original Data

MODEL 7		
Init 1	+ F	0.57143
Init 2	+ F	0.42857
CALCITE		-5.17232
GYPSUM	+	0.13759
ANORTH	+	4.55654
Mg-MONT	-	-0.65660
K-MONT	-	-0.21572
ALBITE		-1.97693
EXCHANGE	+	0.21120
		Computed Observed
Carbon-13		-6.1718 -5.6000
C-14 (% mod)		13.8417* 2.8000

Adjusted C-14 age in years: 13211.* * = based on Original Data

MODEL 8		
Init 1	+ F	0.57143
Init 2	+ F	0.42857
CALCITE		-5.17232
GYPSUM	+	0.13759
ANORTH	+	4.34533
Na-MONT	-	-0.96889
K-MONT	-	-0.21572
ALBITE		-1.45410
Mg/Na EX	+	0.10965
		Computed Observed
Carbon-13		-6.1718 -5.6000
C-14 (% mod)		13.8417* 2.8000

Adjusted C-14 age in years: 13211.* * = based on Original Data

MODEL 9		
Init 1	+ F	0.57143
Init 2	+ F	0.42857
CALCITE		-5.17232
GYPSUM	+	0.13759
ANORTH	+	4.34533
K-MONT	-	-1.18462
ALBITE		-1.77383
K-SPAR	+	0.31973
Mg/Na EX	+	0.10965
		Computed Observed
Carbon-13		-6.1718 -5.6000
C-14 (% mod)		13.8417* 2.8000

Adjusted C-14 age in years: 13211.* * = based on Original Data

MODEL 10		
Init 1	+ F	0.57143
Init 2	+ F	0.42857
CALCITE		-5.17232
GYPSUM	+	0.13759
ANORTH	+	4.99449
K-MONT	-	-0.21572
ALBITE		-3.07215
EXCHANGE	+	0.64916
Mg/Na EX	+	0.10965
		Computed Observed
Carbon-13		-6.1718 -5.6000
C-14 (% mod)		13.8417* 2.8000

Adjusted C-14 age in years: 13211.* * = based on Original Data

appendix

4

Initial Well 1 : Water Well C-1
Initial Well 2 : Cold Creek Spring
Initial Well 3 : UE-5e PW-3
Final well : Army #1 Water Well

	Final	Initial 1	Initial 2	Initial 3
C	4.8251	14.0236	4.6291	2.2559
S	0.5655	0.6825	0.0885	0.3676
CA	1.1258	1.8831	1.7247	0.4567
MG	0.8889	1.2228	0.6995	0.2296
NA	1.6406	5.5295	0.0827	2.4671
K	0.1400	0.3584	0.0148	0.1573
SI	0.3164	0.4998	0.1166	0.6510
CL	0.4600	0.9486	0.0452	0.2596

CALCITE	CA	1.0000	C	1.0000	RS	4.0000	I1	0.0000	I2	0.0000
DOLOMITE	CA	1.0000	MG	1.0000	C	2.0000	RS	8.0000	I1	0.0000
	I2	0.0000								
GYPSUM	CA	1.0000	S	1.0000	RS	6.0000	I3	22.0000		
ANORTH	CA	1.0000	AL	2.0000	SI	2.0000				
Ca-MONT	CA	0.1670	AL	2.3300	SI	3.6700				
Mg-MONT	MG	0.1670	AL	2.3300	SI	3.6700				
Na-MONT	NA	0.3300	AL	2.3300	SI	3.6700				
K-MONT	K	0.3300	AL	2.3300	SI	3.6700				
ALBITE	NA	1.0000	AL	1.0000	SI	3.0000				
K-SPAR	K	1.0000	AL	1.0000	SI	3.0000				
EXCHANGE	CA	-1.0000	NA	2.0000	MG	0.0000				
Mg/Na EX	NA	2.0000	MG	-1.0000						

792 models checked
3 models found

	MODEL	1
Init 1	+ F	0.43881
Init 2	+ F	0.47553
Init 3	+ F	0.08566
CALCITE		-3.72312
GYPSUM	+	0.19246
ANORTH	+	2.97088
Ca-MONT	-	0.00000
Na-MONT	-	-0.90519
K-MONT	-	-0.11465
ALBITE		-0.73769
	Computed	Observed
Carbon-13	-6.3026	-5.6000
C-14 (% mod)	18.1022*	2.8000

Adjusted C-14 age in years: 15429.* * = based on Original Data

	MODEL	2
Init 1	+ F	0.43881
Init 2	+ F	0.47553
Init 3	+ F	0.08566
CALCITE		-3.72312
GYPSUM	+	0.19246
ANORTH	+	2.97088
Ca-MONT	-	0.00000
K-MONT	-	-1.01984
ALBITE		-1.03640
K-SPAR	+	0.29871
	Computed	Observed
Carbon-13	-6.3026	-5.6000
C-14 (% mod)	18.1022*	2.8000

Adjusted C-14 age in years: 15429.* * = based on Original Data

	MODEL	3
Init 1	+ F	0.43881
Init 2	+ F	0.47553
Init 3	+ F	0.08566
CALCITE		-3.72312
GYPSUM	+	0.19246
ANORTH	+	2.97088
Na-MONT	-	0.00000
K-MONT	-	-1.01984
ALBITE		-1.03640
K-SPAR	+	0.29871
	Computed	Observed
Carbon-13	-6.3026	-5.6000
C-14 (% mod)	18.1022*	2.8000

Adjusted C-14 age in years: 15429.* * = based on Original Data

appendix

5

Initial Well 1 : Water Well C-1
Initial Well 2 : Cold Creek Spring
Initial Well 3 : UE-5e PW-3
Final well : Army #1 Water Well

	Final	Initial 1	Initial 2	Initial 3
C	4.8251	14.0236	4.6291	2.2559
S	0.5655	0.6825	0.0885	0.3676
CA	1.1258	1.8831	1.7247	0.4567
MG	0.8889	1.2228	0.6995	0.2296
NA	1.6406	5.5295	0.0827	2.4671
K	0.1400	0.3584	0.0148	0.1573
SI	0.3164	0.4998	0.1166	0.6510
18	-14.1000	-14.4000	-13.7000	-13.3000

