DOE/NV/10384-21

DESERT RESEARCH INSTITUTE
UNIVERSITY OF NEVADA SYSTEM

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Publication # 45062

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Prepared for
the U.S. Department of Energy
Nevada Operations Office
Las Vegas, Nevada
under Contract DE-AC08-85NV10384

April 1988

ABSTRACT

Rainier Mesa, a primary site for nuclear testing, is located in the north-central area of the Nevada Test Site and is composed of highly fractured and altered Tertiary tuffs. A hydrogeologic study was conducted within the mesa concentrating on several parameters: 1) the source of fracture water found there, 2) period of principal recharge, 3) hydraulic residence time, 4) hydraulic response lag time, 5) total amount of recharge per year infiltrating into the U12n tunnel catchment basin, 6) extent of mixing between fracture systems, and 7) the effects of nuclear testing on localized ground-water chemistry and discharge. The data base consists of the precipitation record, discharge record of seeps, the gross chemistry and stable isotopic composition of these seeps, and two tracer studies conducted on the mesa surface.

Results indicate that for Rainier Mesa: 1) ground water is of recent meteoric origin, 2) the period of principal recharge is from late fall to early spring, 3) the period of hydrologic response is at least four months, 4) the total recharge through the U12n catchment basin is approximately 8% of the precipitation which falls on the mesa, and 5) travel time is estimated as greater than one year and less than six. It was also determined that the active fracture systems are poorly interconnected, and that the effects of nuclear testing increase discharge and the concentration of ionic species within fracture-seep water. The most likely mechanism through which these occur is the seismic P wave generated by a nuclear explosion. This flux of interstitial water increases discharge at the tunnel seeps and produces a concurrent increase in the TDS of the seep water.

These observations reflect an environment which has been subjected to nuclear testing since 1957. Whether or not this is representative of the hydrogeologic regime which existed before nuclear testing, is unknown.

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ACKNOWLEDGMENTS

This study was supported financially and logistically by the U.S. Department of Energy under Contract DE-AC08-85NV10384. The authors wish to thank Craig Shadel and James Heidker for the isotopic and chemical analysis used in the research, and Mike Campana and Roger Jacobson for technical review.

SECTION 1
INTRODUCTION

Since 1957, nuclear testing has been conducted within the adit systems mined into Rainier Mesa, Nevada Test Site. These adits are commonly referred to as tunnels. There is concern that migration of radionuclides may occur from the testing areas in the tunnels to the regional ground-water system. The primary purpose of this paper is to quantitatively delineate the hydrogeologic processes which occur within Rainier Mesa in order that later studies may predict the rate and extent of radionuclide migration. This paper is the result of one of the few field data sets for vadose zone fracture flow in tuffs and should be of interest to others working in this field. The objective of this study is to quantitatively investigate the hydrogeologic regime of Rainier Mesa.

OBJECTIVES

The specific objectives are to identify the 1) origin of perched water within the vadose zone, 2) period of principal recharge, 3) total ground-water flux through the U12n tunnel catchment basin, 4) lag time, 5) hydraulic residence time between the mesa surface and the tunnel level, 6) extent of mixing between the fracture systems, and 7) effect of nuclear testing on local ground-water discharge and chemistry.

To delineate the flow system of Rainier Mesa, the following were obtained: perched ground-water discharge from two seeps within U12n tunnel and from the portal of U12n tunnel, the stable isotopic and geochemical data from the tunnel seeps, data from two tracer studies incorporating four different tracer types, precipitation data from the mesa surface, and tritium samples from within the tunnels.

PREVIOUS WORK

Owing to the nature of the tests conducted within Rainier Mesa, a considerable number of studies have been previously undertaken. These studies have examined the stratigraphy, mineralogy and structure of the formations within the mesa, the hydrology and geochemistry of the mesa ground water found there, and the effects of nuclear testing on those parameters. Johnson and Hibbard (1957) conducted the first in-depth geological study of Rainier Mesa. This study concluded by naming the series of tuffs composing Rainier Mesa as the Oak Spring Formation. The evolution of the stratigraphic nomenclature of Rainier Mesa continued with Hansen *et al.* (1963), Hinrichs and Orkild (1961), Poole and McKeown (1962), Sargent *et al.* (1965), Orkild (1967), Dixon *et al.* (1975), and Byers *et al.* (1976) resulting in the stratigraphy presented in this report. Houser and Poole (1960) examined the structural features of the Oak Spring Formation as they occur within the mesa, and their relationship to pre–Tertiary topography. Keller (1960) undertook a study of the physical properties of the tuffs of the Oak Spring Formation.

Wilmarth *et al.* (1960) documented the extent of alteration of the Oak Spring Tuffs by the 1957 Rainier underground nuclear test. Wilmarth and McKeown (1960) examined the structural effects of the Rainier, Logan, and Blanca underground nuclear tests. In 1962, Cattermole and Hansen published their report on the the geologic effects of conventional high explosive tests on the USGS tunnel area of Rainier Mesa. The initial findings of most of the above authors were incorporated into the process which made Rainier Mesa a site for nuclear testing.

Gibbons *et al.* (1963) published a geologic map of Rainier Mesa Quadrangle and in that same year Hansen *et al.* (1963) conducted extensive work on the stratigraphy and structure of the Rainier and USGS tunnel areas in Rainier Mesa. From the 1960's to the present, numerous technical letters and reports have been published by the USGS. These reports document the structure, stratigraphy, mineralogy, and physical properties of site–specific locations in Rainier Mesa for use in delineating working points for nuclear testing. The most recent USGS report published about Rainier Mesa is by Carroll and Magner (1986) and deals with seismic investigations in U12t.04 drift.

The first study of the hydrology of Rainier Mesa was undertaken by Clebsch (1960) in which he published a report on the hydrogeologic effects of the Rainier underground nuclear test. In 1961, he also published a report on the tritium age of the ground water at Rainier Mesa and other areas of the test site. A travel time of 0.8 to 6 years was derived for the perched ground water. In the same year Byers (1961) examined the porosity, density, and water content of the tuff of the Oak Spring Formation.

Schoff and Moore (1964) examined the chemistry and movement of ground water within the Nevada Test Site including Rainier Mesa. Thordarson (1965) conducted the most extensive hydrologic study to date of Rainier Mesa. In his study he examined the occurrence, mode of transport, recharge, and hydraulic parameters of Rainier Mesa ground water. Winograd and Thordarson (1975) added to this work by investigating a regional flow system of which Rainier Mesa is part.

Besides the aforementioned chemistry studies by Schoff and Moore (1964), several other geochemical studies have been done in relation to Rainier Mesa. Clebsch and Barker (1960) undertook the first chemical analyses of ground water from Rainier Mesa tunnel seeps. In the years after 1960, chemical analysis were done by the REECo Health and Safety Division on a fairly regular basis in order to monitor for radionuclide contamination. Benson (1976) examined water chemistry and diagenetic minerals within the perched saturated zone of Rainier Mesa in order to derive a qualitative mass transport for the ground water occurring there. Claassen and White (1978) and White and Claassen (1978 and 1979) attempted to relate kinetic data to the real–world application of modeling geochemical processes for Rainier Mesa ground waters. White, Claassen, and Benson (1980) examined the affect of volcanic glass on the water chemistry of the mesa. These studies culminated in Henne (1982) in which kinetic data for the dissolution of silica and ground–water analysis were used in an effort to date the water from Rainier Mesa tunnel seeps. Kerrisk (1983) further examined the reaction paths of ground water and mineral formation of Rainier Mesa and compared it to Yucca Mountain.

SECTION 2
ENVIRONMENTAL SETTING

GEOGRAPHY

Rainier Mesa is located in the north-central portion of the Nevada Test Site, approximately 140 km northwest of Las Vegas, Nevada (Figure 1). The top of the mesa covers approximately 11.4 km^2 and has an average elevation of 2200 m (Figure 2). The mesa is the highest point of the north-south trending Belted Range and is a typical fault block mountain of the Basin and Range province (Hansen *et al.*, 1963).

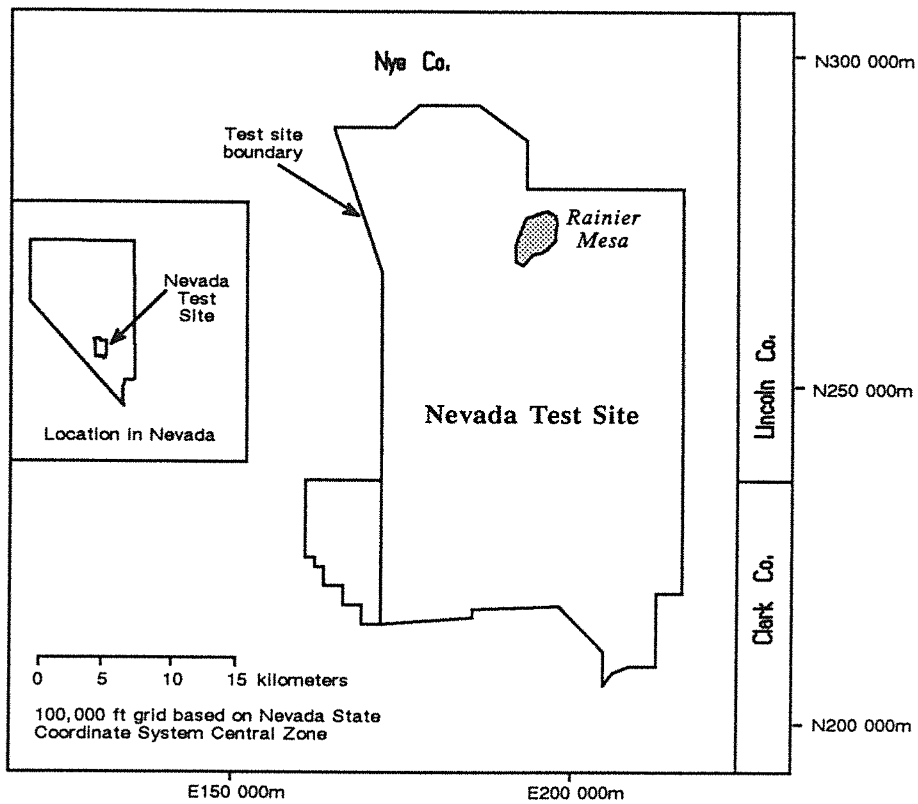

Figure 1. The location of Rainier Mesa relative to the Nevada Test Site and vicinity.

METEOROLOGY

Rainier Mesa is characterized by low precipitation, low relative humidity and large daily variations in temperature. Climatological data for the mesa have been collected since 1959 by the National Weather Service. The mean precipitation is approximately 32

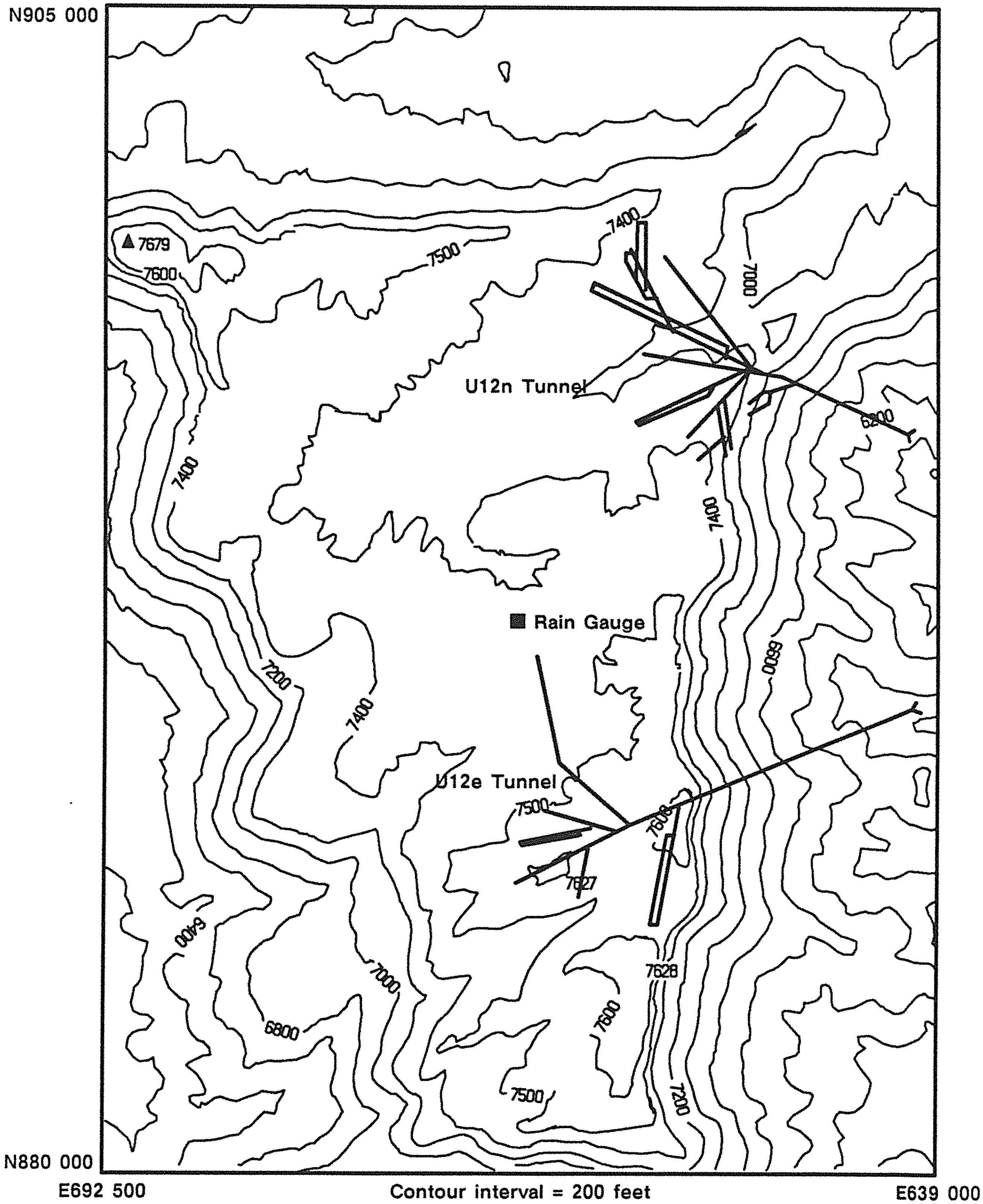

Figure 2. Rainier Mesa, U12n, and U12e tunnel systems and rain station.

cm per year and is seasonal (Figure 3). Most precipitation occurs in the late winter months as snow which is normally found on the higher elevations from late November through April. Summer precipitation is derived primarily from infrequent thundershowers.

Wide temperature variations occur seasonally and daily. The mean summer temperature is approximately 32°C with a recorded maximum of 42°C. The mean winter temperature is approximately -4°C with a recorded low of -17°C. Daily variations in temperature also occur, with fluctuations of 10°C being common.

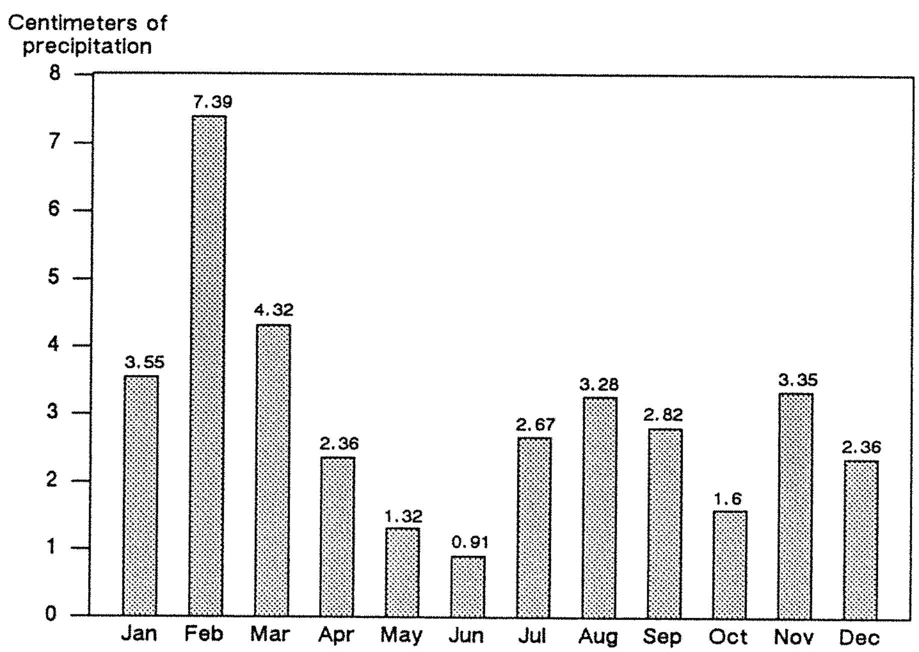

Figure 3. Rainier Mesa average monthly precipitation (French, 1986).

SECTION 3
GEOLOGY

The geology of Rainier Mesa controls the occurrence, mode of transport and geochemistry of the ground water there. In order to understand the ground–water regime, a good understanding of the geology must also exist.

STRATIGRAPHY AND LITHOLOGY

The regional geology surrounding Rainier Mesa consists of complexly–faulted Cenozoic volcanics, Mesozoic granitic stocks, and Paleozoic sediments, which unconformably overlie a Precambrian metamorphic complex. The Cenozoic section, of which Rainier Mesa is a part, is primarily composed of a 12,000 m thick composite section of Tertiary volcanics. Within the region are large–scale strike–slip faults such as the Las Vegas Shear Zone which is to the south and southwest of Rainier Mesa.

The mesa is the remnant of a volcanic plateau uplifted during an episode of tectonic extension during the middle to late Cenozoic. It is composed of a series of nearly parallel, roughly planar Miocene tuffs which dip 10° to 25° to the west (Hansen *et al.*, 1963). The tuffs are in some horizons welded and in others non–welded, and consist of ashflow, and ashfull tuffs. Zones of alteration exist in which the principal alteration minerals are illite, analcime, clinoptilolite, mordenite, and heulandite (Benson, 1976). These tuffs originated from a series of calderas to the west, south, and southwest of the mesa. The Silent Canyon caldera, borders Rainier Mesa on its western slope.

The stratigraphy of Rainier Mesa is listed in Table 1. In certain areas of interest, such as in the U12n.10 #1 well, the stratigraphic column is abbreviated because of nondeposition of ashfall tuffs over a paleotopographic high (Fairier *et al.*, 1979). However, in nearby wells these units are present. Table 1 is derived from lithologic logs from selected drill holes on Rainier Mesa and is a summary of Maldonado *et al.*, 1979.