CALCITE	CA	1.0000	C	1.0000	RS	4.0000	I1	0.0000	I2	0.0000
DOLOMITE	CA	1.0000	MG	1.0000	C	2.0000	RS	8.0000	I1	0.0000
			I2	0.0000						
GYPSUM	CA	1.0000	S	1.0000	RS	6.0000	I3	22.0000		
ANORTH	CA	1.0000	AL	2.0000	SI	2.0000				
Ca-MONT	CA	0.1670	AL	2.3300	SI	3.6700				
Mg-MONT	MG	0.1670	AL	2.3300	SI	3.6700				
Na-MONT	NA	0.3300	AL	2.3300	SI	3.6700				
K-MONT	K	0.3300	AL	2.3300	SI	3.6700				
ALBITE	NA	1.0000	AL	1.0000	SI	3.0000				
K-SPAR	K	1.0000	AL	1.0000	SI	3.0000				
EXCHANGE	CA	-1.0000	NA	2.0000	MG	0.0000				
Mg/Na EX	NA	2.0000	MG	-1.0000						

792 models checked
3 models found

	MODEL	1
Init 1	+ F	0.69855
Init 2	+ F	0.07900
Init 3	+ F	0.22246
CALCITE		-5.83859
ANORTH	+	5.44203
Ca-MONT	-	-0.18505
Mg-MONT	-	0.00000
K-MONT	-	-0.44411
ALBITE		-2.92061
Mg/Na EX	+	0.07164
	Computed	Observed
Carbon-13		-5.5527 -5.6000
C-14 (% mod)		3.8163* 2.8000

Adjusted C-14 age in years: 2560.* * = based on Original Data

	MODEL	2
Init 1	+ F	0.69855
Init 2	+ F	0.07900
Init 3	+ F	0.22246
CALCITE		-5.83859
ANORTH	+	5.44203
Ca-MONT	-	-0.18505
Na-MONT	-	0.00000
K-MONT	-	-0.44411
ALBITE		-2.92061
Mg/Na EX	+	0.07164
	Computed	Observed
Carbon-13		-5.5527 -5.6000
C-14 (% mod)		3.8163* 2.8000

Adjusted C-14 age in years: 2560.* * = based on Original Data

	MODEL	3
Init 1	+ F	0.69855
Init 2	+ F	0.07900
Init 3	+ F	0.22246
CALCITE		-5.83859
ANORTH	+	5.41113
Mg-MONT	-	0.00000
Na-MONT	-	-0.23034
K-MONT	-	-0.44411
ALBITE		-2.84460
Mg/Na EX	+	0.07164
	Computed	Observed
Carbon-13		-5.5527 -5.6000
C-14 (% mod)		3.8163* 2.8000

Adjusted C-14 age in years: 2560.* * = based on Original Data

appendix

6

Initial Well 1 : Water Well C-1
Initial Well 2 : UE-5e PW-3
Initial Well 3 : Cold Creek Spring
Final well : Amargosa Tracer Well #2

	Final	Initial 1	Initial 2	Initial 3
C	5.1051	14.0236	2.2559	4.6291
S	0.7301	0.6825	0.3676	0.0885
CA	1.1109	1.8831	0.4567	1.7247
MG	0.8066	1.2228	0.2296	0.6995
NA	2.8115	5.5295	2.4671	0.0827
K	0.1996	0.3584	0.1573	0.0148
SI	0.3664	0.4998	0.6510	0.1166
CL	0.5616	0.9486	0.2596	0.0452

CALCITE	CA	1.0000	C	1.0000	RS	4.0000	I1	0.0000	I2	0.0000
DOLOMITE	CA	1.0000	MG	1.0000	C	2.0000	RS	8.0000	I1	0.0000
			I2							
GYPSUM	CA	1.0000	S	1.0000	RS	6.0000	I3	22.0000		
ANORTH	CA	1.0000	AL	2.0000	SI	2.0000				
Ca-MONT	CA	0.1670	AL	2.3300	SI	3.6700				
Mg-MONT	MG	0.1670	AL	2.3300	SI	3.6700				
Na-MONT	NA	0.3300	AL	2.3300	SI	3.6700				
K-MONT	K	0.3300	AL	2.3300	SI	3.6700				
ALBITE	NA	1.0000	AL	1.0000	SI	3.0000				
K-SPAR	K	1.0000	AL	1.0000	SI	3.0000				
EXCHANGE	CA	-1.0000	NA	2.0000	MG	0.0000				
Mg/Na	EX	2.0000	MG	-1.0000						

792 models checked
3 models found

	MODEL	1
Init 1	+ F	0.49492
Init 2	+ F	0.32318
Init 3	+ F	0.18190
CALCITE		-3.40657
GYPSUM	+	0.25745
ANORTH	+	2.86670
Ca-MONT	-	0.00000
Na-MONT	-	-1.22573
K-MONT	-	-0.09492
ALBITE		-0.33306
	Computed	Observed
Carbon-13	-5.5503	-4.6000
C-14 (% mod)	8.6998*	1.8000

Adjusted C-14 age in years: 13024.* * = based on Original Data

	MODEL	2
Init 1	+ F	0.49492
Init 2	+ F	0.32318
Init 3	+ F	0.18190
CALCITE		-3.40657
GYPSUM	+	0.25745
ANORTH	+	2.86670
Ca-MONT	-	0.00000
K-MONT	-	-1.32065
ALBITE		-0.73755
K-SPAR	+	0.40449
	Computed	Observed
Carbon-13	-5.5503	-4.6000
C-14 (% mod)	8.6998*	1.8000

Adjusted C-14 age in years: 13024.* * = based on Original Data

	MODEL	3
Init 1	+ F	0.49492
Init 2	+ F	0.32318
Init 3	+ F	0.18190
CALCITE		-3.40657
GYPSUM	+	0.25745
ANORTH	+	2.86670
Mg-MONT	-	0.00000
Na-MONT	-	-1.22573
K-MONT	-	-0.09492
ALBITE		-0.33306
	Computed	Observed
Carbon-13	-5.5503	-4.6000
C-14 (% mod)	8.6998*	1.8000

Adjusted C-14 age in years: 13024.* * = based on Original Data

appendix

7

Initial Well 1 : Water Well C-1
Initial Well 2 : UE-5e PW-3
Initial Well 3 : Cold Creek Spring
Final well : Amargosa Tracer Well #2