STRUCTURE

Two orogenies have affected Rainier Mesa and vicinity during the Phanerozoic. In the late Mesozoic, major folding and thrust faulting of the Precambrian and Paleozoic formations occurred. Within the vicinity of Rainier Mesa, these structural events affected the

TABLE 1. THE STRATIGRAPHY OF RAINIER MESA

Unit	Mean and range of thickness (m)		Brief geologic description
Timber Mountain Tuff, Rainier Mesa Member	76.9	13 - 182	Ash-flow tuff, non-welded to densely welded
Paintbrush Tuff	157.3	34 - 220	Ash-flow, ash-fall, welded to non-welded, some members bedded.
Tiva Canyon Member		0 - 25	Moderately to densely welded ash-flow tuff.
Informal Bedded unit		34 - 195	Slightly indurated ashfall and reworked ash-flow tuff, zeoltized at base.
Stockade Wash Tuff	8.7	0 - 14	Non-welded to partially welded massive tuff - locally zeolitized base.
Bedded and ash-flow tuffs of Area 20	40.7	0 - 63	Ash-fall, non-welded, zeolitized
Lava and tuff of Dead Horse Flat	14.6	0 - 39	Ash-flow, densely welded to non-welded
Grouse Canyon Member, Belted Range Tuff	15.9	0 - 32.4	Ash-flow and ash-fall, welded to non-welded, zeolitized in lower portion.
Tunnel bed, Unit 5	30.6	3 - 49	Ash-fall, non-welded, zeolitized
Tunnel bed, Unit 4	94.1	0 - 169	Ash-fall, non-welded, zeolitized
Tunnel bed, Unit 3	49.4	22 - 96	Ash-fall, non-welded, zeolitized
Belted Range Tuff, Tub Spring Member	6.5	0 - 21	Ash-flow, ash-fall, partially welded in some sections, zeolitized
Tunnel bed, Unit 2	44.0	0 - 68	Ash-fall, non-welded, zeolitized
Crater Flat Tuff	10.6	0 - 68	Ash-flow, non-welded to densely welded, some sections zeolitized
Tunnel bed, Unit 1	18.1	0 - 82	Ash-fall, non-welded, zeolitized

Gold Meadows Monzonite, the Wood Canyon Schist, the Stirling Quartzite, as well as older units.

During the middle to late Cenozoic, major extensional block faulting occurred and created the Basin and Range province of which Rainier Mesa is a part. This structural deformation affected all of the formations found within the mesa. During both events, strike-slip faults such as the Las Vegas Shear Zone occurred with displacements of up to six or seven kilometers.

The most important structural feature of Rainier Mesa is the northeast-trending Aqueduct Syncline. This syncline bisects the mesa into subequal parts with the limbs dipping 2° to 12° to the west (Gibbons *et al.*, 1963). Superimposed on the east limb of the Aqueduct Syncline are several smaller folds that trend northeast to east and plunge toward the syncline axis (Hansen *et al.*, 1963). The Aqueduct Syncline and smaller folds are due to the settling of ash-flows and ash-falls on a prominent pre-Tertiary topography (Houser and Poole, 1960). Successive ash deposits have subdued the effect of the pre-Tertiary relief to such an extent that the youngest volcanic strata within Rainier Mesa are almost horizontal except where affected by Cenozoic block faulting.

Numerous geologic studies during the last two decades have documented fracture frequency, orientation, and density in Rainier Mesa. It was found that many fractures are preserved in the more competent units of the mesa. Most are either cooling joints or normal dip–slip faults formed during block faulting. The cooling joints trend from the northeast to the northwest and dip predominately 70° to vertical, both to the east and west. The normal faults trend approximately north–south and are steeply dipping with surface traces extending up to 100 m.

Other types of primary structures also characterize parts of the strata within Rainier Mesa: cross–bedding, ripple marks, erosional unconformities, graded bedding, and faults of small offset associated with slump structures. These structures indicate that the tuffs were redistributed to some degree by slumping, fluvial, and possibly eolian transport (Poole, 1962).

SECTION 4
HYDROGEOLOGY

The geologic units that compose Rainier Mesa are divided into hydrogeologic units based on the degree of welding, fracture density, porosity, matrix permeability, and hydraulic conductivity. This work is roughly based on Thordarson (1965), Winograd and Thordarson (1975), and Byers *et al.* (1976). The geologic and corresponding hydrologic units are presented in Table 2.

TABLE 2. RAINIER MESA GEOLOGIC AND HYDROGEOLOGIC UNITS

Member	Hydrogeologic units	Thickness	Lithology
Alluvium	alluvium	0 - 10 m	alluvium and colluvium ranging from silt to boulder size
Rainier Mesa Member, Timber Mountain Tuff	welded to partially welded tuff	13 - 182 m	moderately to densely welded ash-flow tuff
Tiva Canyon Member, Paintbrush Tuff	welded to partially welded tuff	0 - 25 m	moderately to densely welded ash-flow tuff
Stockade Wash Formation	welded to partially welded tuff	0 - 120 m	non-welded to partially welded massive tuff locally zeolitized at base
Informal Bedded Tuff, Paintbrush Tuff	friable bedded tuff, zeolitic bedded tuff	30 - 300 m	ash-fall and fluvially reworked ash-flow tuff, slightly moderated locally zeolitized in the basal 50 m
Grouse Canyon Member, Belted Range Tuff	welded or partially welded tuff, friable bedded tuff	13 - 60 m	ash-flow tuff densely welded. Basal segment is friable vitric tuff, zeolitized in sections.
Tub Spring Member, Belted Range Tuff	welded and partilly welded tuff	0 - 120 m	welded ash-flow tuff
Informal Tunnel Beds	zeolitic bedded tuff	200 - 600 m	zeolitized ash-fall tuffs

(Thordarson, 1965)

Each of the hydrogeologic units described in Table 2 are categorized into one of three broadly-defined hydrogeologic units described qualitatively below:

1) The Rainier Mesa Member, Tiva Canyon Member, Stockade Wash Formation, upper part of the Grouse Canyon Member, and the Tub Spring Member are a part of the welded to partially welded hydrogeologic unit. These units are characterized by low-saturated hydraulic conductivity (4.72×10^{-9} to 2.8×10^{-10} m/s; Thordarson, 1965) and relatively high fracture densities (10 to 40 fractures/m^3). The degree of fracturing is directly controlled by the degree of welding of the unit. Fracture flow is the dominant method of transport in these highly-saturated units.

2) The informal bedded tuff of the Paintbrush Tuff and the lower portion of the Grouse Canyon Member compose the friable bedded tuff hydrogeologic unit. These units have a low–fracture density (1 to 3 fractures/m^3) and are characterized by relatively large saturated matrix hydraulic conductivity (1.5 x 10^{-6} m/s; Thordarson, 1965). Interstitial porosity is approximately 40% with saturation ranging from 60 to 100%. Matrix flow is the dominant flow regime.

3) The lower portion of the Bedded Tuff, the lower portion of the Grouse Canyon member, and the tunnel beds compose the zeolitic bedded tuffs. These units are tuffs that have been altered to zeolites and clays. The saturated matrix hydraulic conductivity ranges from 1.8 x 10^{-10} to 9.44 x 10^{-10} m/s. Fracture densities are small (< 1 fracture/m^3) and matrix porosity ranges from 25 to 38%. Matrix flow dominates areally, however, isolated saturated fractures do occur and may account for a large portion of the total flux through the formation.

The saturated hydraulic parameters for each geologic unit is summarized in Table 3. The unsaturated zones of Rainier Mesa have yet to be characterized. Studies investigating fracture porosity, hydraulic conductivity versus degree of saturation, and moisture retention curves have yet to be undertaken.

TABLE 3. FORMATIONS OF RAINIER MESA AND A SUMMARY OF THEIR HYDRAULIC PROPERTIES USING AVAILABLE DATA

Formation and Member	Interstitial hydraulic conductivity (m/s)	Interstitial porosity	Effective permeability
Timber Mountain Tuff, Rainier Mesa Member	4.72 x 10^{-9}	14%	fracture
Paintbrush Tuff	1.75 x 10^{-6}	40%	interstitial
Belted Range Tuff, Grouse Canyon Member	2.80 x 10^{-9}	19%	fracture
Tunnel Bed Unit 4, Indian Trail Formation	9.44 x 10^{-9}	38%	fracture
Unit 3	1.40 x 10^{-9}	35%	fracture
Unit 2	--------	32%	fracture
Unit 1	--------	25%	fracture

(Thordarson, 1965)

Unsaturated zone studies have been accomplished in similar tuffaceous units at Yucca Mountain. In a qualitative sense the results can be applied to Rainier Mesa. Since the degree of matric saturation in Rainier Mesa is quite high in all of the units, fractures should act as a conduit for fluid flow, whereas at Yucca Mountain they do not. Fractures not hydraulically connected to the recharge system can act as a barrier to interstitial flow until saturation of the matrix occurs (Montazer and Wilson, 1984; Klavetter and Peters, 1986).

Spatial variability of moisture in an unsaturated zone has been determined for Yucca Mountain (Whitfield, 1985). The neutron log profiles of unsaturated zone wells indicate higher moisture contents in the welded tuffs relative to the non–welded tuffs. This may be true for Rainier Mesa.

The spatial distribution of the perched saturated zone within Rainier Mesa has never been determined. However, as observed from various wells, the tops of the perched ground water lenses are at an elevation of 1820 ± 100 m and extend through the bottom of the tunnel bed formation.

A conceptual flow model of Rainier Mesa is presented here and is based on Thordarson (1965) and newer concepts derived for Yucca Mountain by Montazer and Wilson (1984). Recharge from winter storms is thought to rapidly infiltrate the Rainier Mesa Member of the Timber Mountain Tuff. The recharge is thought to travel vertically, in pulse form, through the unit to the stratigraphic contact with the underlying Tiva Canyon Member of the Paintbrush Tuff. The ground–water pulse also infiltrates into the matrix of the Timber Mountain Tuff as it passes through. The rate of interstitial infiltration is a function of the fracture and matric potentials and the rate of recharge. Possible down–dip horizontal flow occurs at the boundary of the two hydrogeologic units.

Similar processes may occur as the ground–water pulse travels through the Tiva Canyon Member and Stockade Wash Tuff. The recharge pulse reaches the boundary of the informal bedded tuffs of the Paintbrush Tuff where matrix flow can begin to dominate. Fractures do exist within this unit and matrix saturation is high enough that fracture flow may be initiated and sustained, allowing for rapid transit of fracture flow through the Paintbrush Tuff.

Fracture and the slower process of matrix flow is thought to occur through the Paintbrush Tuff until the Grouse Canyon Member of the Belted Range Tuff is reached. Capillary barriers, as documented at Yucca Mountain by Montazar and Wilson (1984), may exist between the lower matric potentials of the interstitial pores of the Paintbrush Tuff and the larger fracture potentials of the underlying Grouse Canyon Member. This barrier could allow for horizontal, down–dip flow to occur.

Fracture flow is thought to dominate in the Grouse Canyon Member and is rapid until the friable bedded tuff units are encountered. In this portion, flow is dominantly through the matrix and through the few existing fractures. Flow is rapid through the welded portions of the Belted Range Tuff until the zeolitic bedded tuffs of the tunnel beds are reached. It is at this unit where the smallest hydraulic conductivities exist. The matrix is completely saturated allowing for fracture flow to occur. Fracture flow is much more rapid than interstitial flow within this unit. An idealized hydrogeologic cross-section of Rainier Mesa is presented in Figure 4. The nature of the flow processes in units below the tunnel beds is discussed by Winograd and Thordarson (1975).

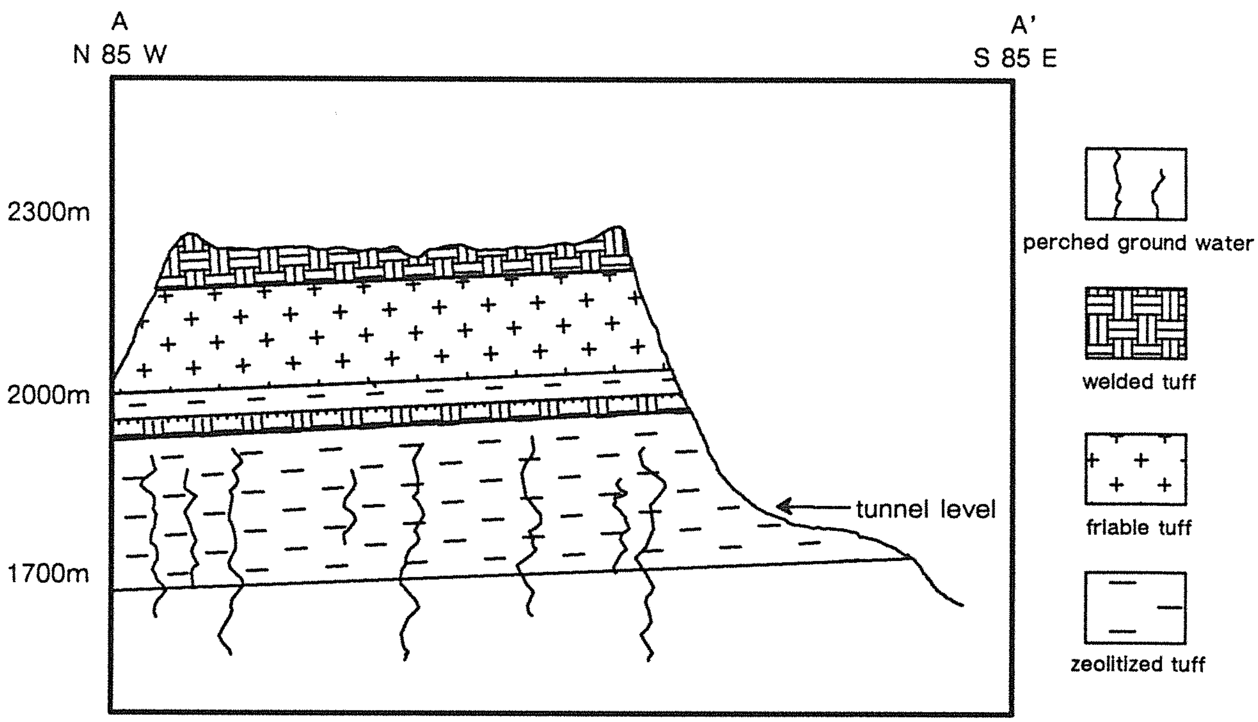

Figure 4. An idealized cross-section of Rainier Mesa showing the three types of hydrogeologic units found there and the mode and occurrence of perched ground-water lenses.

SECTION 5
METHODOLOGY

FIELD METHODS

A variety of field techniques were used to gather the data necessary for this research. The data base consists of the following parameters: 1) the discharge record from U12n.03, 2) U12n.05 and the portal seeps, 3) the stable isotopic ratios of oxygen and hydrogen from the U12n tunnel seeps and Rainier Mesa precipitation, and 4) tritium concentrations and gross chemistry from these same seeps. A record of humidity was collected from within U12n tunnel, as was a precipitation record from the top of Rainier Mesa. Lithium bromide and fluorescent dye concentrations within tunnel seep waters were also recorded.

The seeps within U12n.03 and U12n.05 drifts have undergone integrated sampling for gross chemistry, stable isotopes, and lithium bromide concentrations. Samples were collected automatically by two Manning S–4400 portable discrete samplers. The samplers were set to take a one–hundred ml sample daily and integrate five of these into a 500 ml sample. All samples were collected approximately every two weeks. Within each of the two drifts were Stevens model 68 F–type recorders with quartz multi–speed timers. The chart recorders were set on 11.5° v–notch weirs in order to record discharge from the respective seeps. The recorded heads from these weirs were applied to the following equation from King and Brater (1963):

$$Q = 7.13\ H^{2.5} \tag{1}$$

where Q is equal to discharge in liters/second and H is equal to head in feet. At the U12n tunnel portal, a similar recorder was set up to measure the total tunnel discharge (Figure 5). Due to the larger discharge, this recorder was set up on a 90° v–notch weir. The discharge equation for this wier was also derived from King and Brater (1963):

$$Q = 70.8\ H^{2.5} \tag{2}$$

Within the U12n.03, U12n.05, and U12n.10 drifts, humidity measurements were taken in order to determine the moisture content of the air. The humidity data were measured with a Bacharach sling psychrometer on a biweekly basis. The data were com-

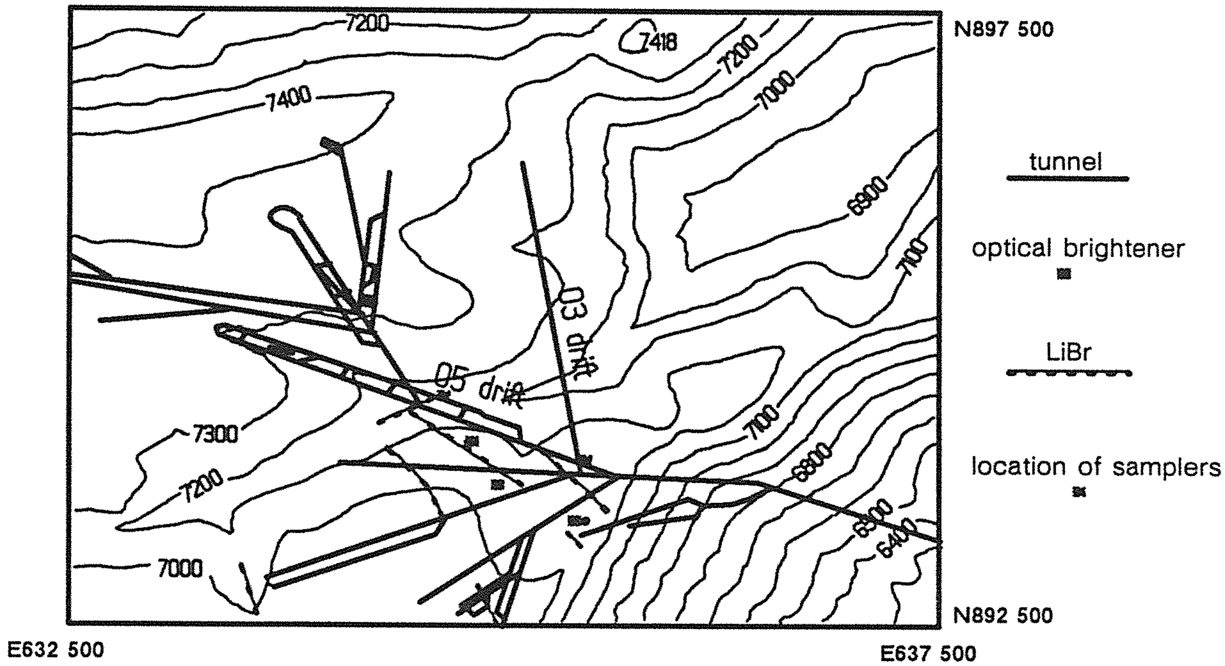

Figure 5. U12n tunnel, location of sampling points and areas of LiBr and optical brightener emplacement.

bined with the ventilating system's flow rates in order to determine the contribution of evaporation to the total discharge of U12n tunnel.

Within all of the above three drifts and both the portals of E tunnel and N tunnel, cotton fluorescent dye receptors consisting of pure cotton surrounded by fiberglass screening were emplaced. The receptors were intended to detect small quantities of fluorescent dyes within the ground water. The dye receptors were exchanged on a biweekly basis. Two-hundred-fifty ml samples of discharge water were also taken on a biweekly basis at U12n and U12e tunnel portals. These samples were analyzed for their lithium bromide concentration.

On the top of Rainier Mesa, a daily precipitation record has been established by the United States Department of Commerce Weather Bureau since 1959. The data for the last four years have been incorporated into this study.

Two tracer tests were also conducted on Rainier Mesa. The first was conducted at approximately N 894,300, E 634,600 Nevada State coordinates (Figure 6). This position is located on the top of Rainier Mesa in a canyon known as the Aqueduct. It is directly over

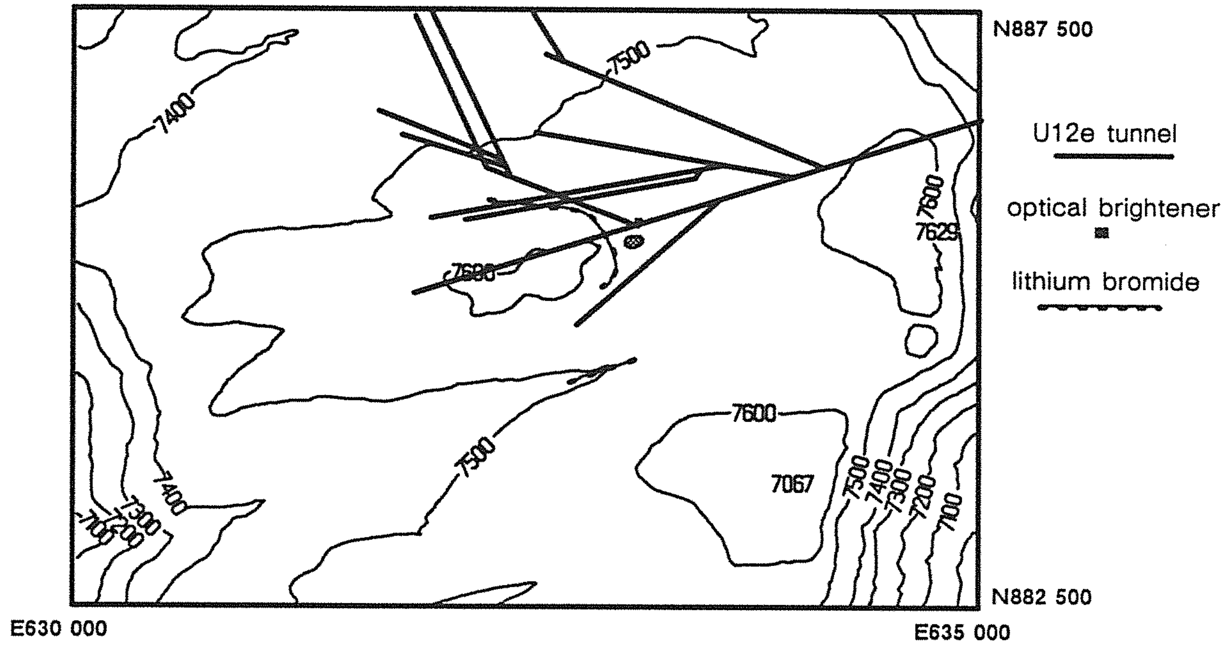

Figure 6. U12e tunnel and dye emplacement areas.

and 340 m above U12n.05 drift. This study was designed and directed by Howard Koltermann of the Desert Research Institute and was later monitored by the authors.

For this study, two small berms were constructed on July 17, 1984, which were to act as small detention basins. The soil behind each berm was heavily saturated with direct yellow and fluorescene dyes. Within a month, precipitation had pooled behind the berms facilitating infiltration of the dyes. Activated charcoal and cotton dye receptors were emplaced within U12n.03, U12n.05, and U12n.10 adits and were monitored monthly for traces of the dyes. It was determined that a point source tracer study was inadequate for an environment that is dominated by low hydraulic conductivity between water-bearing fractures. Thus, a two-part, diffuse tracer test was implemented during the spring of 1986. The two tracers used were lithium bromide and Tinopal 5BM, an optical brightener. The lithium ion has been used extensively by the U.S. Geological Survey as a tracer in tuffaceous units within the Nevada Test Site. The bromide ion has been documented as a conservative tracer detectable down to the ppb level (Schmotzer *et al.*, 1973). Optical brightener was tried as an alternative to the fluorescene and direct yellow dyes.

On March 3, 1986, 8 kg of lithium bromide were dissolved into 757 liters of water, resulting in a concentration of 1050 ppm. This solution was subsequently sprayed by hand–held sprayers, along surface fault traces above the U12n and U12e tunnels as shown in Figures 5 and 6. Approximately 500 liters were sprayed on faults above U12n tunnel and 250 liters were sprayed on faults above U12e tunnel. A smaller quantity of the tracer was used at U12e tunnel due to uncertainty of access for sampling.

Dilution of the tracer fluid may be a problem with this study. Background lithium and bromide concentrations were measured at 0.035 to 0.07 mg/l. The initial tracer concentration was 7.04 gm/l. If this initial concentration is mixed with an entire year's worth of recharge at U12n (35,000 m^3 of water), then a final concentration at .23 mg/l results. This assumes that all recharge occurs through the sprayed fractures, all of the tracer infiltrates, dilution with pre–existing ground water does not occur, and that the tracer travels as a pulse. It is unlikely that all of the above assumptions are correct. However, due to the unknown variability of recharge and the degree of dilution of the tracer, there is a possibility that a detectable spike of lithium bromide will occur at the seeps. Due to the possiblility of health hazards, more concentrated solutions were not used.

Deployment of the tracer fluid was originally planned for January 1986 during spring runoff; however, the project was delayed until official permission for the test was granted by the Department of Energy. One third of the LiBr solution was discharged into a large fault trace above U12n tunnel that had been reactivated by nuclear testing. This was done in order to facilitate infiltration of the solution. The precipitation record was also monitored during this period to determine if and when infiltration occurred.

On May 1, 1986, 8 kg of Tinopal 5BM, a concentrated optical brightener, was dissolved into 568 liters of water, resulting in a concentration of 1400 ppm. This tracer was then pumped into three known fracture traces on the surface of Rainier Mesa above U12n tunnel with a total of 190 liters of the tracer solution going into each fracture. The solution was pumped with a small–capacity, gasoline–powered water pump through a garden hose into the fracture. Beginning in June 1986, the activated charcoal dye receptors were discontinued because of redundancy with respect to the cotton receptors. The cotton receptors were continued to be exchanged every other week as they were able to detect both the flourescene and direct yellow dyes, as well as the optical brighteners. Water samples were also taken on a biweekly basis from both E and N tunnels and analyzed for LiBr concentrations.

SECTION 6
RESULTS AND DISCUSSION

SOURCE OF WATER

Thordarson (1965), through the use of the Eakin (1962) reconnaissance method, estimated that recharge was occurring on Rainier Mesa. However, this methodology is useful only for regional estimates, and not for site-specific studies such as at Rainier Mesa. A purpose of this study is to validate this estimate with field data.

To investigate if recharge is occurring, two ground-water parameters were monitored over time: the stable isotopic composition and discharge of actively-flowing seeps within the tunnel system. A graph of ground-water discharge from a seep in U12n.05 drift from March 1986 is presented in Figure 7. An increase in discharge throughout the month of March indicates that some type of recharge is occurring. Other seeps that were monitored have also exhibited such increases in flow. The U12n tunnel system seems to be wetter

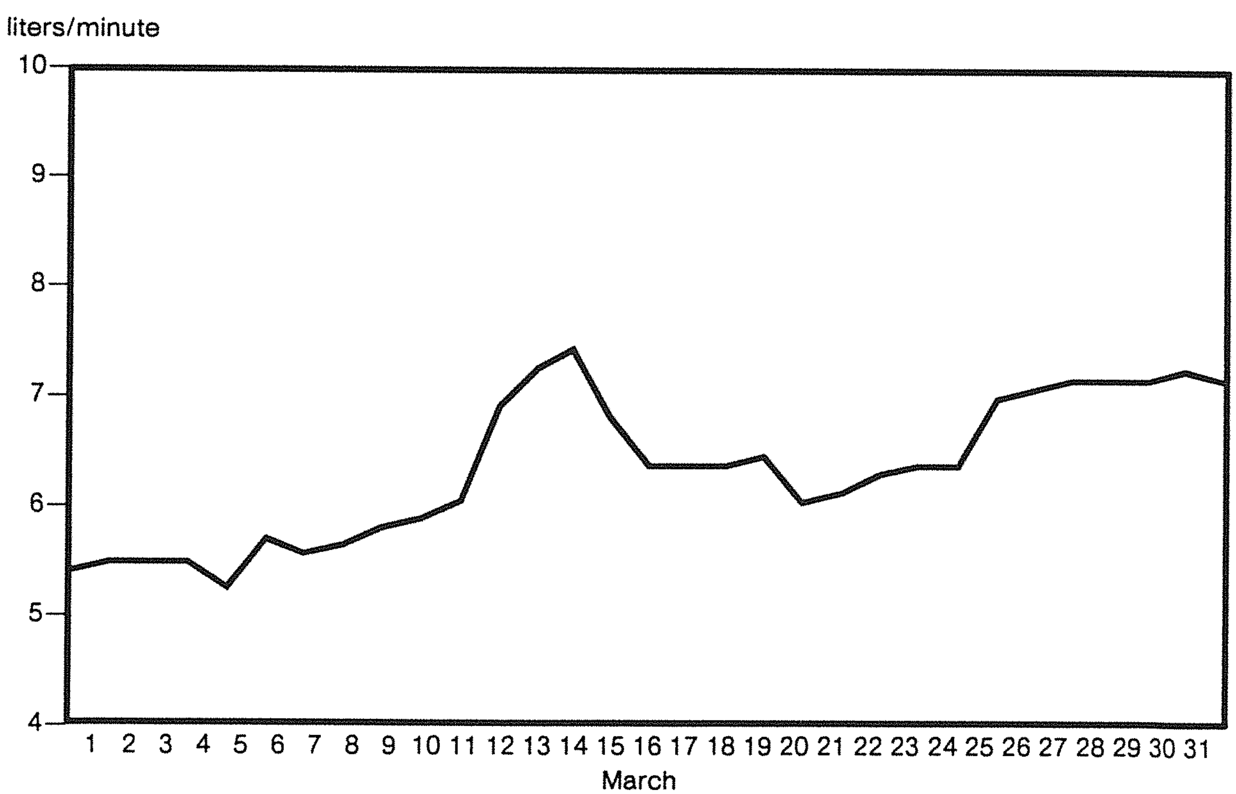

Figure 7. U12n.05 drift discharge for March 1986.

during the early spring months, with an increase in the number and frequency of drips from the tunnel back, as well as a general increase in the discharge of the seeps.

The stable isotopic signatures of both the precipitation and tunnel seeps are plotted in Figure 8. An examination of this figure reveals that the isotopic signature of the ground water falls on the meteoric water line in the same area as present-day precipitation. Figure 8 indicates that the fracture water found in the U12n.03 and U12n.05 seeps is isotopically similar to present-day precipitation.

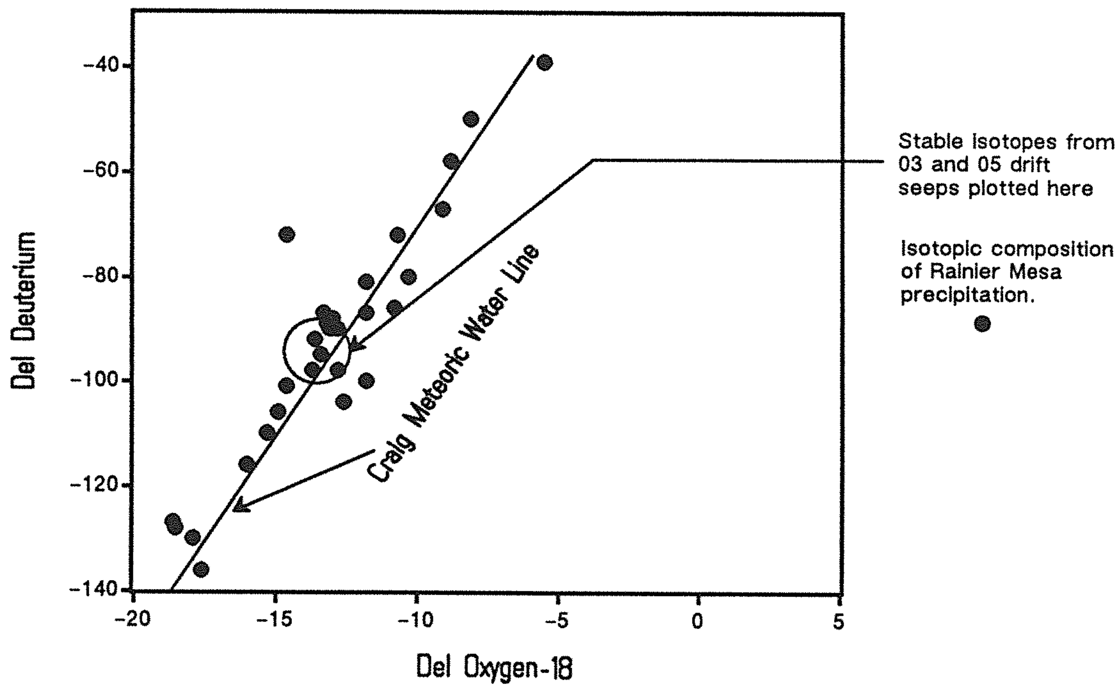

Figure 8. A plot of the isotopic composition of Rainier Mesa precipitation and ground water found in U12n.03 and U12n.05 drift seeps.

The above evidence would seem to indicate that the fracture water is derived from recent precipitation, however, other sources could be responsible for the increased flow. These sources are: 1) a nuclear test near U12n.05, 2) drilling fluid from holes near the seeps, or 3) mining discharge. The increase in discharge due to a nuclear test is characterized by a sharp increase in flow over a one- to two-day period. The discharge in Figure 7 does not show this; however, the sharp increase in discharge beginning on March 11, which is superimposed on the general trend of Figure 7, may be attributable to a relatively distant nuclear test within Rainier Mesa. The abrupt increase in discharge is characteristic of those recorded for other nuclear tests and is presented in a subsequent section. The U12n.05 drift seep is located in the back of the drift, and is in no way affected by mining effluent. Similar records exist for the U12n.03 drift. It seems unlikely that drilling fluid, rather than natural recharge, is responsible for all such increases in discharge.

PERIOD OF PRINCIPAL RECHARGE

The precipitation regime within the area of Rainier Mesa is characterized by a winter maximum and an early summer minimum (Figure 9) with summer temperatures rarely exceeding 32°C and winter temperatures only occasionally dropping below −10°C. These observations would tend to indicate that winter (defined as November through March) is the period of principal recharge. However, summer storms (defined as occurring in April through October) are characterized by extreme intensity over a short period of time and seem just as likely to recharge the mesa. In order to determine which season recharges Rainier Mesa, a graph of the deuterium composition of precipitation and ground-water seeps versus time were plotted in Figure 10. This figure also contains the results of year-round recharge and winter recharge models. The year-round recharge model is presented in Table 4, and the winter recharge model is presented in Table 5. The two models are based on the following equation:

$$A_I = \frac{\Sigma(P \times I_c)}{\Sigma P} \tag{3}$$

where A_I is equal to the average isotopic composition of recharge water, P is equal to the total precipitation between sampling periods, and I_c is the isotopic composition of an integrated precipitation sample representing approximately two months. If we assume that the ground-water isotopic composition is representative of the last few years of precipitation which recharged the mesa, then from Figure 10 the period of principal recharge can

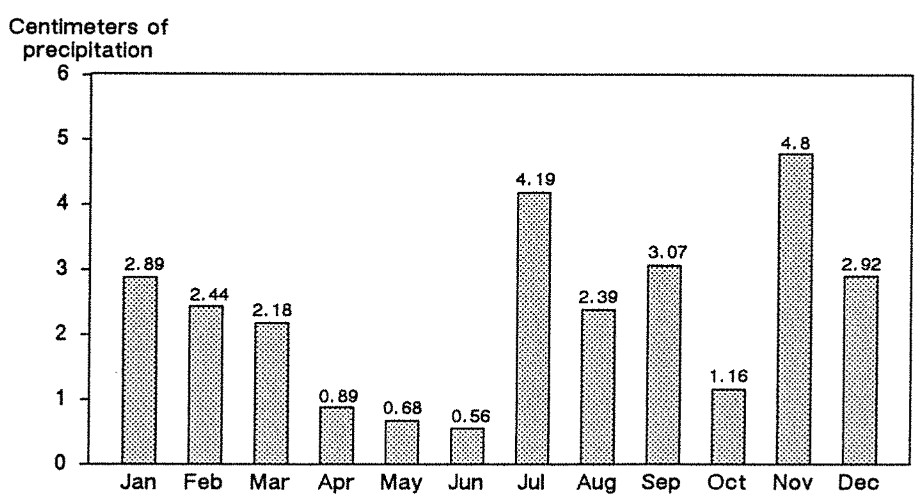

Figure 9. Average monthly precipitation of Rainier Mesa, June 1982 through June 1986 (French, 1986).

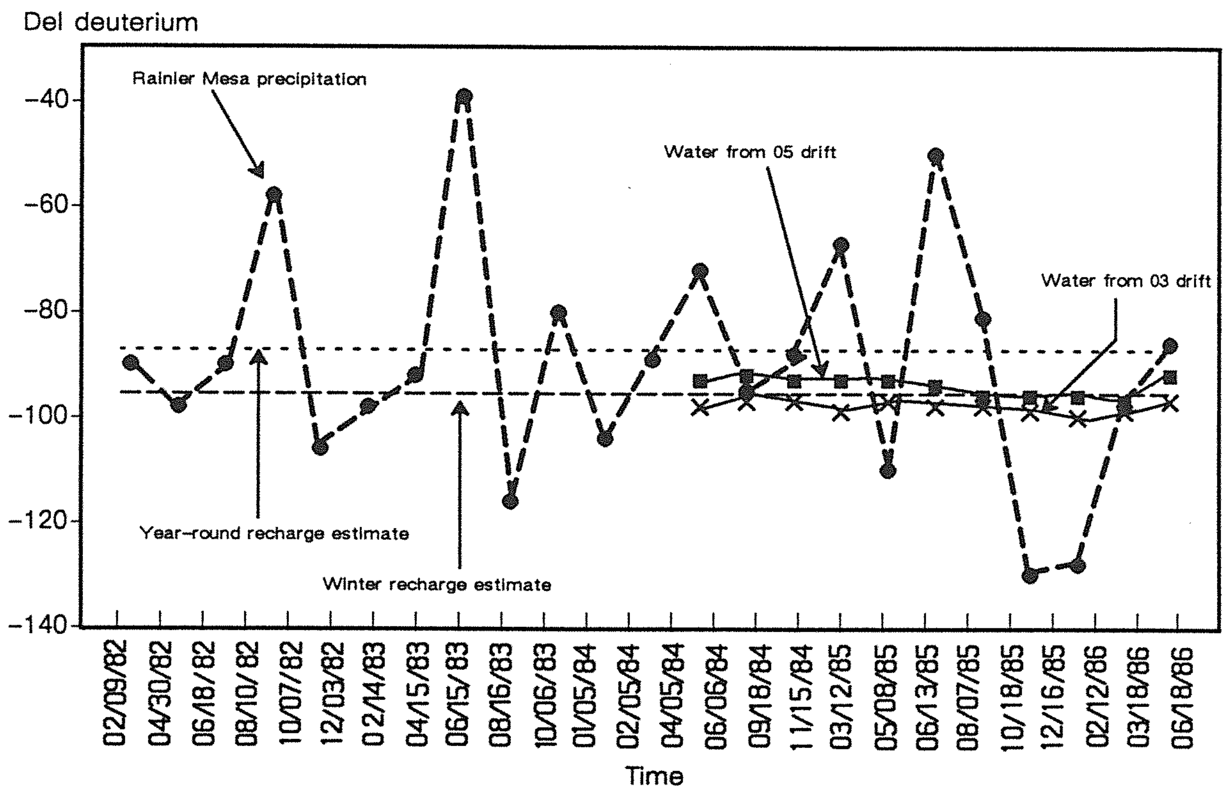

Figure 10. A plot of the isotopic signatures of Rainier Mesa precipitation and ground water found in U12n.03 and U12n.05 drift seeps.