	Final	Initial 1	Initial 2	Initial 3
C	5.1051	14.0236	2.2559	4.6291
S	0.7301	0.6825	0.3676	0.0885
CA	1.1109	1.8831	0.4567	1.7247
MG	0.8066	1.2228	0.2296	0.6995
NA	2.8115	5.5295	2.4671	0.0827
K	0.1996	0.3584	0.1573	0.0148
SI	0.3664	0.4998	0.6510	0.1166
18	-13.6000	-14.4000	-13.3000	-13.7000

CALCITE	CA	1.0000	C	1.0000	RS	4.0000	I1	0.0000	I2	0.0000
DOLOMITE	CA	1.0000	MG	1.0000	C	2.0000	RS	8.0000	I1	0.0000
			I2	0.0000						
GYPSUM	CA	1.0000	S	1.0000	RS	6.0000	I3	22.0000		
ANORTH	CA	1.0000	AL	2.0000	SI	2.0000				
Ca-MONT	CA	0.1670	AL	2.3300	SI	3.6700				
Mg-MONT	MG	0.1670	AL	2.3300	SI	3.6700				
Na-MONT	NA	0.3300	AL	2.3300	SI	3.6700				
K-MONT	K	0.3300	AL	2.3300	SI	3.6700				
ALBITE	NA	1.0000	AL	1.0000	SI	3.0000				
K-SPAR	K	1.0000	AL	1.0000	SI	3.0000				
EXCHANGE	CA	-1.0000	NA	2.0000	MG	0.0000				
Mg/Na EX	NA	2.0000	MG	-1.0000						

792 models checked
41 models found

MODEL 1	
Init 1	+ F 0.25152
Init 2	+ F 0.69017
Init 3	+ F 0.05831
CALCITE	-0.84868
DOLOMITE	+ 0.29982
GYPSUM	+ 0.29961
ANORTH	+ 0.48554
Ca-MONT	- -0.08881
Mg-MONT	- 0.00000
ALBITE	-0.28685
	Computed Observed
Carbon-13	-4.8383 -4.6000
C-14 (% mod)	7.8975* 1.8000

Adjusted C-14 age in years: 12224.* * = based on Original Data

MODEL 2	
Init 1	+ F 0.22170
Init 2	+ F 0.63798
Init 3	+ F 0.14031
CALCITE	-0.67455
DOLOMITE	+ 0.29090
GYPSUM	+ 0.33189
ANORTH	+ 0.24444
Ca-MONT	- -0.19565
Mg-MONT	- 0.00000
K-SPAR	+ 0.01768
	Computed Observed
Carbon-13	-5.1158 -4.6000
C-14 (% mod)	12.0958* 1.8000

Adjusted C-14 age in years: 15749.* * = based on Original Data

MODEL 3	
Init 1	+ F 0.25152
Init 2	+ F 0.69017
Init 3	+ F 0.05831
CALCITE	-0.84868
DOLOMITE	+ 0.29982
GYPSUM	+ 0.29961
ANORTH	+ 0.47071
Ca-MONT	- 0.00000
Na-MONT	- -0.11055
ALBITE	-0.25037
	Computed Observed
Carbon-13	-4.8383 -4.6000
C-14 (% mod)	7.8975* 1.8000

Adjusted C-14 age in years: 12224.* * = based on Original Data

MODEL 4	
Init 1	+ F 0.22895
Init 2	+ F 0.65066
Init 3	+ F 0.12039
CALCITE	-0.71687
DOLOMITE	+ 0.29307
GYPSUM	+ 0.32405
ANORTH	+ 0.27469
Ca-MONT	- 0.00000
Na-MONT	- -0.21122
K-SPAR	+ 0.01338
	Computed Observed
Carbon-13	-5.0467 -4.6000
C-14 (% mod)	11.0512* 1.8000

Adjusted C-14 age in years: 15002.* * = based on Original Data

MODEL 5	
Init 1	+ F 0.22170
Init 2	+ F 0.63798
Init 3	+ F 0.14031
CALCITE	-0.67455
DOLOMITE	+ 0.29090
GYPSUM	+ 0.33189
ANORTH	+ 0.24444
Ca-MONT	- -0.19565
K-MONT	- 0.00000
K-SPAR	+ 0.01768
	Computed Observed
Carbon-13	-5.1158 -4.6000
C-14 (% mod)	12.0958* 1.8000

Adjusted C-14 age in years: 15749.* * = based on Original Data

appendix

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MODEL 6		
Init 1	+ F	0.22170
Init 2	+ F	0.63798
Init 3	+ F	0.14031
CALCITE		-0.67455
DOLOMITE	+	0.29090
GYPSUM	+	0.33189
ANORTH	+	0.24444
Ca-MONT	-	-0.19565
ALBITE		0.00000
K-SPAR	+	0.01768
Computed Observed		
Carbon-13	-5.1158	-4.6000
C-14 (% mod)	12.0958*	1.8000

Adjusted C-14 age in years: 15749.* * = based on Original Data

MODEL 7		
Init 1	+ F	0.16403
Init 2	+ F	0.53705
Init 3	+ F	0.29892
CALCITE		-0.89256
DOLOMITE	+	0.55105
GYPSUM	+	0.39431
ANORTH	+	0.00000
Ca-MONT	-	-0.06967
K-SPAR	+	0.05187
Mg/Na EX	+	0.27739
Computed Observed		
Carbon-13	-5.2911	-4.6000
C-14 (% mod)	18.8073*	1.8000

Adjusted C-14 age in years: 19397.* * = based on Original Data

MODEL 8		
Init 1	+ F	0.25152
Init 2	+ F	0.69017
Init 3	+ F	0.05831
CALCITE		-0.84868
DOLOMITE	+	0.29982
GYPSUM	+	0.29961
ANORTH	+	0.47071
Mg-MONT	-	0.00000
Na-MONT	-	-0.11055
ALBITE		-0.25037
Computed Observed		
Carbon-13	-4.8383	-4.6000
C-14 (% mod)	7.8975*	1.8000

Adjusted C-14 age in years: 12224.* * = based on Original Data

MODEL 9		
Init 1	+ F	0.22895
Init 2	+ F	0.65066
Init 3	+ F	0.12039
CALCITE		-0.71687
DOLOMITE	+	0.29307
GYPSUM	+	0.32405
ANORTH	+	0.27469
Mg-MONT	-	0.00000
Na-MONT	-	-0.21122
K-SPAR	+	0.01338
Computed Observed		
Carbon-13	-5.0467	-4.6000
C-14 (% mod)	11.0512*	1.8000