TABLE 4. THE ESTIMATED ISOTOPIC CONTENT OF RAINIER MESA GROUND WATER IF YEAR-ROUND RECHARGE OCCURRED

Period of time represented by sample	Total precipitation (cm)	Del deuterium ratio	Weighted del deuterium ratio
12/01/81 - 02/09/82	3.45	-90	-310
02/09/82 - 04/30/82	6.88	-98	-674
04/30/82 - 06/18/82	3.35	-90	-302
06/18/82 - 08/10/82	2.46	-58	-143
08/10/82 - 12/03/82	15.34	-106	-1626
12/03/82 - 02/14/83	10.46	-98	-1025
02/14/83 - 04/15/83	1.45	-92	-133
04/15/83 - 08/16/83	4.04	-39	-158
08/16/83 - 10/06/83	5.51	-116	-639
10/06/83 - 01/05/84	6.27	-80	-502
01/05/84 - 04/05/84	2.11	-104	-219
04/05/84 - 06/06/84	0.53	-89	-47
06/06/84 - 09/18/84	15.95	-72	-1148
09/18/84 - 11/15/84	1.12	-95	-106
11/15/84 - 03/12/85	9.96	-88	-876
03/12/85 - 05/08/85	1.35	-67	-90
05/08/85 - 06/13/85	1.57	-110	-173
06/13/85 - 08/07/85	5.18	-50	-259
08/07/85 - 10/15/85	2.06	-81	-167
TOTALS:	99.04		-8597

(average isotopic signature = -87 per mil del deuterium)

TABLE 5. THE ESTIMATED ISOTOPIC CONTENT OF RAINIER MESA GROUND WATER IF ONLY WINTER RECHARGE OCCURRED

Period of time represented by sample	Total precipitation (cm)	Del deuterium ratio	Weighted del deuterium ratio
12/01/81 - 02/09/82	3.45	-90	-310.50
02/09/82 - 04/30/82	6.88	-98	-674.24
*08/10/82 - 12/03/82	15.34	-106	-1626.04
12/03/82 - 02/14/83	10.46	-98	-1025.08
02/14/83 - 04/15/83	1.45	-92	-133.40
10/06/83 - 01/05/84	6.27	-80	-501.60
01/05/84 - 04/05/84	2.11	-104	-219.44
09/18/84 - 11/15/84	1.12	-95	-106.40
11/15/84 - 03/12/85	9.96	-88	-876.48
TOTALS:	57.04		-5473.18
	(average isotopic signature = -96 per mil del deuterium)		

*The isotopic content of the precipitation which fell during 08/10/82 to 12/03/82 contains both summer and winter regimes. Approximately 9 cm of this precipitation fell before November, yet the isotopic content is similar to depleted winter storms. Calculations made without this period's contribution result in an average winter isotopic signature of -92 per mil del deuterium.

be determined. The winter recharge model is the best fit to the ground-water isotopic composition.

From the previous information, it is likely that winter precipitation is the dominant form of recharge for the Rainier Mesa ground-water system. Winograd and Riggs (1984) reached a similar conclusion using isotope analysis on the Spring Mountains, which are approximately 90 km to the southeast of Rainier Mesa and rise in elevation to approximately 4000 m.

ESTIMATED TOTAL RECHARGE THROUGH THE U12N TUNNEL CATCHMENT BASIN

The methodology used to determine the total recharge into the U12n recharge basin consisted of monitoring the U12n portal discharge for both aqueous and vapor transport, determining a total discharge and applying that to several estimated sizes of catchment basins of U12n tunnel. The slopes of the mesa were ignored because the working points of all known nuclear tests underlie the mesa top.

The following equation was used to calculate total discharge from U12n tunnel:

$$T = D + R + E \qquad (4)$$

where T represents the total aqueous and vapor discharge from U12n tunnel, D represents the aqueous discharge passing through the tunnel portal, R represents the ground water found in U12n tunnel which is not discharge through the portal discharge or ventilation system, and E represents the quantity of water moved by vapor transport through the tunnel air circulation system.

Due to the efficiency of the tunnel pumping system, R is assumed to be zero. The portal discharge was monitored for nine months in order to determine the mean discharge of 53 ± 9 l/min. Thus, a total of 27,900 ± 4700 m^3 of water per year are discharged at the tunnel portal. A plot of the base portal discharge is shown in Figures 11 and 12, and the raw data are in Appendix I. In reality, almost twice as much fluid is often discharged at the tunnel portal, however, this extra fluid is anthropogenic effluent which was not taken into account during the calculation of the mean discharge.

In order to determine the total amount of water transported through the air ventilation system, humidity measurements were taken both within and outside the tunnel environment. These data are presented in Table 6. A mean increase of 38 ± 13% relative humidity over the outside environment was recorded. This converts to 5.8 ± 2.0 gm of water per cubic meter of air using an average tunnel temperature of 18°C. The calculations are shown in Table 7. The circulation system moves 3180 m^3/min of air every 24 hours, 5 days a week, 52 weeks per year for a total of 1.2 x 10^9 m^3 of air per year, or a total of 6900 ± 2400 m^3 of water per year moved by the circulation system.

However, there are several problems with the vapor phase flux estimate. The percent of vapor contributed from various sources to the total relative humidity is unknown. These possible sources include water used in mining activities, water evaporated from interstitial pores, and the evaporation component contributed by fracture waters. If the combined contribution from all three sources is used in the calculations, then a conservative maximum discharge will be the result. The humidity measurements were taken during summer (Appendix II) when the evaporation component is larger, so the estimate is a conservative one with respect to this factor as well. From the following equations, the total discharge from U12n tunnel is:

$$T = D + E \tag{5}$$

$$T = (27900 \pm 4700) + (6900 \pm 2400) = 34800 \pm 5300 \tag{6}$$

More appropriately, 35000 ± 5300 m^3 of ground water are discharged per year from U12n tunnel. A source of error in this estimate is the possible contribution to the total flow from drilling fluid. Over the last 30 years, an estimated 377,000 m^3 of drilling fluid were lost to the entire mesa (Thordarson, W., personal communication, June 1987). However, considering the time and area in which the drilling fluid was lost, this contribution to yearly flow from U12n tunnel is probably a minor component to the total flow. A second problem is the existence of nuclear test-generated fractures, and the well holes themselves. These features tend to increase recharge by increasing the permeability of the

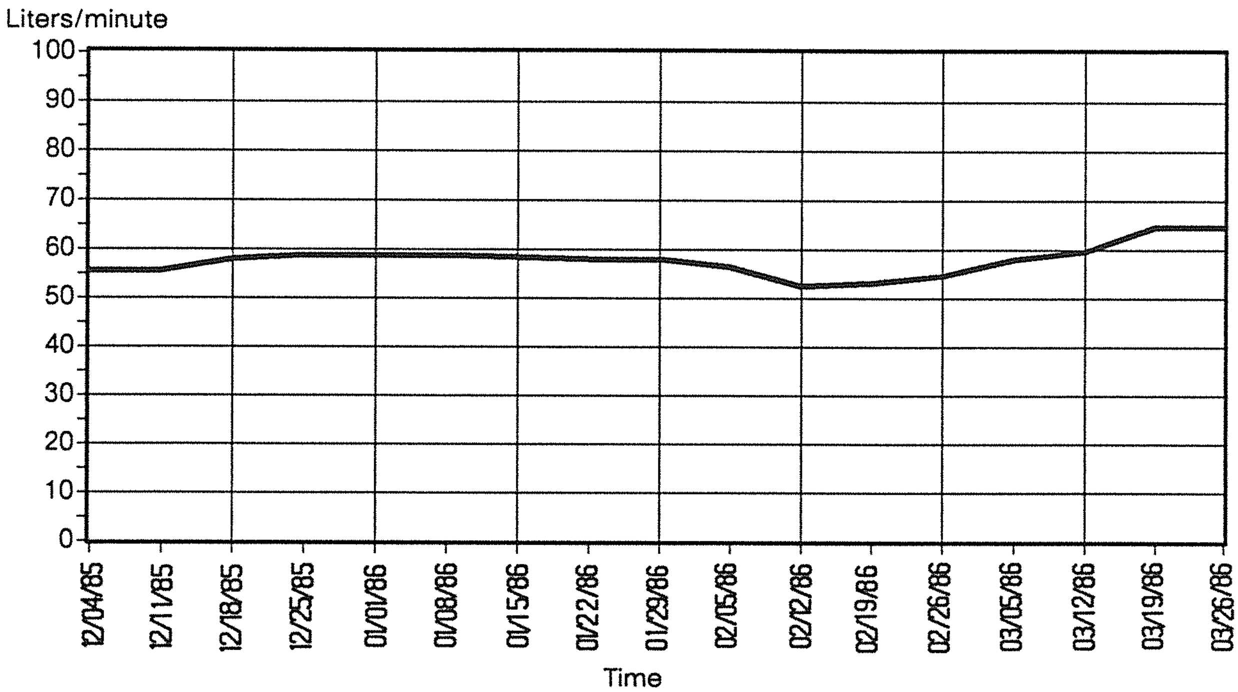

Figure 11. The estimated natural U12n portal discharge for December 1985 to March 1986.

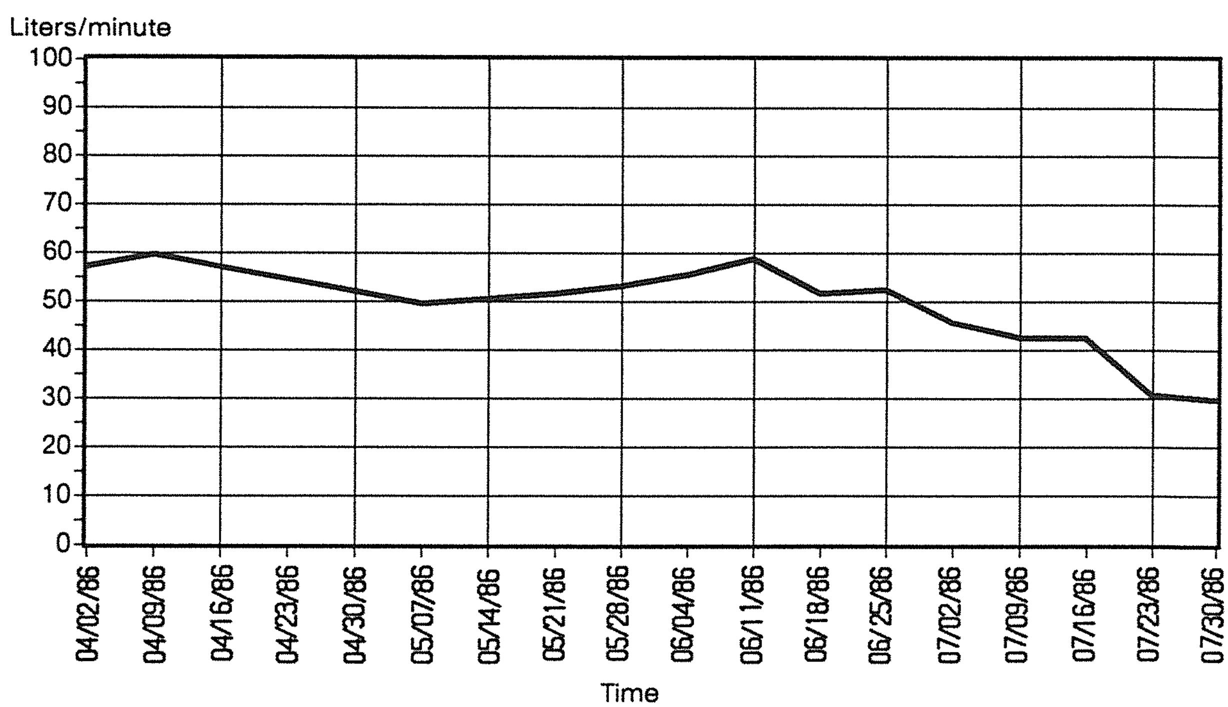

Figure 12. The estimated natural U12n portal discharge for April to July 1986.

TABLE 6. TEMPERATURE AND RELATIVE HUMIDITY DATA FOR U12N TUNNEL

Unit	Mean relative humidity (%)	Mean temperature (°C)	Mean relative humidity change between U12n tunnel and the surrounding environment
03 Drift	65 ± 10	19 ± 1.0	37 ± 17
05 Drift	69 ± 5	16 ± 1.0	42 ± 11
010 Drift	67 ± 7	18 ± 1.0	36 ± 11
Mean for the entire U12n tunnel	67 ± 8	18 ± 1.0	38 ± 13
Outside environment	28 ± 13	29 ± 4.0	

Raw data in Appendix II.

TABLE 7. CALCULATIONS FOR GROUND-WATER TRANSPORT BY EVAPORATION FROM U12N TUNNEL

	Temperature (°C)	Mean relative humidity	Unit of mass in gm of an m^3 of saturated aqueous vapor*	gm/m^3 of U12n tunnel air
Mean amount of water per m^3 of tunnel air:	17.8	38 ± 13%	15.29	5.8 ± 2.0
Greatest possible amount of water per m^3 of tunnel air:	18.9	59%	16.12	9.5
Least possible amount of water per m^3 of tunnel air:	18.3	14%	15.65	2.1

*Values from Weast (1979).

formations, thus, the recharge estimate from this study may be larger than that from the pre-nuclear period for Rainier Mesa.

Figure 13 shows the best estimate for the catchment basin for U12n tunnel. The boundaries of this catchment basin were plotted using the orientation and extent of known faults and the topography of the mesa surface. It is known that 50 to 60% of faults carry ground water in Rainier Mesa. These faults are oriented approximately north-south and are steeply dipping (Thordarson, 1965).

Also in Figure 13 are two more recharge basins which are ± 30% the size of the previous estimate. These secondary basins are included to encompass the unknown areal extent of the recharge basin and reasonably expected deviations in the parameters which affect fracture recharge. It is unknown if deviations greater than this are present. Assuming that Rainier Mesa is homogeneous with respect to fracture transport of ground water, and assuming the recharge basin falls into the above range of areas, then the recharge per unit area for U12n recharge basin may be calculated:

$$R_u = \frac{T}{U} \tag{7}$$

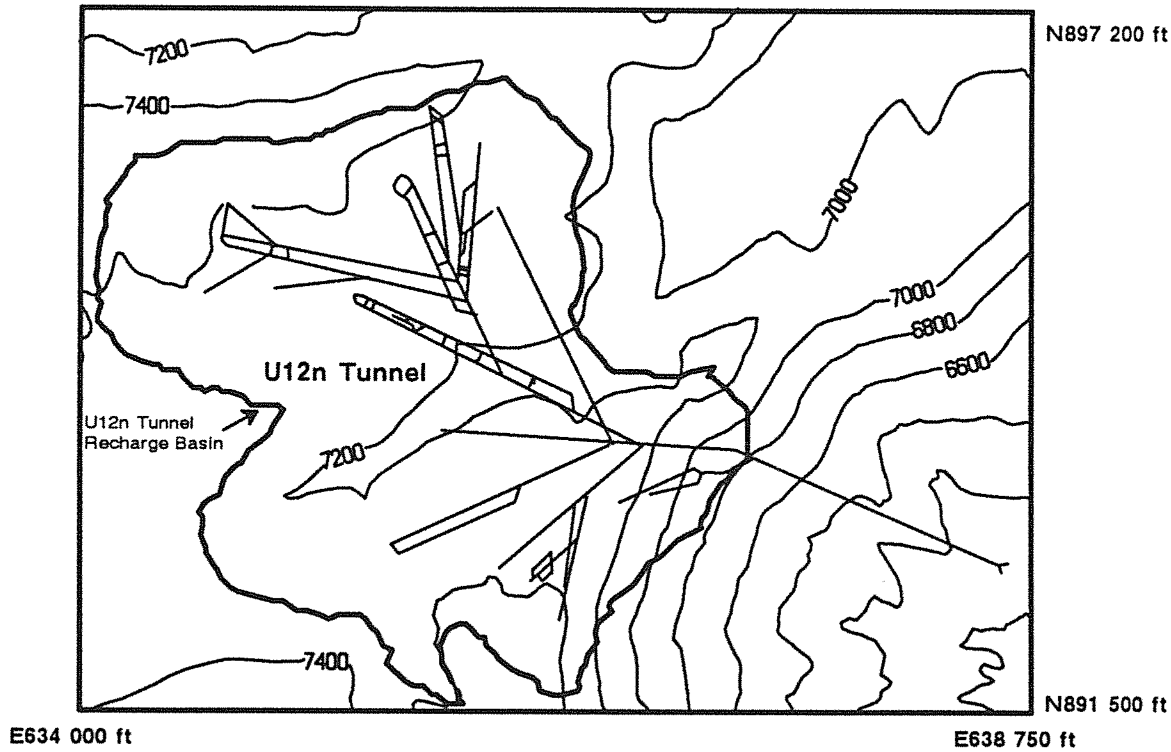

Figure 13. The estimated U12n tunnel catchment basins.

where R_u equals the recharge per unit area for U12n recharge basin, T is the total ground–water discharge from U12n tunnel, and U is the area of the U12n tunnel recharge basin. This simple equation is based on the following assumptions: 1) Ground water flow is dominantly within the fractures and the matrix acts as storage rather than a conduit for ground–water transport. 2) All of the fractures drain into the U12n tunnel recharge basin. 3) Recharge is uniform throughout the U12n tunnel recharge basin, both spatially and temporally. 4) The actual area of recharge is contained within the estimated areas of recharge basins. The area of the best estimate for the recharge basin is 1.4 x 10^6 m^2. The secondary basins are within ± 30% of this estimate, or 1.03 x 10^6 m^2 and 1.9 x 10^6 m^2, respectively. The calculations for total recharge to the best estimate is as follows:

$$R_u = (34800 \pm 5300 \ m^3/yr) \div 1.47 \ km^2 = 23700 \pm 3600 \ m^3/yr/km^2$$

for the secondary basins —

$$R_u = (34800 \pm 5300 \ m^3/yr) \div 1.03 \ km^2 = 33800 \pm 5100 \ m^3/yr/km^2$$

$$R_u = (34800 \pm 5300 \ m^3/yr) \div 1.91 \ km^2 = 18200 \pm 2800 \ m^3/yr/km^2.$$

These calculations are an estimated range of recharge per unit area for the U12n tunnel catchment basin. The recharge estimate is for a perched water zone within Rainier Mesa. Percolation of the ground water continues past the tunnel beds, through the Paleozoic dolomites into the regional carbonate aquifer.

The area of Rainier Mesa directly above U12n tunnel may be more conducive to recharge than other areas. The Aqueduct, the principal surface drainage of Rainier Mesa, is directly over portions of the tunnel. This could promote increased infiltration with respect to other areas of the mesa. The tunnel also cross-cuts the Aqueduct Syncline, a major structural feature of Rainier Mesa. Down-dip flow in the vadose zone is possible and may be contributing to greater discharge values than would normally be expected.

This study needs to be conducted on the other tunnel systems within the mesa in order to arrive at an estimated total recharge. Preliminary discharge estimates have been made for several other tunnels (Table 8).