Adjusted C-14 age in years: 15002.* * = based on Original Data

MODEL 10		
Init 1	+ F	0.22170
Init 2	+ F	0.63798
Init 3	+ F	0.14031
CALCITE		-0.73990
DOLOMITE	+	0.32358
GYPSUM	+	0.33189
ANORTH	+	0.24444
Mg-MONT	-	-0.19565
K-MONT	-	0.00000
K-SPAR	+	0.01768
Computed Observed		
Carbon-13	-5.0737	-4.6000
C-14 (% mod)	11.9428*	1.8000

Adjusted C-14 age in years: 15643.* * = based on Original Data

MODEL 11		
Init 1	+ F	0.22170
Init 2	+ F	0.63798
Init 3	+ F	0.14031
CALCITE		-0.73990
DOLOMITE	+	0.32358
GYPSUM	+	0.33189
ANORTH	+	0.24444
Mg-MONT	-	-0.19565
ALBITE		0.00000
K-SPAR	+	0.01768
Computed Observed		
Carbon-13	-5.0737	-4.6000
C-14 (% mod)	11.9428*	1.8000

Adjusted C-14 age in years: 15643.* * = based on Original Data

appendix

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MODEL 12		
Init 1	+ F	0.16403
Init 2	+ F	0.53705
Init 3	+ F	0.29892
CALCITE		-0.91583
DOLOMITE	+	0.56269
GYPSUM	+	0.39431
ANORTH	+	0.00000
Mg-MONT	-	-0.06967
K-SPAR	+	0.05187
Mg/Na EX	+	0.27739
Computed Observed		
Carbon-13	-5.2746	-4.6000
C-14 (% mod)	18.7196*	1.8000

Adjusted C-14 age in years: 19359.* * = based on Original Data

MODEL 13		
Init 1	+ F	0.22895
Init 2	+ F	0.65066
Init 3	+ F	0.12039
CALCITE		-0.71687
DOLOMITE	+	0.29307
GYPSUM	+	0.32405
ANORTH	+	0.27469
Na-MONT	-	-0.21122
K-MONT	-	0.00000
K-SPAR	+	0.01338
Computed Observed		
Carbon-13	-5.0467	-4.6000
C-14 (% mod)	11.0512*	1.8000

Adjusted C-14 age in years: 15002.* * = based on Original Data

MODEL 14		
Init 1	+ F	0.22895
Init 2	+ F	0.65066
Init 3	+ F	0.12039
CALCITE		-0.71687
DOLOMITE	+	0.29307
GYPSUM	+	0.32405
ANORTH	+	0.27469
Na-MONT	-	-0.21122
ALBITE		0.00000
K-SPAR	+	0.01338
Computed Observed		
Carbon-13	-5.0467	-4.6000
C-14 (% mod)	11.0512*	1.8000

Adjusted C-14 age in years: 15002.* * = based on Original Data

MODEL 15		
Init 1	+ F	0.16407
Init 2	+ F	0.53712
Init 3	+ F	0.29882
CALCITE		-0.91541
DOLOMITE	+	0.56238
GYPSUM	+	0.39427
ANORTH	+	0.00000
Na-MONT	-	-0.06966
K-SPAR	+	0.05185
Mg/Na EX	+	0.28872
Computed Observed		
Carbon-13	-5.2747	-4.6000
C-14 (% mod)	18.7167*	1.8000

Adjusted C-14 age in years: 19357.* * = based on Original Data

MODEL 16		
Init 1	+ F	0.22170
Init 2	+ F	0.63798
Init 3	+ F	0.14031
CALCITE		-0.67455
DOLOMITE	+	0.29090
GYPSUM	+	0.33189
ANORTH	+	0.21177
K-MONT	-	-0.24354
ALBITE		0.00000
K-SPAR	+	0.09805
Computed Observed		
Carbon-13	-5.1158	-4.6000
C-14 (% mod)	12.0958*	1.8000

Adjusted C-14 age in years: 15749.* * = based on Original Data

MODEL 17		
Init 1	+ F	0.16703
Init 2	+ F	0.54231
Init 3	+ F	0.29066
CALCITE		-0.88120
DOLOMITE	+	0.53750
GYPSUM	+	0.39106
ANORTH	+	0.00000
K-MONT	-	-0.09489
K-SPAR	+	0.08141
Mg/Na EX	+	0.26295
Computed Observed		
Carbon-13	-5.2830	-4.6000
C-14 (% mod)	18.4756*	1.8000

Adjusted C-14 age in years: 19250.* * = based on Original Data

MODEL 18		
Init 1	+ F	0.15587
Init 2	+ F	0.52278
Init 3	+ F	0.32135
CALCITE		-0.29012
DOLOMITE	+	0.27122
GYPSUM	+	0.40314
ANORTH	+	0.00000
ALBITE		-0.08648
K-SPAR	+	0.05671
EXCHANGE	+	0.35988
<hr/>		
		Computed Observed
Carbon-13		-5.8010 -4.6000
C-14 (% mod)		22.3805* 1.8000

Adjusted C-14 age in years: 20835.* * = based on Original Data

MODEL 19		
Init 1	+ F	0.15587
Init 2	+ F	0.52278
Init 3	+ F	0.32135
CALCITE		-1.00988
DOLOMITE	+	0.63109
GYPSUM	+	0.40314
ANORTH	+	0.00000
ALBITE		-0.08648
K-SPAR	+	0.05671
Mg/Na EX	+	0.35988
<hr/>		
		Computed Observed
Carbon-13		-5.2508 -4.6000
C-14 (% mod)		19.3577* 1.8000

Adjusted C-14 age in years: 19636.* * = based on Original Data

MODEL 20		
Init 1	+ F	0.19147
Init 2	+ F	0.58507
Init 3	+ F	0.22346
CALCITE		-0.49800
DOLOMITE	+	0.28186
GYPSUM	+	0.36461
Ca-MONT	-	-0.30397
Mg-MONT	-	0.00000
ALBITE		0.29084
K-SPAR	+	0.03561
<hr/>		
		Computed Observed
Carbon-13		-5.4173 -4.6000
C-14 (% mod)		16.6343* 1.8000