TABLE 8. DISCHARGE FROM OTHER TUNNEL SYSTEMS

Tunnel	Fluid discharge (l/min)	Source
U12g	0.036	Fernandez and Freshley (1984)
U12n	53.0	Russell et al. (1987)
U12e	19.0	S. Tyler, field inspection 02/13/87
U12t	26.5	S. Tyler, field inspection 02/13/87

The discharge for U12e tunnel represents only passive flow from the portal. An active drainage system is absent, thus, infiltration rates through the tunnel floor are probably high. Thordarson (1965) estimated an average portal discharge of 20 to 38 l/min for U12e tunnel for the period of December 1961 to December 1963. Thus, flows from U12e tunnel may be larger than observed. Thordarson estimated a total recharge value of 172,600 m3/yr for Rainier Mesa using the Maxey-Eakin method. U12n tunnel accounts for 6% of the area of the mesa's caprock and slopes, and 20% of Thordarson's estimated total recharge through the mesa. This incongruency indicates a need for further study in this area.

The percent of precipitation which recharges the U12n catchment basin can be calculated from the following:

$$pr = \frac{T \times 100}{P} \tag{8}$$

where *pr* is the percent of precipitation which recharges, *P* is the yearly average of precipitation which fell on the U12n recharge basin over the last four years, and *T* is the total discharge from U12n tunnel. From Equation (6):

$$pr = (34800 \pm 5300 \text{ m}^3\text{/yr} \times 100) \div (.279 \pm .059 \text{ m/yr} \times [1.47 \times 10^6 \text{ m}^2]) = 8.5 \pm 4.6\%$$

therefore, approximately 8% of all precipitation which falls on Rainier Mesa is recharged. This is very close to Eakins's estimate of 7% as reported by Thordarson (1965).

HYDRAULIC RESPONSE TIME

The period of hydraulic response is the period of time it takes for a given recharge event to cause a corresponding increase in discharge at the seeps. In order to determine this parameter, two pieces of information are required. The first is a complete precipitation record for the mesa, and the second is discharge records from the seeps within the mesa for the same time period. Only large-scale winter recharge events were used in determining the period of hydraulic response. This was done in order to eliminate those precipitation events which may not have recharged the mesa. The precipitation record was examined from September 1, 1983 to August 31, 1986. Discharge was measured at three points: the 03 drift, 05 drift, and the portal weirs, from September 1985 to July 1986.

The two types of data were subjected to cross-correlation analysis in order to determine if there was any significant correlation between recharge and discharge events. Unfortunately, this technique was unsuccessful. The next step was to apply an average response technique. This technique averages the discharge records following suspected recharge events. It is used to isolate an average response time following a given stimulus (Kinnison, 1986; personal communication). An example is given in Figures 14 to 16. This example uses two major storms from November 11, 1985 and January 29, 1986 as stimuli, and the discharge record following those storms. The six discharge records in Figures 14 and 15 were averaged to create Figure 16. From this figure, a large increase in discharge is noted at a time lag of approximately 120 days with a secondary increase at a time lag of 40 days. The increase at a lag of 40 days could be a reflection of the increase in discharge created by the November 11th storm, as recorded by the second record which started on January 29, 1986. The time difference between the two is approximately 100 days.

The averaged response of the six discharge records indicates a period of hydraulic response of approximately four months. A response time of four months is considered the

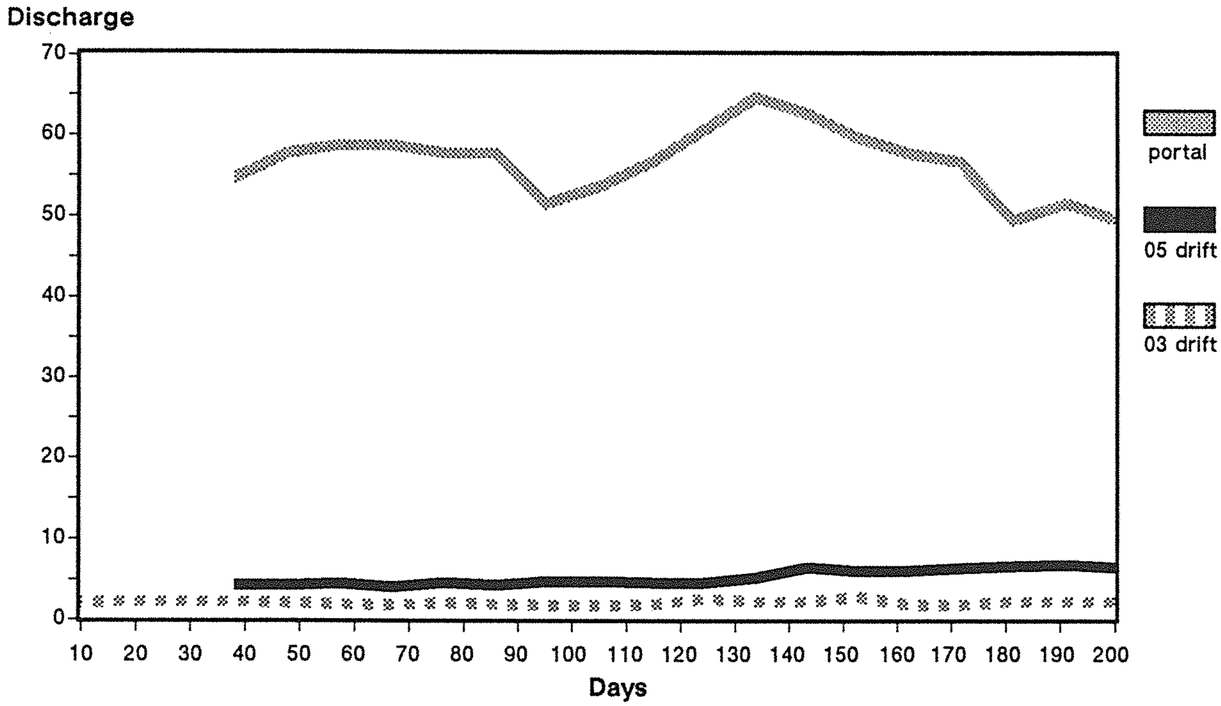

Figure 14. A plot of the U12n.03, U12n.05, and portal discharges following the precipitation event of November 11, 1985.

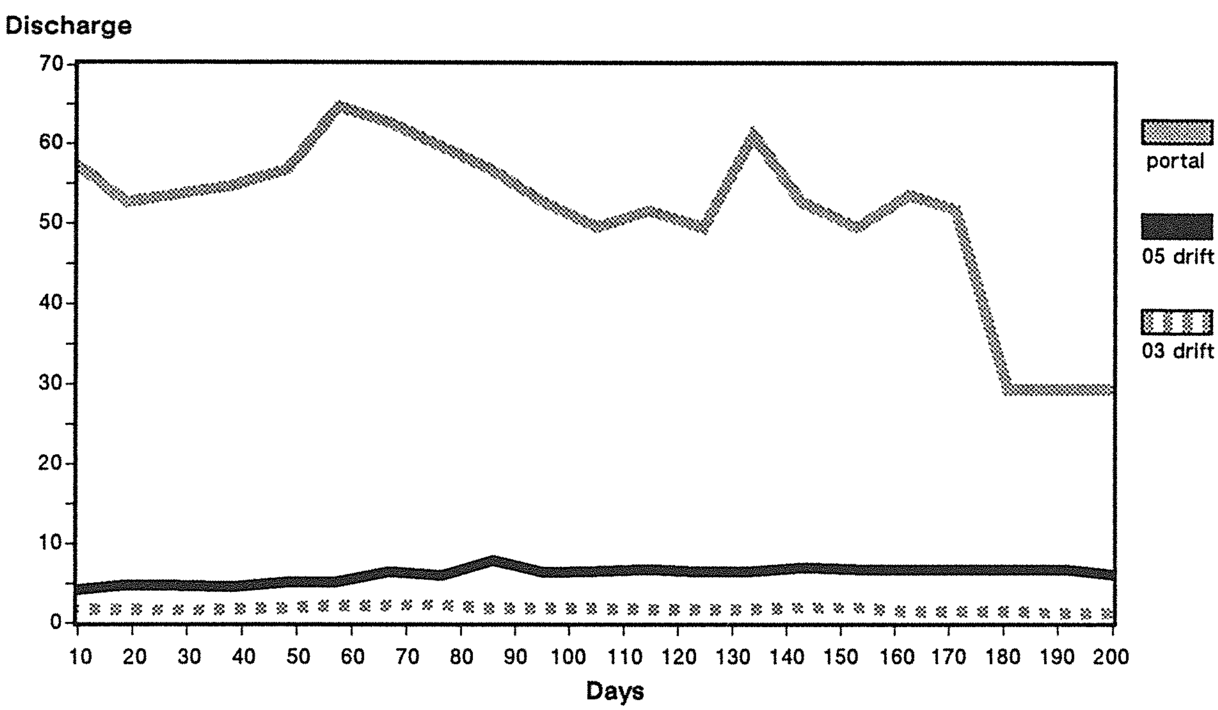

Figure 15. A plot of the U12n.03, U12n.05, and portal discharges following the precipitation event of January 29, 1986.

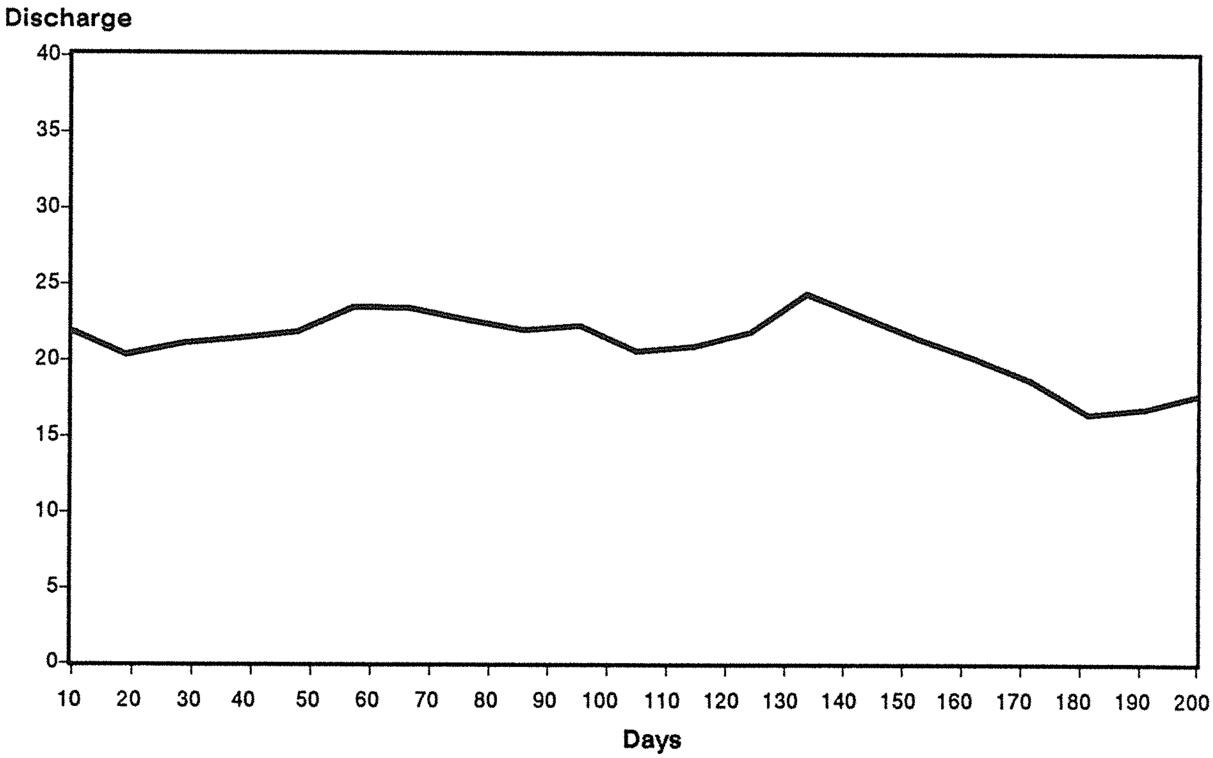

Figure 16. The averaged response of six discharge events from U12n tunnel seeps.

extreme minimum in which a hydraulic response could occur. Each winter season within the record contained storms that could create the recorded increase in discharge, thus, the period of hydraulic response may be approximately one year and four months, two years and four months, or longer.

The Paintbrush Tuff within Rainier Mesa is the only formation through which interstitial flow is the dominant form of transport. This unit is 120 m thick, is unsaturated, and has a saturated hydraulic conductivity of approximately 1.75 x 10^{-6} m/s. These facts preclude the possibility of a hydraulic response traveling through the mesa in four months. If the Paintbrush Formation is unaltered by nuclear testing, it seems likely that the period of hydraulic response is at least one year and four months or longer. However, the numerous nuclear tests conducted within Rainier Mesa have fractured the zeolitic tuffs of the Indian Trail Formation as well as the Rainier Mesa Member which is the caprock of the mesa. It seems likely that the bedded tuffs of the Paintbrush Formation have been fractured as well. These nuclear test-generated fractures may be intercepting interstitial flow within the Paintbrush Formation allowing the possibility of a period of hydraulic response of four months to exist. If this is true, then the measured period of hydraulic response is not representative of the pre-nuclear test era of Rainier Mesa.

In conclusion, the period of hydraulic response lag time is at an extreme minimum, four months in duration, and is most likely longer.

HYDRAULIC RESIDENCE TIME

Several methodologies were attempted in order to delineate the travel time of ground water in Rainier Mesa. Two tracer studies, a tritium study, and a statistical method were used. For the tracer studies, two tests were performed on the surface of the mesa overlying U12n tunnel.

The first test consisted of fluorescene and direct yellow dyes applied at a topographic low in the canyon known as the Aqueduct, which lies directly over the U12n.05 drift. These dyes have yet to be detected with any degree of confidence at the tunnel level. Several of the cotton detectors have been found to contain trace amounts of fluorescene. These dyes first were detected on February 5, 1987. This would indicate a travel time of approximately 940 days. However, it is not known if the detected dye is a result of contamination in the cotton detector, or if the detector is picking up previous fluorescent dyes used by Sandia and Lawrence Livermore National Laboratories in U12g tunnel as long as five years ago (Abe Ramirez and Carl Smith, personal communication, October 1987). Owing to a distance of approximately 3 km from U12g tunnel to U12n tunnel, it seems unlikely that fluorescent dyes would be found therein, even if significant lateral flow exists within the mesa. Flourescene has been detected in a cotton receptor that was not exposed to Rainier Mesa ground water while other samples prepared in a similar fashion have not indicated the presence of this dye. This indicates that the concentrations of fluorescene detected in tunnel samples may be due to contamination during preparation.

A second test was conducted on March 23, 1986, using optical brightener and lithium bromide. These tracers are thought to be more conservative in a tuffaceous environment. The tracers were applied in a diffuse manner along surficial expressions of faults above the U12n tunnel complex to enhance infiltration and the probability of detection (Figure 17). These dyes have yet to be detected at the tunnel level. One problem with this particular tracer test is the lack of significant recharge events until the winter of 1986 to 1987. Infiltration of the tracers may not have occurred until that winter. Monitoring of these tracers is continuing in the hopes that they will be detected. Dilution of the tracers to background levels may occur if extensive mixing is occurring within the fracture systems. However, the possibility of mixing is discussed in detail in the next section and is not considered to be a problem.

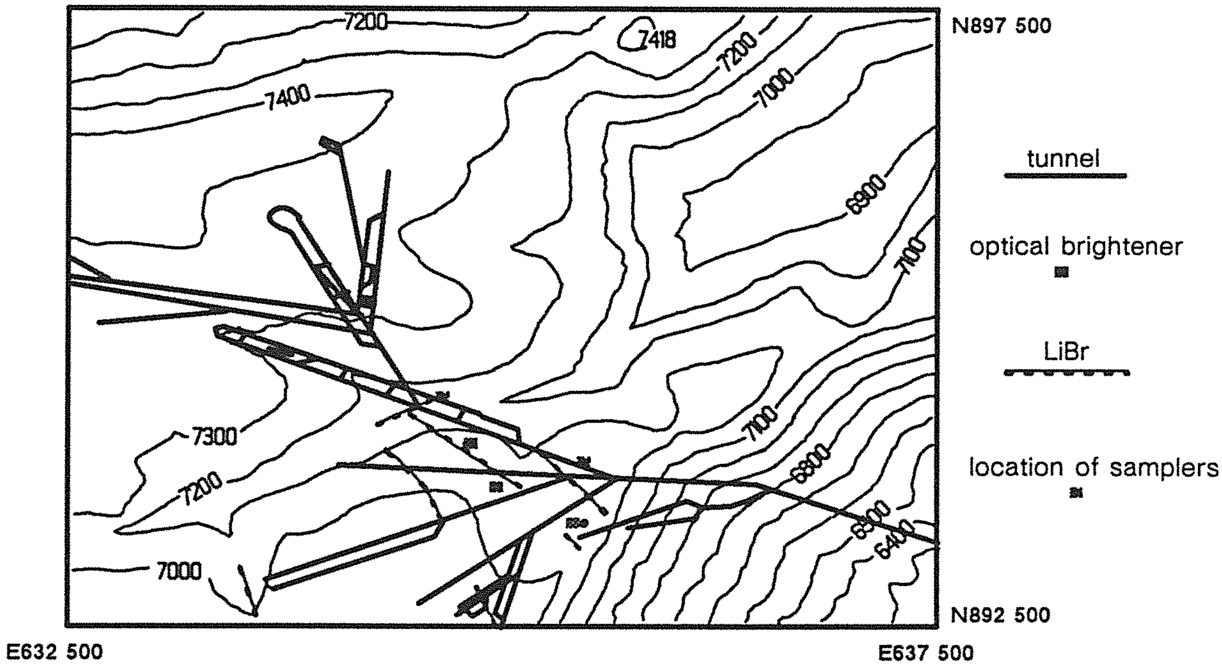

Figure 17. U12n tunnel and areas of LiBr and optical brightener emplacement.

Tritium studies were also conducted at various points within U12n tunnel. However, due to the nature of the testing conducted within the tunnel system, the tritium concentrations are well above atmospheric background levels. The lowest concentration was in the U12n.03 drift, which had a concentration of 267 tritium units. The highest was found at the U12n portal at a level of 697,000 tritium units. This level of contamination effectively blocks the use of tritium in age dating. Clebsch (1960) took one tritium sample of Rainier Mesa ground water from U12e tunnel and calculated a residence time of eight months to six years. The results were duplicated in a sample taken by Clebsch (1960) at a spring in similar stratigraphy near the northern end of Rainier Mesa. At the time of sampling only a few nuclear tests had been conducted in the U12b tunnel at Rainier Mesa. This site is approximately 1 km away from the sample site in U12e tunnel and 7 km away from the spring sample site. This distance is great enough to inhibit tritium contamination due to testing.

The final methodology used to determine residence time was a cross-correlation performed on the precipitation and ground-water isotopic signatures. However, significant correlation was not found at any time lag. As can be seen in Figure 10, there is no apparent correlation of the ground-water isotopes relative to that of the precipitation.

However, if one examines Figure 10, it will be noted that the winter of 1985 to 1986 was characterized by extremely depleted deuterium levels within the precipitation. Mixing calculations utilizing the amount of precipitation and the isotopic signatures for the last three years have been conducted. Results revealed that these recharge events should be detectable in the ground-water seeps. The seeps will be monitored for this drop in the isotopic content of the discharge water. Once this is detected, a better estimate of travel time for ground water in Rainier Mesa will be known. In conclusion, it is known from present monitoring that the travel time is at least one year and probably less than the six years as estimated by Clebsch (1960).

EXTENT OF MIXING BETWEEN THE 03 AND 05 DRIFT SEEPS

A potential problem for contaminant transport within Rainier Mesa is the degree of interconnection among the fracture reservoirs. If each fracture reservoir is well connected to others, radionuclides will be widely disseminated, increasing the bulk area of contamination. If the fracture reservoirs are poorly connected, then the contaminant plume remains relatively small and in a more concentrated state.