Adjusted C-14 age in years: 18382.* * = based on Original Data

MODEL 21		
Init 1	+ F	0.16403
Init 2	+ F	0.53705
Init 3	+ F	0.29892
CALCITE		-0.33777
DOLOMITE	+	0.27366
GYPSUM	+	0.39431
Ca-MONT	-	-0.06967
Mg-MONT	-	0.00000
K-SPAR	+	0.05187
EXCHANGE	+	0.27739
<hr/>		
		Computed Observed
Carbon-13		-5.7102 -4.6000
C-14 (% mod)		21.0227* 1.8000

Adjusted C-14 age in years: 20318.* * = based on Original Data

MODEL 22		
Init 1	+ F	0.16403
Init 2	+ F	0.53705
Init 3	+ F	0.29892
CALCITE		-0.89256
DOLOMITE	+	0.55105
GYPSUM	+	0.39431
Ca-MONT	-	-0.06967
Mg-MONT	-	0.00000
K-SPAR	+	0.05187
Mg/Na EX	+	0.27739
<hr/>		
		Computed Observed
Carbon-13		-5.2911 -4.6000
C-14 (% mod)		18.8073* 1.8000

Adjusted C-14 age in years: 19397.* * = based on Original Data

MODEL 23		
Init 1	+ F	0.19732
Init 2	+ F	0.59530
Init 3	+ F	0.20738
CALCITE		-0.53214
DOLOMITE	+	0.28361
GYPSUM	+	0.35829
Ca-MONT	-	0.00000
Na-MONT	-	-0.35230
ALBITE		0.35086
K-SPAR	+	0.03214
<hr/>		
		Computed Observed
Carbon-13		-5.3574 -4.6000
C-14 (% mod)		15.7334* 1.8000

Adjusted C-14 age in years: 17922.* * = based on Original Data

MODEL 24		
Init 1	+ F	0.16407
Init 2	+ F	0.53712
Init 3	+ F	0.29882
CALCITE		-0.33798
DOLOMITE	+	0.27367
GYPSUM	+	0.39427
Ca-MONT	-	0.00000
Na-MONT	-	-0.06966
K-SPAR	+	0.05185
EXCHANGE	+	0.28872
	Computed	Observed
Carbon-13	-5.7098	-4.6000
C-14 (% mod)	21.0167*	1.8000

Adjusted C-14 age in years: 20316.* * = based on Original Data

MODEL 25		
Init 1	+ F	0.16407
Init 2	+ F	0.53712
Init 3	+ F	0.29882
CALCITE		-0.91541
DOLOMITE	+	0.56238
GYPSUM	+	0.39427
Ca-MONT	-	0.00000
Na-MONT	-	-0.06966
K-SPAR	+	0.05185
Mg/Na EX	+	0.28872
	Computed	Observed
Carbon-13	-5.2747	-4.6000
C-14 (% mod)	18.7167*	1.8000

Adjusted C-14 age in years: 19357.* * = based on Original Data

MODEL 26		
Init 1	+ F	0.19147
Init 2	+ F	0.58507
Init 3	+ F	0.22346
CALCITE		-0.49800
DOLOMITE	+	0.28186
GYPSUM	+	0.36461
Ca-MONT	-	-0.30397
K-MONT	-	0.00000
ALBITE		0.29084
K-SPAR	+	0.03561
	Computed	Observed
Carbon-13	-5.4173	-4.6000
C-14 (% mod)	16.6343*	1.8000

Adjusted C-14 age in years: 18382.* * = based on Original Data

MODEL 27		
Init 1	+ F	0.16403
Init 2	+ F	0.53705
Init 3	+ F	0.29892
CALCITE		-0.33777
DOLOMITE	+	0.27366
GYPSUM	+	0.39431
Ca-MONT	-	-0.06967
K-MONT	-	0.00000
K-SPAR	+	0.05187
EXCHANGE	+	0.27739
	Computed	Observed
Carbon-13	-5.7102	-4.6000
C-14 (% mod)	21.0227*	1.8000

Adjusted C-14 age in years: 20318.* * = based on Original Data

MODEL 28		
Init 1	+ F	0.16403
Init 2	+ F	0.53705
Init 3	+ F	0.29892
CALCITE		-0.89256
DOLOMITE	+	0.55105
GYPSUM	+	0.39431
Ca-MONT	-	-0.06967
K-MONT	-	0.00000
K-SPAR	+	0.05187
Mg/Na EX	+	0.27739
	Computed	Observed
Carbon-13	-5.2911	-4.6000
C-14 (% mod)	18.8073*	1.8000

Adjusted C-14 age in years: 19397.* * = based on Original Data

MODEL 29		
Init 1	+ F	0.16403
Init 2	+ F	0.53705
Init 3	+ F	0.29892
CALCITE		-0.33777
DOLOMITE	+	0.27366
GYPSUM	+	0.39431
Ca-MONT	-	-0.06967
ALBITE		0.00000
K-SPAR	+	0.05187
EXCHANGE	+	0.27739
	Computed	Observed
Carbon-13	-5.7102	-4.6000
C-14 (% mod)	21.0227*	1.8000

Adjusted C-14 age in years: 20318.* * = based on Original Data

MODEL 30			
Init 1	+ F	0.19732	
Init 2	+ F	0.59530	
Init 3	+ F	0.20738	
CALCITE		-0.53214	
DOLOMITE	+	0.28361	
GYPSUM	+	0.35829	
Mg-MONT	-	0.00000	
Na-MONT	-	-0.35230	
ALBITE		0.35086	
K-SPAR	+	0.03214	
		Computed	Observed
Carbon-13		-5.3574	-4.6000
C-14 (% mod)		15.7334*	1.8000

Adjusted C-14 age in years: 17922.* * = based on Original Data

MODEL 31			
Init 1	+ F	0.16407	
Init 2	+ F	0.53712	
Init 3	+ F	0.29882	
CALCITE		-0.33798	
DOLOMITE	+	0.27367	
GYPSUM	+	0.39427	
Mg-MONT	-	0.00000	
Na-MONT	-	-0.06966	
K-SPAR	+	0.05185	
EXCHANGE	+	0.28872	
		Computed	Observed
Carbon-13		-5.7098	-4.6000
C-14 (% mod)		21.0167*	1.8000