Two data bases were used to determine the extent of mixing between the 03 and 05 drift seeps: the gross chemistries and the isotopic ratios of the two seeps. A Stiff diagram of the chemistry of the U12n.03 drift is presented in Figure 18 and a similar diagram for the U12n.05 geochemistry is presented in Figure 19. Four samples were used in order to delineate the differences in geochemistry between the 03 and 05 drift seeps. An examination of the chemistry reveals remarkably similar waters, even during periods of maximum and minimum discharge rates. There are two possible reasons for this. The first is that the fractures are well-connected and the similar chemistry is a result of well-mixed ground water supplying the two seeps. This would indicate well-connected fracture reservoirs. The second possibility is that the two fracture reservoirs are not well-connected. Similar geochemical processes could create the similar ground-water chemistries.

To further investigate this, the isotopic ratios of the two seeps were examined. This information is plotted in Figure 20 which shows that the 03 drift seep del deuterium is generally 3 to 4 per mil depleted with respect to the 05 drift seeps. This general difference in isotopic ratios would seem to indicate that the fracture reservoirs are poorly connected between the two seeps, and that the similar geochemistry of the water is actually due to similar geochemical processes rather than the mixing of the two waters.

The general variation of 3 to 4 per mil del deuterium between the 03 and 05 drift seeps could be attributed to three possibilities. The first is an elevation difference between

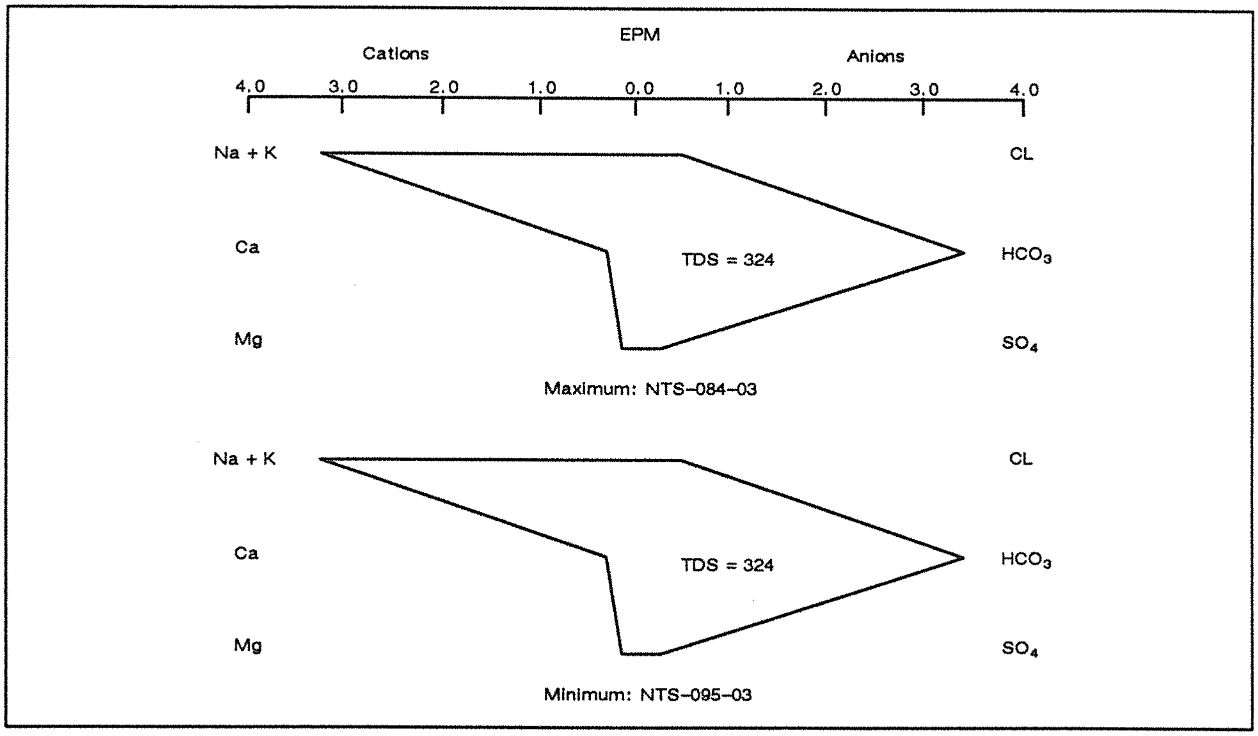

Figure 18. Stiff diagram of U12n.03 seep at maximum and minimum flows.

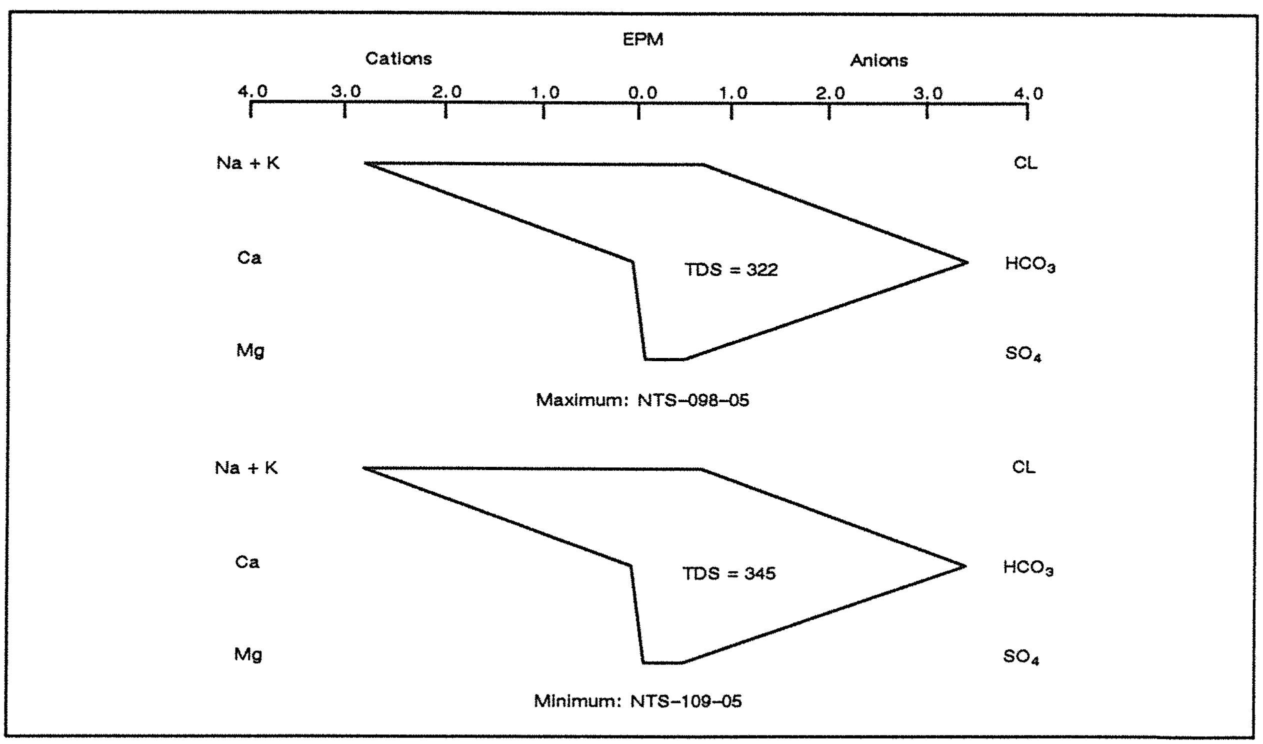

Figure 19. Stiff diagram of U12n.05 seep at maximum and minimum flows.

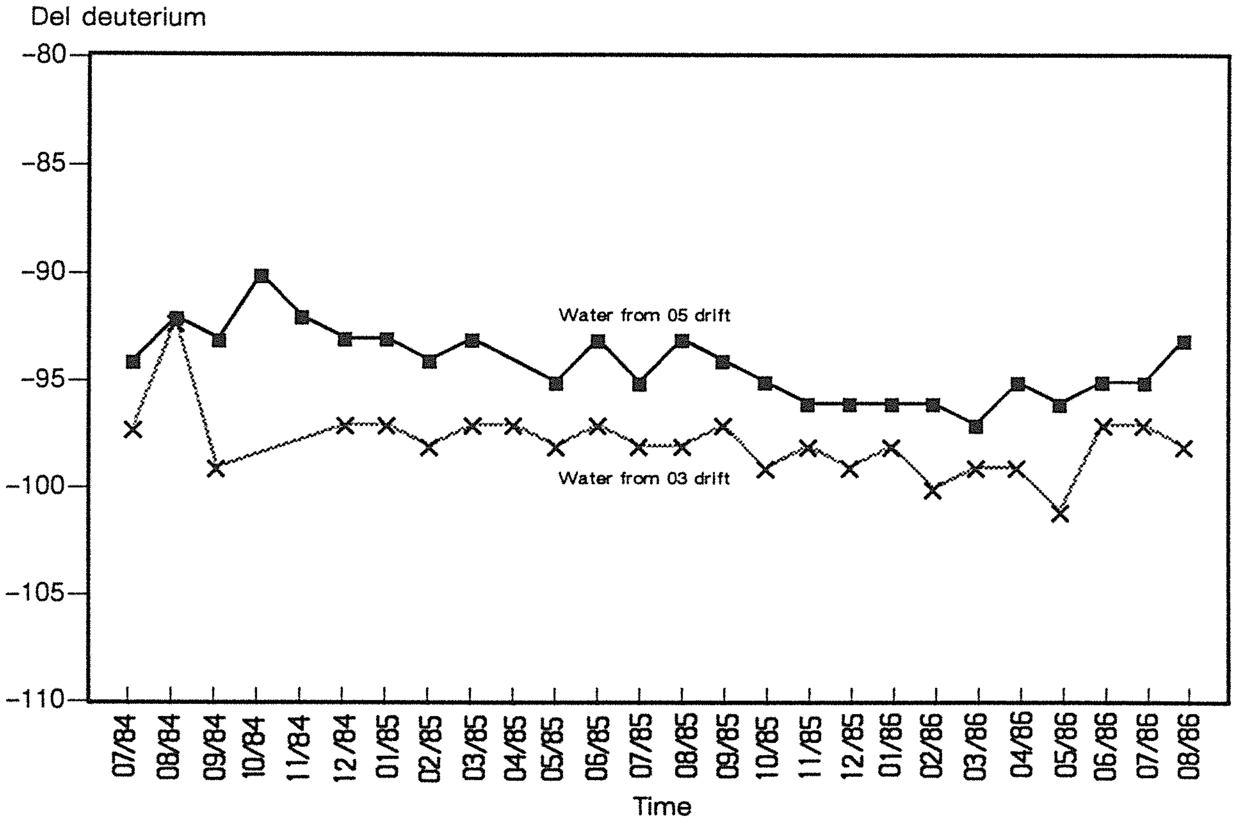

Figure 20. A plot of deuterium versus time for the U12n.03 and U12n.05 drift seeps.

the recharge area of the two seeps. Dansgaard (1964) reported a fractionation effect due to differences in altitude. The greater the altitude, the isotopically lighter the precipitation. Gradients of 1.2 to 4 per mil del deuterium per 100 m are considered average. Using this gradient and the 3 to 4 per mil del deuterium difference between the two seeps, it can be concluded that since the 05 drift seep is 3 to 4 per mil heavier than the 03 drift seep, then the 05 seep recharge area is lower in altitude than the 03 seep recharge area. The surface elevation of the mesa directly above the U12n.03 drift is approximately 50 m higher than the area above the U12n.05 drift. The elevation difference is not enough to account for the enrichment of deuterium in the 05 drift water relative to the 03 drift water. An isotopic data base currently being collected for the Nevada Test Site by the Desert Research Institute has found very little isotopic fractionation as a function of elevation at the test site (R. Jacobson, personal communication, October 1987).

The second possibility deals with a variation in seasonal recharge due to each fracture system's location. The 05 fracture system recharge area is probably located at the bottom of the Aqueduct canyon. This is an ideal location for summer recharge to occur because it is the largest wash on Rainier Mesa. The 03 fracture system recharge area is probably located on the mesa surface above the drift itself. This locality is not as conducive to summer recharge due to its relative flatness. Since summer recharge is isotopically heavier than winter recharge, the 05 fracture water should be isotopically heavier than the 03 fracture water. This observation can be verified by Figures 20 and 21.

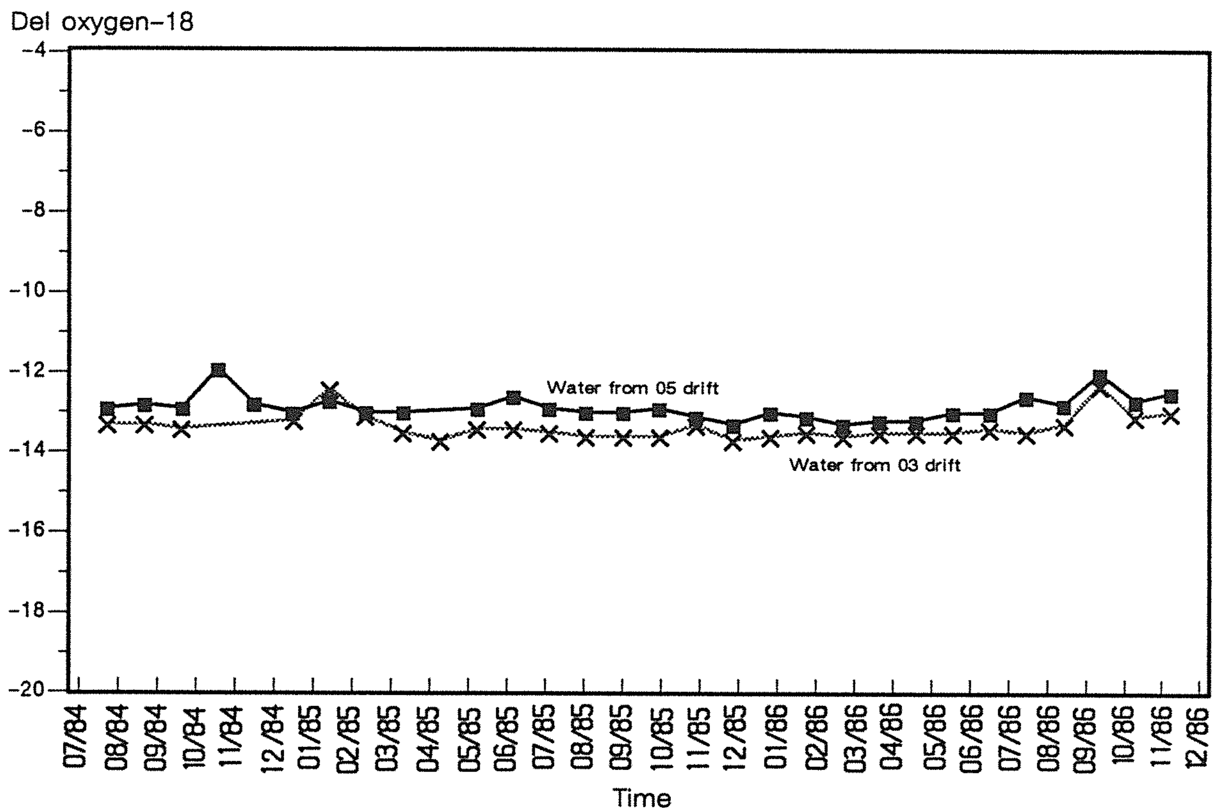

Figure 21. A plot of oxygen-18 versus time for the U12n.03 and U12n.05 drift seeps.

A third possibility also exists. An examination of the data in Appendix IV reveals that the 05 drift has a concentration of 13,000 tritium units while the 03 drift has 240. Thus, the 05 drift has undergone a greater degree of contamination from nuclear testing than the 03 drift. It is possible that the enriched stable isotopic ratios of the 05 drift are a product of nuclear testing. However, a literature search failed to find supporting evidence for this assumption.

Figure 21 is a graph of the oxygen-18 isotopic signatures of the two drifts over time. There is a general enrichment of approximately 0.3 to 0.5 per mil of oxygen-18 in the 05 drift relative to the 03 drift waters. Dansgaard (1964) reported a gradient of 0.15 to 0.5 per mil oxygen–18 per 100 m. The altitude difference between the 03 and 05 drifts is not great enough to account for the 05 drift enrichment.

Since there is an elevation difference between the two recharge areas, and the 05 recharge area is in an area more likely to receive isotopically–enriched summer recharge, and there has been greater contamination of the 05 drift relative to the 03 drift, perhaps it is a combination of these three factors which create the isotopically–enriched waters of the U12n.05 fracture reservoir.

THE EFFECTS OF NUCLEAR TESTING ON GROUND–WATER DISCHARGE AND CHEMISTRY

Several studies have investigated the effects of nuclear testing on the formations within Rainier Mesa (Cattermole and Hansen, 1962; Wilmarth *et al.*, 1960; and Wilmarth and McKeown, 1960). There was also a study investigating the effect of nuclear testing on the hydraulic properties of these formations (Clebsch, 1961). The Clebsch (1961) study documents the effects of a nuclear explosion on local ground–water discharge and chemistry.

During the course of this investigation, a data base was created using the discharge of the 05 seep and the chemistry of both the 03 and 05 seeps. The discharge record of the 05 drift seep for the month of April 1986 is plotted in Figure 22. An announced nuclear test was conducted on April 10, 1986, and corresponding to this date is a two–fold increase in ground–water discharge. The test–related increased discharge will henceforth be named the bomb pulse. The bomb pulse for this particular event lasted for 18 days. Other announced tests within Rainier Mesa have been recorded as bomb pulses by the discharge record of the 03 and 05 drift seeps. The question of importance is what is the source of the additional discharge, is it accelerated fracture flow or increased discharge from interstitial pores?

Corresponding with the bomb–pulse discharge is an increase in the total dissolved solids of the seep waters. Graphs illustrating the change for specific ions after a nuclear test are presented in Figures 23 to 26. Figures 23 and 24 are for a nuclear test conducted on April 6, 1985, as recorded at the 03 drift; Figures 25 and 26 are for a test conducted on April 10, 1986, as recorded at the 05 drift. The graphs show an increase in concentration for most dissolved species with a large increase in concentration for sodium, sulfate, and bicarbonate. The large increase in total dissolved solids would likely be from an increased component of flow derived from a source that has a longer residence time

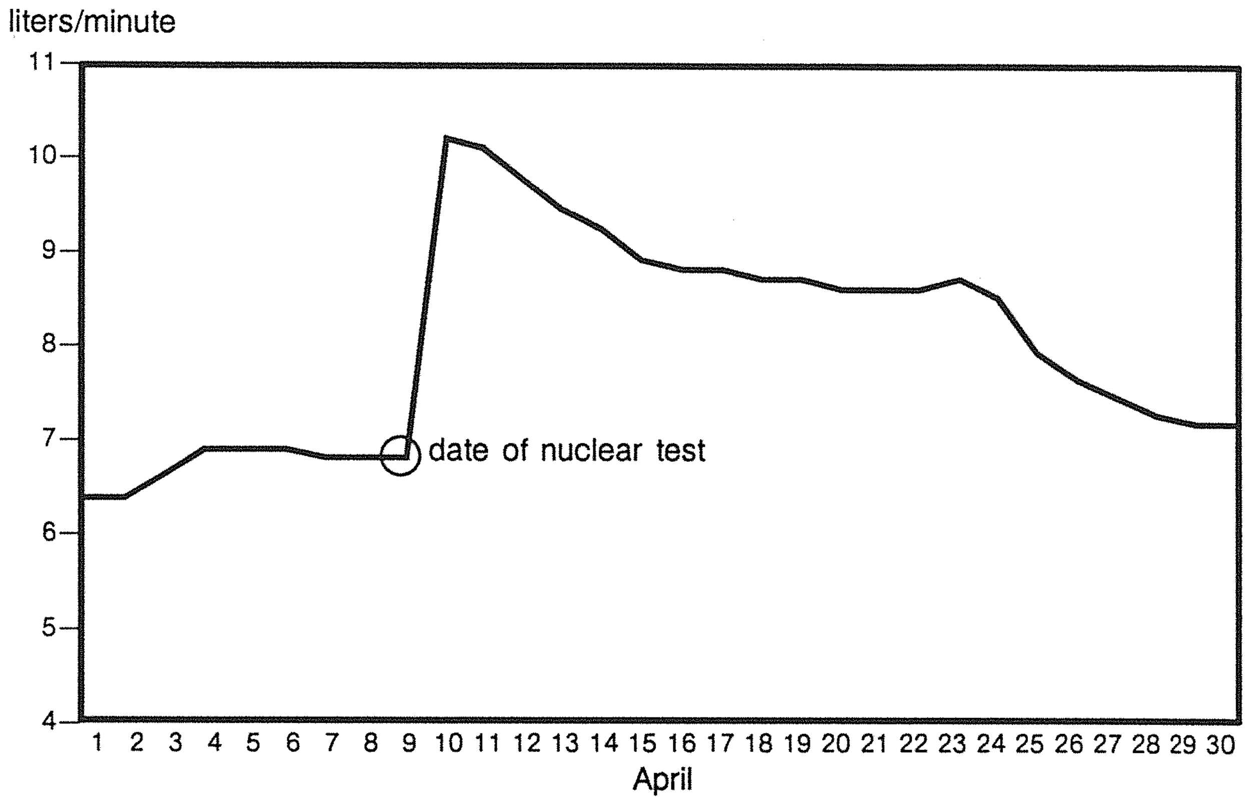

Figure 22. U12n.05 discharge for April 1986 shows an increase due to an announced nuclear test conducted on April 10, 1986.

within the formations of Rainier Mesa. This is probably the interstitial water which, due to the low permeability of the matrix, has a relatively longer residence time than the fracture waters. The bomb pulses are probably a mixture of fracture water and an increased flux of interstitial water caused by the nuclear tests.

The changes in water chemistry before and after are presented in the Stiff diagrams of Figures 27 and 28. Normal discharge waters are already elevated in sodium and bicarbonate as described by White *et al.* (1980). Within the bomb pulses, the sodium and bicarbonate are increased in concentration, as is sulfate. The Stiff diagrams reveal that the April 6, 1985, bomb pulse had a much greater ionic concentration of sulfate relative to the April 10, 1986, bomb pulse. A reason for this is that the 03 drift is much closer to the working point of the April 6, 1985, test than the 05 drift was to that of the second test. The effect that a nuclear explosion creates on the discharge is amplified for the 03 drift relative to the 05 drift.

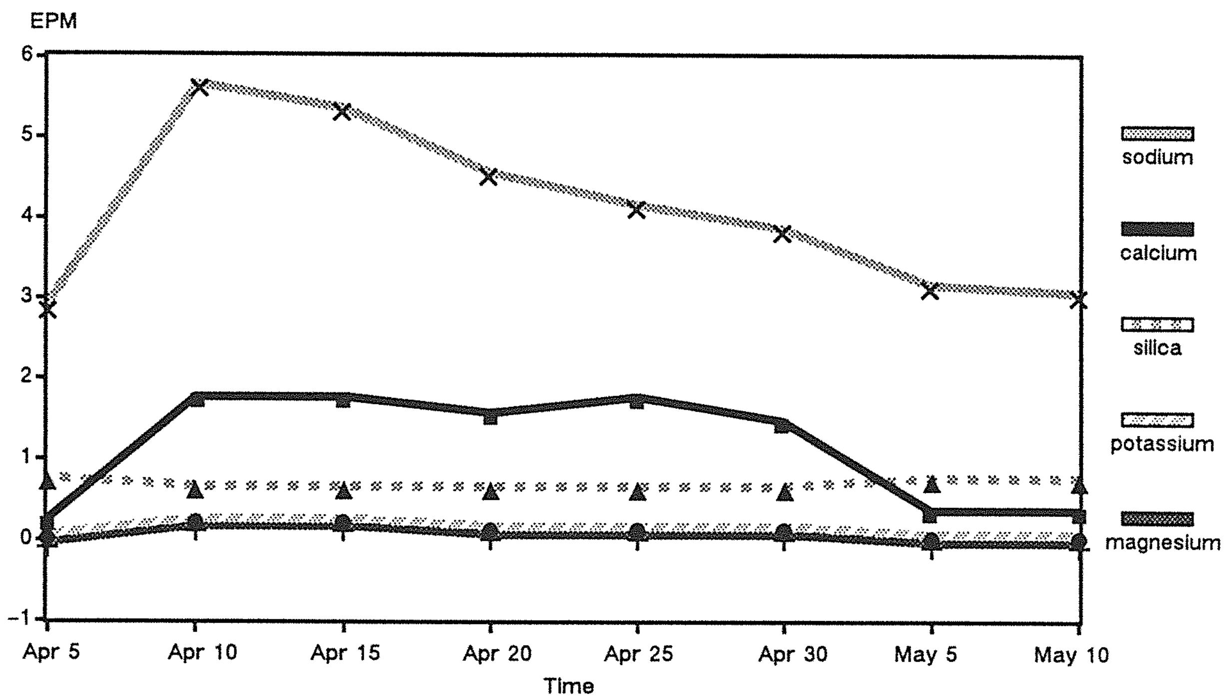

Figure 23. A plot of SiO2, Na, K, Ca and Mg versus time following an announced nuclear test conducted on April 6, 1985 from the 03 drift.

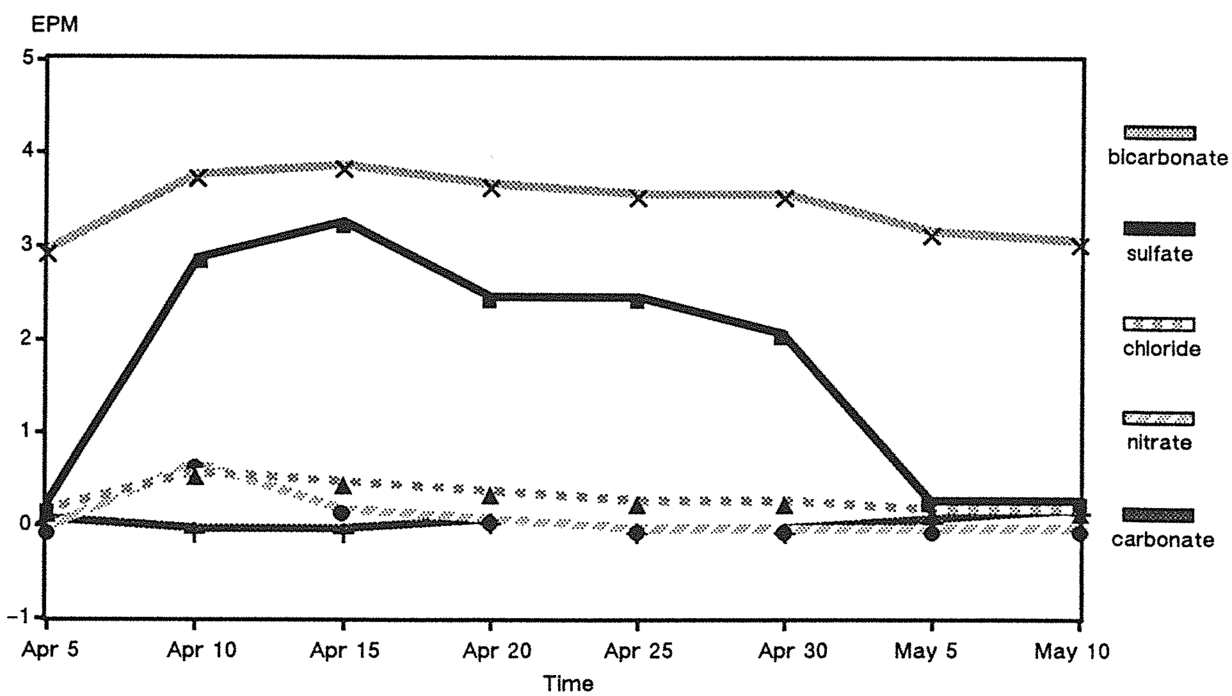

Figure 24. A plot of HCO_3, CO_3, Cl, SO_4 and NO_3 versus time following an announced nuclear test conducted on April 6, 1985 from the 03 drift.

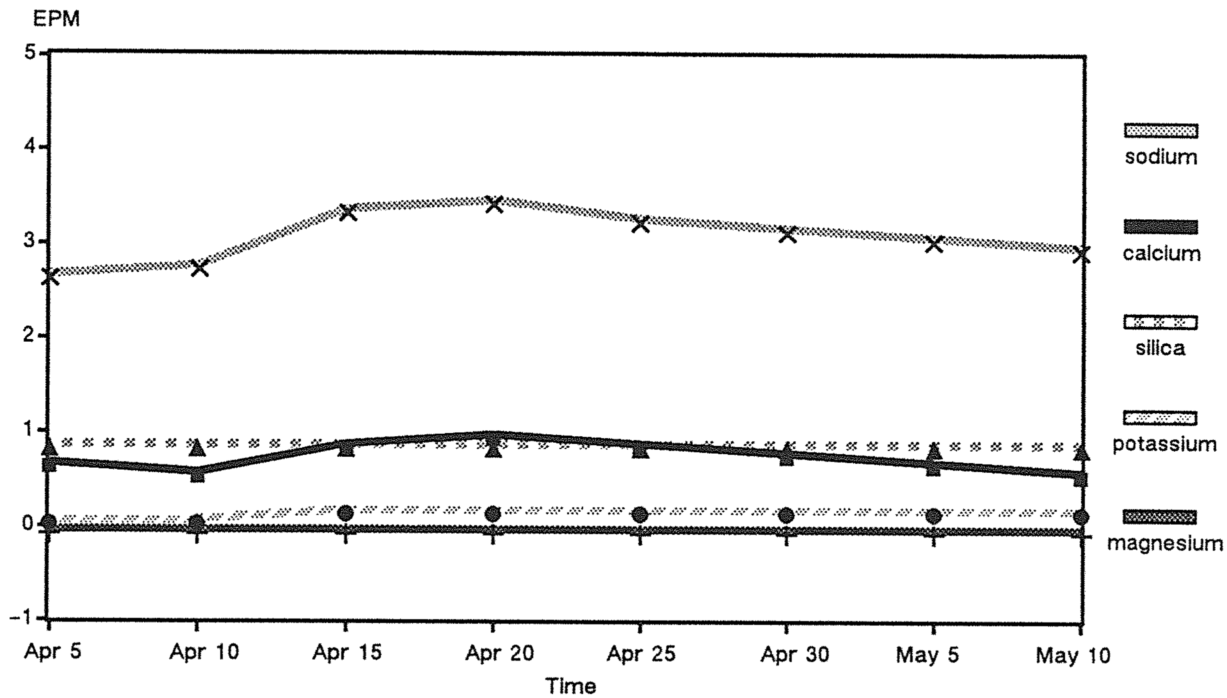

Figure 25. A plot of SiO_2, Na, K, Ca and Mg versus time following an announced nuclear test conducted on April 10, 1986 from the 05 drift.

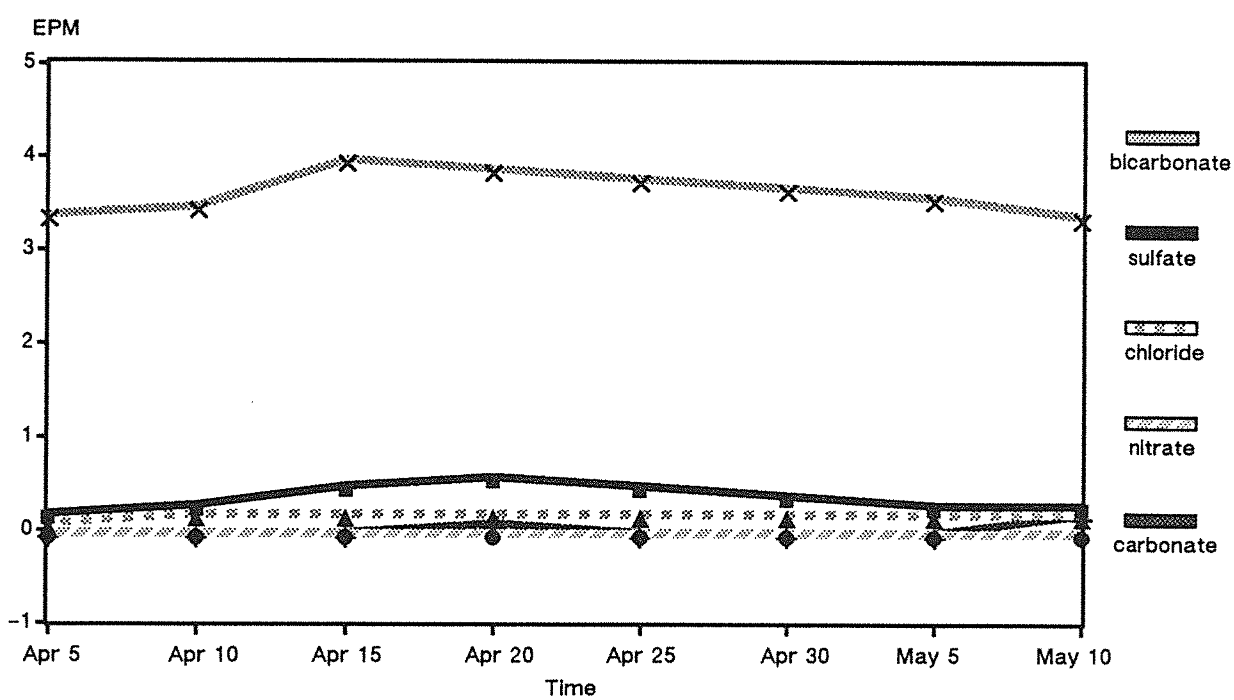

Figure 26. A plot of HCO_3, CO_3, C1, SO_4 and NO_3 versus time following an announced nuclear test conducted on April 10, 1986 from the 05 drift.

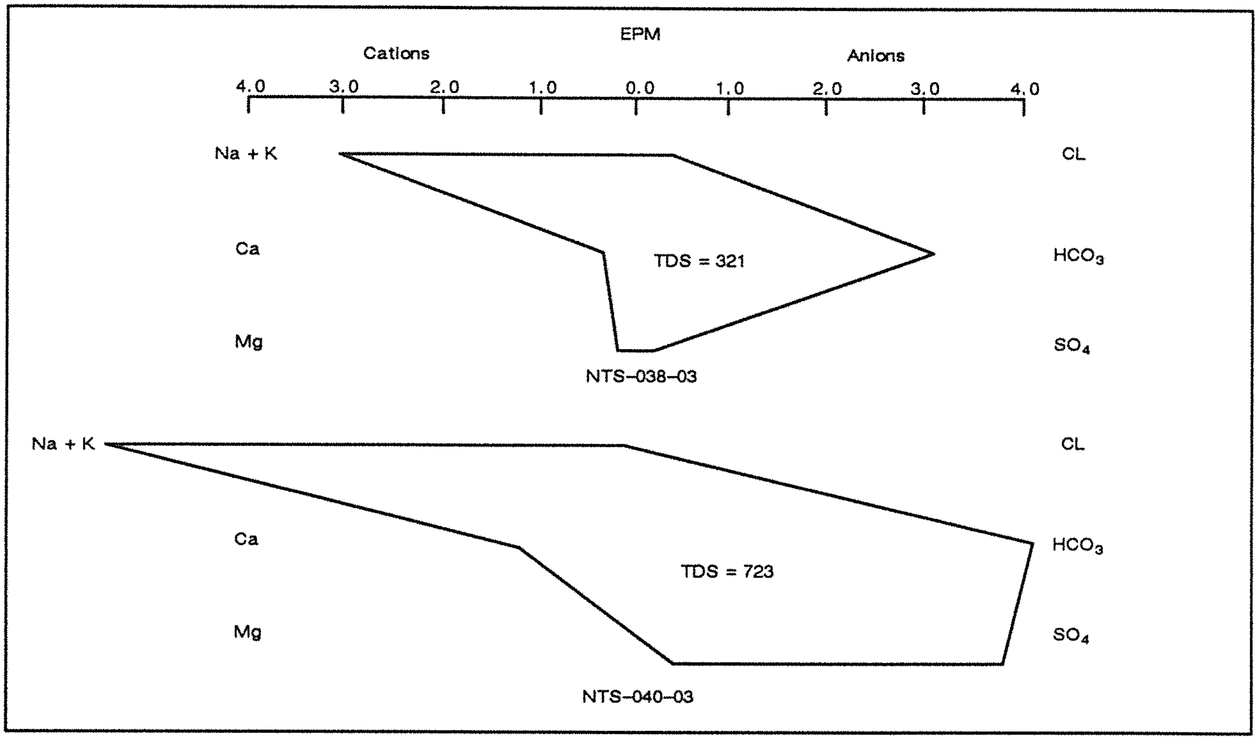

Figure 27. Stiff diagram of before and after the April 6, 1985 nuclear test.

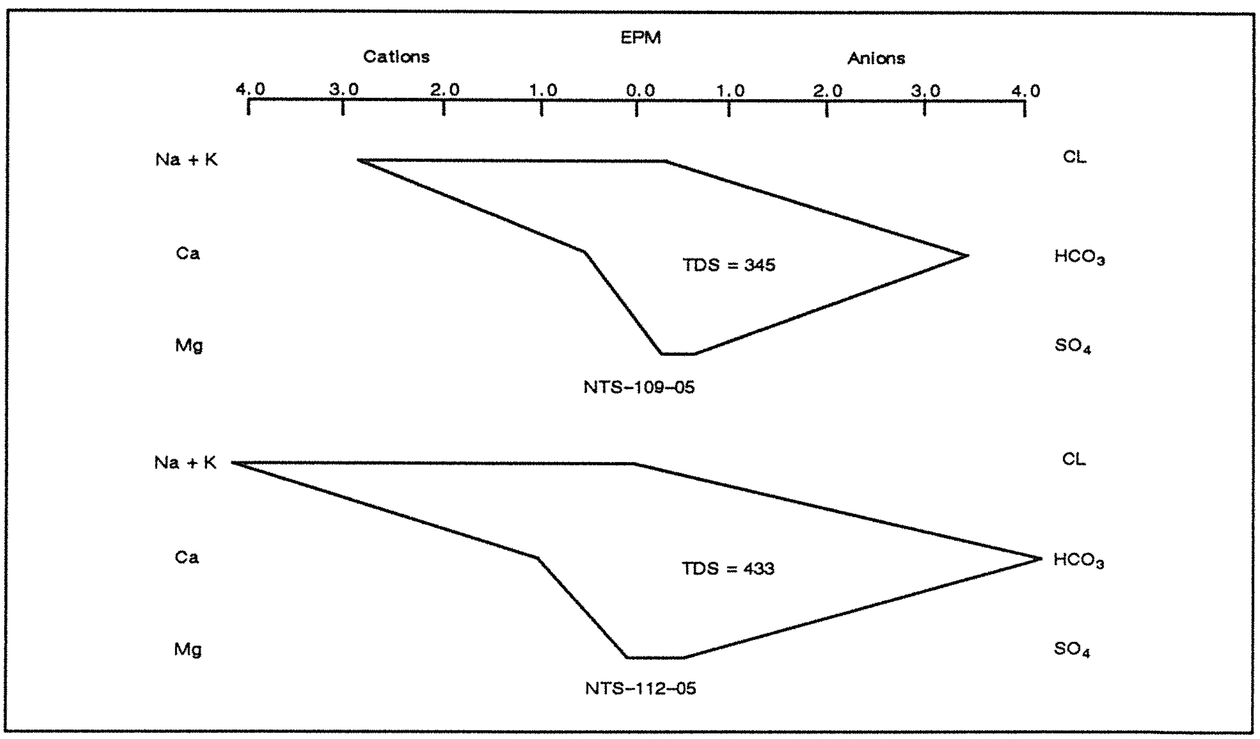

Figure 28. Stiff diagram of before and after the April 10, 1986 nuclear test.