Adjusted C-14 age in years: 20316.* * = based on Original Data

MODEL 32			
Init 1	+ F	0.16407	
Init 2	+ F	0.53712	
Init 3	+ F	0.29882	
CALCITE		-0.91541	
DOLOMITE	+	0.56238	
GYPSUM	+	0.39427	
Mg-MONT	-	0.00000	
Na-MONT	-	-0.06966	
K-SPAR	+	0.05185	
Mg/Na EX	+	0.28872	
		Computed	Observed
Carbon-13		-5.2747	-4.6000
C-14 (% mod)		18.7167*	1.8000

Adjusted C-14 age in years: 19357.* * = based on Original Data

MODEL 33			
Init 1	+ F	0.19147	
Init 2	+ F	0.58507	
Init 3	+ F	0.22346	
CALCITE		-0.59953	
DOLOMITE	+	0.33263	
GYPSUM	+	0.36461	
Mg-MONT	-	-0.30397	
K-MONT	-	0.00000	
ALBITE		0.29084	
K-SPAR	+	0.03561	
		Computed	Observed
Carbon-13		-5.3445	-4.6000
C-14 (% mod)		16.3035*	1.8000

Adjusted C-14 age in years: 18216.* * = based on Original Data

MODEL 34			
Init 1	+ F	0.16403	
Init 2	+ F	0.53705	
Init 3	+ F	0.29892	
CALCITE		-0.36104	
DOLOMITE	+	0.28529	
GYPSUM	+	0.39431	
Mg-MONT	-	-0.06967	
K-MONT	-	0.00000	
K-SPAR	+	0.05187	
EXCHANGE	+	0.27739	
		Computed	Observed
Carbon-13		-5.6916	-4.6000
C-14 (% mod)		20.9247*	1.8000

Adjusted C-14 age in years: 20279.* * = based on Original Data

MODEL 35			
Init 1	+ F	0.16403	
Init 2	+ F	0.53705	
Init 3	+ F	0.29892	
CALCITE		-0.91583	
DOLOMITE	+	0.56269	
GYPSUM	+	0.39431	
Mg-MONT	-	-0.06967	
K-MONT	-	0.00000	
K-SPAR	+	0.05187	
Mg/Na EX	+	0.27739	
		Computed	Observed
Carbon-13		-5.2746	-4.6000
C-14 (% mod)		18.7196*	1.8000

Adjusted C-14 age in years: 19359.* * = based on Original Data

MODEL 36		
Init 1	+ F	0.16403
Init 2	+ F	0.53705
Init 3	+ F	0.29892
CALCITE		-0.36104
DOLOMITE	+	0.28529
GYPSUM	+	0.39431
Mg-MONT	-	-0.06967
ALBITE		0.00000
K-SPAR	+	0.05187
EXCHANGE	+	0.27739
		Computed Observed
Carbon-13		-5.6916 -4.6000
C-14 (% mod)		20.9247* 1.8000

Adjusted C-14 age in years: 20279.* * = based on Original Data

MODEL 37		
Init 1	+ F	0.19732
Init 2	+ F	0.59530
Init 3	+ F	0.20738
CALCITE		-0.53214
DOLOMITE	+	0.28361
GYPSUM	+	0.35829
Na-MONT	-	-0.35230
K-MONT	-	0.00000
ALBITE		0.35086
K-SPAR	+	0.03214
		Computed Observed
Carbon-13		-5.3574 -4.6000
C-14 (% mod)		15.7334* 1.8000

Adjusted C-14 age in years: 17922.* * = based on Original Data

MODEL 38		
Init 1	+ F	0.16407
Init 2	+ F	0.53712
Init 3	+ F	0.29882
CALCITE		-0.33798
DOLOMITE	+	0.27367
GYPSUM	+	0.39427
Na-MONT	-	-0.06966
K-MONT	-	0.00000
K-SPAR	+	0.05185
EXCHANGE	+	0.28872
		Computed Observed
Carbon-13		-5.7098 -4.6000
C-14 (% mod)		21.0167* 1.8000

Adjusted C-14 age in years: 20316.* * = based on Original Data

MODEL 39		
Init 1	+ F	0.16407
Init 2	+ F	0.53712
Init 3	+ F	0.29882
CALCITE		-0.91541
DOLOMITE	+	0.56238
GYPSUM	+	0.39427
Na-MONT	-	-0.06966
K-MONT	-	0.00000
K-SPAR	+	0.05185
Mg/Na EX	+	0.28872
		Computed Observed
Carbon-13		-5.2747 -4.6000
C-14 (% mod)		18.7167* 1.8000

Adjusted C-14 age in years: 19357.* * = based on Original Data

MODEL 40		
Init 1	+ F	0.16407
Init 2	+ F	0.53712
Init 3	+ F	0.29882
CALCITE		-0.33798
DOLOMITE	+	0.27367
GYPSUM	+	0.39427
Na-MONT	-	-0.06966
ALBITE		0.00000
K-SPAR	+	0.05185
EXCHANGE	+	0.28872
		Computed Observed
Carbon-13		-5.7098 -4.6000
C-14 (% mod)		21.0167* 1.8000

Adjusted C-14 age in years: 20316.* * = based on Original Data

MODEL 41		
Init 1	+ F	0.19732
Init 2	+ F	0.59530
Init 3	+ F	0.20738
CALCITE		-0.53214
DOLOMITE	+	0.28361
GYPSUM	+	0.35829
K-MONT	-	-0.35230
ALBITE		0.23460
K-SPAR	+	0.14840
EXCHANGE	+	0.00000
		Computed Observed
Carbon-13		-5.3574 -4.6000
C-14 (% mod)		15.7334* 1.8000

Adjusted C-14 age in years: 17922.* * = based on Original Data

Initial Well : Army #1 Water Well
Final Well : Amargosa Tracer Well #2

	Final	Initial
C	5.1051	4.8251
S	0.7301	0.5655
CA	1.1109	1.1258
MG	0.8066	0.8889
NA	2.8115	1.6406
K	0.1996	0.1400
SI	0.3664	0.3164

CALCITE	CA	1.0000	C	1.0000	RS	4.0000	I1	0.0000	I2	0.0000
DOLOMITE	CA	1.0000	MG	1.0000	C	2.0000	RS	8.0000	I1	0.0000
			I2	0.0000						
GYPSUM	CA	1.0000	S	1.0000	RS	6.0000	I3	22.0000		
ANORTH	CA	1.0000	AL	2.0000	SI	2.0000				
Ca-MONT	CA	0.1670	AL	2.3300	SI	3.6700				
Mg-MONT	MG	0.1670	AL	2.3300	SI	3.6700				
Na-MONT	NA	0.3300	AL	2.3300	SI	3.6700				
K-MONT	K	0.3300	AL	2.3300	SI	3.6700				
ALBITE	NA	1.0000	AL	1.0000	SI	3.0000				
K-SPAR	K	1.0000	AL	1.0000	SI	3.0000				
EXCHANGE	CA	-1.0000	NA	2.0000	MG	0.0000				
Mg/Na EX	NA	2.0000	MG	-1.0000						

792 models checked
27 models found

MODEL 1		
CALCITE		-0.72629
DOLOMITE	+	0.50316
GYPSUM	+	0.16461
ANORTH	+	0.05442
Ca-MONT	-	-0.06478
K-SPAR	+	0.05963
Mg/Na EX	+	0.58541
	Computed	Observed
Carbon-13	-4.8050	-4.6000
C-14 (% mod)	2.2850*	1.8000

Adjusted C-14 age in years: 1972.* * = based on Original Data

MODEL 2		
CALCITE		-0.74793
DOLOMITE	+	0.51398
GYPSUM	+	0.16461
ANORTH	+	0.05442
Mg-MONT	-	-0.06478
K-SPAR	+	0.05963
Mg/Na EX	+	0.58541
	Computed	Observed
Carbon-13	-4.7915	-4.6000
C-14 (% mod)	2.2750*	1.8000

Adjusted C-14 age in years: 1936.* * = based on Original Data

MODEL 3		
CALCITE		-0.74764
DOLOMITE	+	0.51384
GYPSUM	+	0.16461
ANORTH	+	0.05428
Na-MONT	-	-0.06471
K-SPAR	+	0.05963
Mg/Na EX	+	0.59609
	Computed	Observed
Carbon-13	-4.7917	-4.6000
C-14 (% mod)	2.2752*	1.8000

Adjusted C-14 age in years: 1937.* * = based on Original Data

MODEL 4		
CALCITE		-0.72629
DOLOMITE	+	0.50316
GYPSUM	+	0.16461
ANORTH	+	0.04360
K-MONT	-	-0.08064
K-SPAR	+	0.08624
Mg/Na EX	+	0.58541
	Computed	Observed
Carbon-13	-4.8050	-4.6000
C-14 (% mod)	2.2850*	1.8000

Adjusted C-14 age in years: 1972.* * = based on Original Data

MODEL 5		
CALCITE		-0.83435
DOLOMITE	+	0.55719
GYPSUM	+	0.16461
ANORTH	+	0.09763
ALBITE		-0.10806
K-SPAR	+	0.05963
Mg/Na EX	+	0.63944
	Computed	Observed
Carbon-13	-4.7383	-4.6000
C-14 (% mod)	2.2356*	1.8000

Adjusted C-14 age in years: 1792.* * = based on Original Data

MODEL 6		
CALCITE		-0.59019
DOLOMITE	+	0.43511
GYPSUM	+	0.16461
Ca-MONT	-	-0.14638
ALBITE		0.13610
K-SPAR	+	0.05963
Mg/Na EX	+	0.51736
	Computed	Observed
Carbon-13	-4.8910	-4.6000
C-14 (% mod)	2.3488*	1.8000

Adjusted C-14 age in years: 2200.* * = based on Original Data

MODEL 7

CALCITE		-0.63908
DOLOMITE	+	0.45956
GYPSUM	+	0.16461
Mg-MONT	-	-0.14638
ALBITE		0.13610
K-SPAR	+	0.05963
Mg/Na EX	+	0.51736
		Computed Observed
Carbon-13		-4.8598 -4.6000
C-14 (% mod)		2.3257* 1.8000

Adjusted C-14 age in years: 2118.* * = based on Original Data

MODEL 8

CALCITE		-0.63908
DOLOMITE	+	0.45956
GYPSUM	+	0.16461
Na-MONT	-	-0.14572
ALBITE		0.13530
K-SPAR	+	0.05963
Mg/Na EX	+	0.54181
		Computed Observed
Carbon-13		-4.8598 -4.6000
C-14 (% mod)		2.3257* 1.8000

Adjusted C-14 age in years: 2118.* * = based on Original Data

MODEL 9

CALCITE		-0.63908
DOLOMITE	+	0.45956
GYPSUM	+	0.16461
K-MONT	-	-0.14572
ALBITE		0.08721
K-SPAR	+	0.10772
Mg/Na EX	+	0.54181
		Computed Observed
Carbon-13		-4.8598 -4.6000
C-14 (% mod)		2.3257* 1.8000

Adjusted C-14 age in years: 2118.* * = based on Original Data

MODEL 10

CALCITE		0.28004
GYPSUM	+	0.16461
ANORTH	+	0.05442
Ca-MONT	-	-0.06478
K-SPAR	+	0.05963
EXCHANGE	+	0.50316
Mg/Na EX	+	0.08225
		Computed Observed
Carbon-13		-5.2928 -4.6000
C-14 (% mod)		2.6464* 1.8000

Adjusted C-14 age in years: 3186.* * = based on Original Data

MODEL 11

CALCITE		0.28004
GYPSUM	+	0.16461
ANORTH	+	0.05442
Mg-MONT	-	-0.06478
K-SPAR	+	0.05963
EXCHANGE	+	0.51398
Mg/Na EX	+	0.07143
		Computed Observed
Carbon-13		-5.2928 -4.6000
C-14 (% mod)		2.6464* 1.8000

Adjusted C-14 age in years: 3186.* * = based on Original Data

MODEL 12

CALCITE		0.28004
GYPSUM	+	0.16461
ANORTH	+	0.05428
Na-MONT	-	-0.06471
K-SPAR	+	0.05963
EXCHANGE	+	0.51384
Mg/Na EX	+	0.08225
		Computed Observed
Carbon-13		-5.2928 -4.6000
C-14 (% mod)		2.6464* 1.8000

Adjusted C-14 age in years: 3186.* * = based on Original Data

MODEL 13

CALCITE		0.28004
GYPSUM	+	0.16461
ANORTH	+	0.04360
K-MONT	-	-0.08064
K-SPAR	+	0.08624
EXCHANGE	+	0.50316
Mg/Na EX	+	0.08225
		Computed Observed
Carbon-13		-5.2928 -4.6000
C-14 (% mod)		2.6464* 1.8000

Adjusted C-14 age in years: 3186.* * = based on Original Data

MODEL 14

CALCITE		0.28004
GYPSUM	+	0.16461
ANORTH	+	0.09763
ALBITE		-0.10806
K-SPAR	+	0.05963
EXCHANGE	+	0.55719
Mg/Na EX	+	0.08225
		Computed Observed
Carbon-13		-5.2928 -4.6000
C-14 (% mod)		2.6464* 1.8000

Adjusted C-14 age in years: 3186.* * = based on Original Data

MODEL 15

CALCITE		0.28004
GYPSUM	+	0.16461
Ca-MONT	-	-0.14638
ALBITE		0.13610
K-SPAR	+	0.05963
EXCHANGE	+	0.43511
Mg/Na EX	+	0.08225
		Computed Observed
Carbon-13		-5.2928 -4.6000
C-14 (% mod)		2.6464* 1.8000

Adjusted C-14 age in years: 3186.* * = based on Original Data

MODEL 16

CALCITE		0.28004
GYPSUM	+	0.16461
Mg-MONT	-	-0.14638
ALBITE		0.13610
K-SPAR	+	0.05963
EXCHANGE	+	0.45956
Mg/Na EX	+	0.05780
		Computed Observed
Carbon-13		-5.2928 -4.6000
C-14 (% mod)		2.6464* 1.8000

Adjusted C-14 age in years: 3186.* * = based on Original Data

MODEL 17

CALCITE		0.28004
GYPSUM	+	0.16461
Na-MONT	-	-0.14572
ALBITE		0.13530
K-SPAR	+	0.05963
EXCHANGE	+	0.45956
Mg/Na EX	+	0.08225
		Computed Observed
Carbon-13		-5.2928 -4.6000
C-14 (% mod)		2.6464* 1.8000

Adjusted C-14 age in years: 3186.* * = based on Original Data

MODEL 18

CALCITE		0.28004
GYPSUM	+	0.16461
K-MONT	-	-0.14572
ALBITE		0.08721
K-SPAR	+	0.10772
EXCHANGE	+	0.45956
Mg/Na EX	+	0.08225
		Computed Observed
Carbon-13		-5.2928 -4.6000
C-14 (% mod)		2.6464* 1.8000

Adjusted C-14 age in years: 3186.* * = based on Original Data

MODEL 19

DOLOMITE	+	0.14002
GYPSUM	+	0.16461
ANORTH	+	0.05442
Ca-MONT	-	-0.06478
K-SPAR	+	0.05963
EXCHANGE	+	0.36314
Mg/Na EX	+	0.22227
		Computed Observed
Carbon-13		-5.2928 -4.6000
C-14 (% mod)		2.6464* 1.8000

Adjusted C-14 age in years: 3186.* * = based on Original Data

MODEL 20

DOLOMITE	+	0.14002
GYPSUM	+	0.16461
ANORTH	+	0.05442
Mg-MONT	-	-0.06478
K-SPAR	+	0.05963
EXCHANGE	+	0.37396
Mg/Na EX	+	0.21145
		Computed Observed
Carbon-13		-5.2928 -4.6000
C-14 (% mod)		2.6464* 1.8000

Adjusted C-14 age in years: 3186.* * = based on Original Data

MODEL 21

DOLOMITE	+	0.14002
GYPSUM	+	0.16461
ANORTH	+	0.05428
Na-MONT	-	-0.06471
K-SPAR	+	0.05963
EXCHANGE	+	0.37382
Mg/Na EX	+	0.22227
		Computed Observed
Carbon-13		-5.2928 -4.6000
C-14 (% mod)		2.6464* 1.8000

Adjusted C-14 age in years: 3186.* * = based on Original Data

MODEL 22

DOLOMITE	+	0.14002
GYPSUM	+	0.16461
ANORTH	+	0.04360
K-MONT	-	-0.08064
K-SPAR	+	0.08624
EXCHANGE	+	0.36314
Mg/Na EX	+	0.22227
		Computed Observed
Carbon-13		-5.2928 -4.6000
C-14 (% mod)		2.6464* 1.8000

Adjusted C-14 age in years: 3186.* * = based on Original Data

appendix

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MODEL 23		
DOLOMITE	+	0.14002
GYPSUM	+	0.16461
ANORTH	+	0.09763
ALBITE		-0.10806
K-SPAR	+	0.05963
EXCHANGE	+	0.41717
Mg/Na EX	+	0.22227
	Computed	Observed
Carbon-13	-5.2928	-4.6000
C-14 (% mod)	2.6464*	1.8000

Adjusted C-14 age in years: 3186.* * = based on Original Data

MODEL 24		
DOLOMITE	+	0.14002
GYPSUM	+	0.16461
Ca-MONT	-	-0.14638
ALBITE		0.13610
K-SPAR	+	0.05963
EXCHANGE	+	0.29509
Mg/Na EX	+	0.22227
	Computed	Observed
Carbon-13	-5.2928	-4.6000
C-14 (% mod)	2.6464*	1.8000

Adjusted C-14 age in years: 3186.* * = based on Original Data

MODEL 25		
DOLOMITE	+	0.14002
GYPSUM	+	0.16461
Mg-MONT	-	-0.14638
ALBITE		0.13610
K-SPAR	+	0.05963
EXCHANGE	+	0.31954
Mg/Na EX	+	0.19782
	Computed	Observed
Carbon-13	-5.2928	-4.6000
C-14 (% mod)	2.6464*	1.8000

Adjusted C-14 age in years: 3186.* * = based on Original Data

MODEL 26		
DOLOMITE	+	0.14002
GYPSUM	+	0.16461
Na-MONT	-	-0.14572
ALBITE		0.13530
K-SPAR	+	0.05963
EXCHANGE	+	0.31954
Mg/Na EX	+	0.22227
	Computed	Observed
Carbon-13	-5.2928	-4.6000
C-14 (% mod)	2.6464*	1.8000

Adjusted C-14 age in years: 3186.* * = based on Original Data

MODEL 27		
DOLOMITE	+	0.14002
GYPSUM	+	0.16461
K-MONT	-	-0.14572
ALBITE		0.08721
K-SPAR	+	0.10772
EXCHANGE	+	0.31954
Mg/Na EX	+	0.22227
	Computed	Observed
Carbon-13	-5.2928	-4.6000
C-14 (% mod)	2.6464*	1.8000

Adjusted C-14 age in years: 3186.* * = based on Original Data

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