The large component of sulfate for these waters is not characteristic of fracture water (Figures 18 and 19). However, the presence of lenses of gypsum have been found within the bedded tuffs and probably accounts for the high sulfate component. Another hypothesis noted by White *et al.* (1980) is the presence of a relict water high in sulfate which remains from the time of deposition of the formations. The matric permeability is such that interstitial ground water is estimated to reside within the tunnel beds for approximately 20,000 years. This is an extremely short period of time with respect to the age of the formation (approximately 13 million years old) and therefore seems highly unlikely.

If the bomb pulse is derived from interstitial water, then it is possible that simple mixing calculations performed on it should reveal a water that is chemically similar to that of interstitial water. The following variables are used:

Q_1 = pre–bomb pulse discharge,
Q_2 = pulse of discharge attributed to the effects of the nuclear test,
Q_t = total discharge during bomb pulse,
C_1 = species concentration for Q_1,
C_2 = species concentration for Q_2, and
C_t = species concentration for Q_t,

where:

$$Q_t - Q_1 = Q_2$$

and

$$Q_tC_t = Q_1C_1 + Q_2C_2$$

thus,

$$(Q_tC_t - Q_1C_1)/Q_2 = C_2.$$

Only for the April 10, 1986, bomb pulse do the required chemistry and discharge variables exist. From the calculations, Q_1 = 6.82 l/min which is the discharge on April 7, 1986. This value is taken from the 05 discharge in Appendix III. The concentrations of dissolved species for this time are recorded in Table 9 under Column C_1. The total bomb pulse discharge is assumed to peak on April 22, 1986, at Q_t = 8.54 l/min. The concentration of dissolved species for this discharge is listed in Table 9 under Column C_t. Solving for Q_2:

$Q_t - Q_1 = Q_2$, and 8.54 – 6.82 = 1.72 l/min.

Now that Q_1, Q_2, Q_t, C_1 and C_t are known, by substituting in the values for the appropriate variables for each chemical species, the chemical composition of the component of flow contributed solely by the bomb pulse can be calculated. The composition is

TABLE 9. VARIABLES AND RESULTS OF MIXING CALCULATIONS USED TO OBTAIN THE COMPOSITION OF INTERSTITIAL WATER CONTRIBUTED DURING A NUCLEAR TEST AS RECORDED IN THE 05 DRIFT

(Q1 = 6.82 l/min, Q2 = 1.72 l/min, Q3 = 8.54 l/min; all concentrations given in ppm)

Species	C1	C_t	C2
pH	8.31	8.38	8.65
TDS	348	434	775
Bicarbonate	205	241	383
Sulfate	11.5	25.0	78.5
Chloride	8.4	9.9	15.8
Carbonate	0.6	2.4	9.53
Nitrate	0.53	<0.04	<0.04
Silica	51	51	51
Calcium	13.90	17.94	33.90
Magnesium	0.41	0.41	0.41
Sodium	63	79.5	144.9
Potassium	7.68	9.81	31.4

given in Table 9 under the heading C_2. A Stiff diagram for the resultant water is in Figure 29. Included in this figure are two comparative samples #3 and #16 taken by Benson (1976) from vertical drillhole UE12t#2 and UE12t#3 on Rainier Mesa. The calculated C_2 water is somewhat similar to Benson's Sample #3. The increased discharge at the 05 drift seep resulting from the 1986 nuclear test is most likely interstitial waters forced into the fracture system during the test.

The isotopic ratios of both the 03 and 05 drift seeps were taken during the previously discussed nuclear tests. Figures 30 and 31 demonstrate that the isotopic ratios of the discharge associated with nuclear tests consist of enriched trends for both oxygen-18 and deuterium. The record of the test conducted during 1986 is not as complete as that for 1985 due to equipment failure, nor is the isotopic enrichment as great. The primary reason for the decrease in amplitude is the greater relative distance from the 1986 sampling point to the test area as compared to that of the 1985 test.

Since the above changes in the isotopic signatures are quite large, one would have to assume that the interstitial water within Rainier Mesa is different both chemically and isotopically from that of the fracture waters. This is further proof that the increased flow during a bomb pulse is increased interstitial flow caused by a nuclear test.

The mechanism by which the increased interstitial flow is created is easily explained. An underground nuclear test is a strong source of seismic energy. One of the primary products of a test is a seismic P or compressional wave. The P wave increases the stress on a porous medium causing a porosity reduction and forcing out interstitial fluid into a nearby fracture system. This process is reflected in an increase in discharge as well as an increase in concentration of the dissolved ions and an enrichment of the ground-water isotopic composition at the tunnel seep.

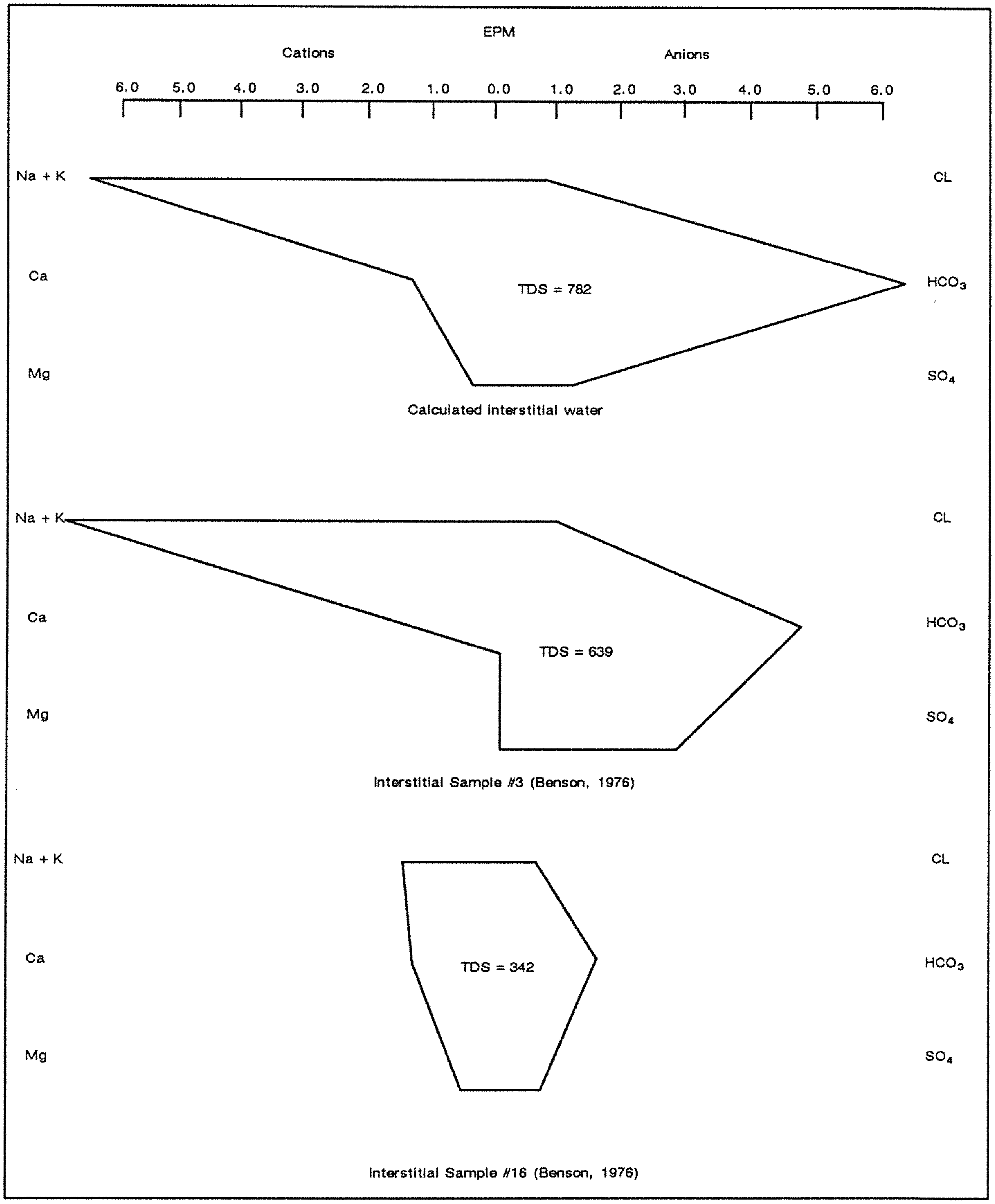

Figure 29. Stiff diagram of a calculated interstitial water from a bomb pulse from U12n.05 drift and two interstitial samples from vertical drillholes above U12t tunnel.

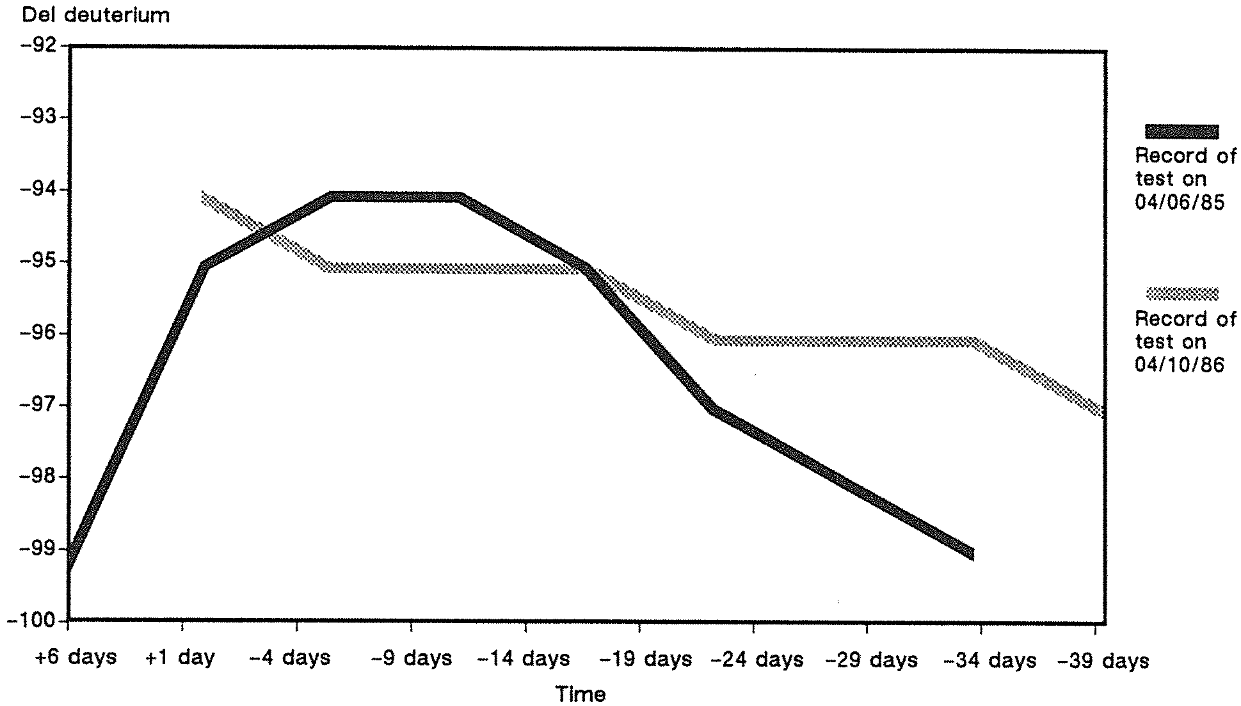

Figure 30. A plot of deuterium versus time following a nuclear test.

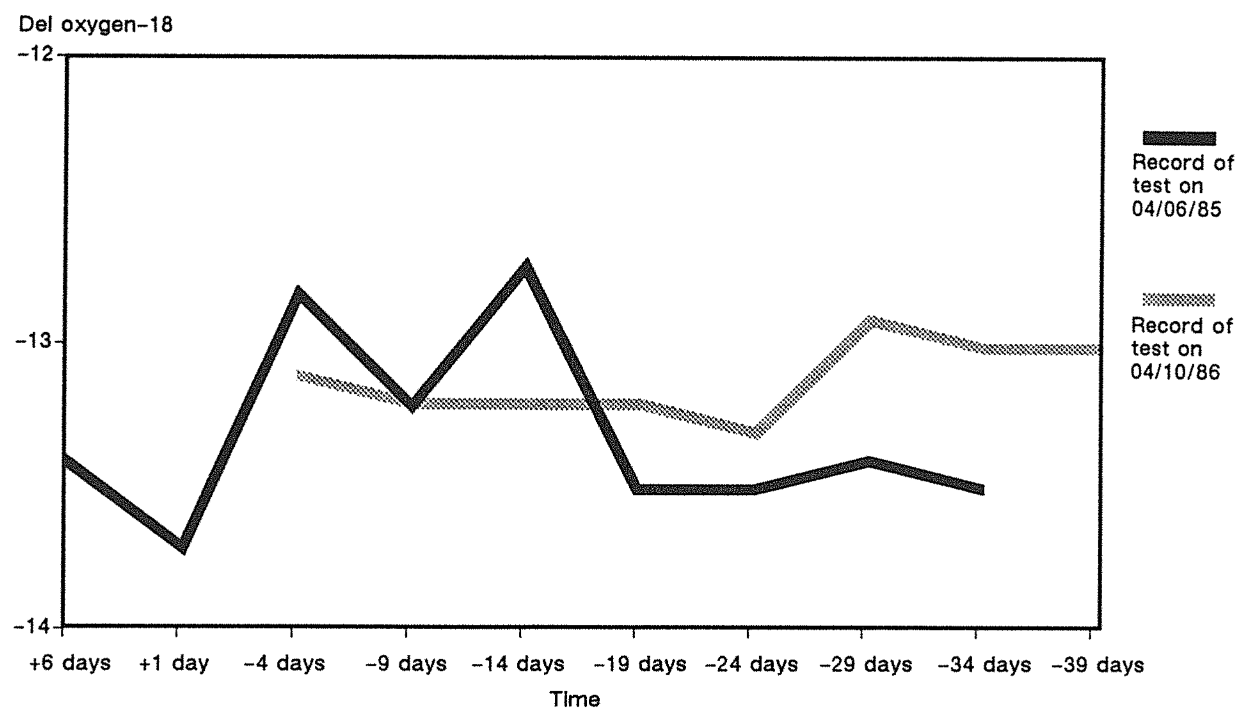

Figure 31. A plot of oxygen-18 versus time following a nuclear test.

SECTION 7
SUMMARY AND CONCLUSIONS

The ground–water regime in Rainier Mesa is conceptualized as rapid fracture flow in the upper welded formations, slower interstitial flow through the bedded tuffs of the Paintbrush Formation, and slow fracture flow through the aquitard created by the highly zeolitized Indian Trail Formation. From this study, it has been ascertained that the source of perched ground water found in Rainier Mesa is of recent meteoric origin and is recharged primarily by late fall to early spring precipitation. An estimated amount of 34,800 $\pm$ 5,300 m^3 of water per year recharge or flow laterally into the U12n recharge basin at an estimated recharge per unit area of 23,700 $\pm$ 3,600 $m^3/yr/km^2$. This recharge estimate suggests that approximately 8% of all precipitation falling on the U12n catchment basin becomes recharge. This estimate includes discharge due to lateral flow to U12n tunnel and should be considered preliminary as the contribution of this flow is unknown. The hydraulic response lag time is at least four months and probably longer. If Clebsch's (1960) estimate is taken into account, then hydraulic residence time is estimated as greater than one year and less than six years. Mixing of ground water between the U12n.03 and U12n.05 fracture systems does not occur to an appreciable degree, and nuclear testing increases local fracture flow and increases the concentration of the total dissolved solids of the water. This is accomplished by a nuclear–generated seismic P wave which forces interstitial water into the fracture system.

These estimates represent an environment which has been subject to nuclear testing for the last 30 years. It is not known if these estimates are representative of a pre–nuclear environment.

The greatest need for further research is on the ground–water travel times for the mesa. Continued monitoring for the dyes and the isotopic signature of the 1985–1986 winter precipitation will help to delineate this parameter. Once travel times are known, the average flow velocities may be calculated.

Continued monitoring of the precipitation and discharge records of the 03 and 05 drift seeps will further validate the estimated period of hydraulic response. A surficial study of the fractionation of precipitation above the 03 and 05 drift fracture systems would delineate what process is responsible for the continued enrichment of the isotopic composition of the 05 drift seep relative to the 03 drift seep. To achieve an improved estimate for the total recharge passing through Rainier Mesa, one could incorporate more discharge points at the other accessible tunnel portals and use these data to arrive at a more accurate estimate.

Finally, the majority of work done on Rainier Mesa has been concentrated above the tunnel level. To understand the hydrologic regime of the mesa, an intensive study program must be concentrated on the tunnel level to the regional ground–water table. Existing drill holes could be tested for ground–water chemistry and hydrogeologic properties of the formations. New drill holes could also be driven where needed to determine the rate of migration of radionuclides from the work points to the regional ground–water table.

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APPENDIX I
Ground-Water Seep Discharge

U12n.03 Discharge (l/min)

day	Sep 1985			Oct 1985			Nov 1985			Dec 1985			Jan 1986			Feb 1986		
	A.M.	noon	P.M.	A.M.	noon	P.M.	A.M.	noon	P.M.	A.M.	noon	P.M.	A.M.	noon	P.M.	A.M.	noon	P.M.
1				3.25	3.25	3.31	2.81	2.81	2.81	3.08	3.08	3.98	2.71	2.66	2.66	2.66	2.61	2.71
2				3.25	3.31	2.25	2.81	2.81	2.81	3.08	3.08	3.08	2.66	2.61	2.61	2.71	2.71	2.66
3				2.25	3.31	3.36	2.81	2.81	2.81	3.08	3.08	3.08	2.61	2.61	2.61	2.61	2.61	2.61
4				3.36	3.31	3.31	2.81	2.81	2.81	3.08	3.08	3.08	2.61	2.61	2.61	2.61	2.61	2.61
5				3.31	3.31	3.31	2.81	2.81	2.81	3.14	3.25	3.36	2.61	2.61	2.61	2.61	2.61	2.61
6				3.31	3.31	3.31	2.81	2.81	2.81	3.19	3.25	3.19	2.61	2.61	2.61	2.61	2.61	2.61
7				3.31	3.31	3.31	2.81	2.86	2.86	3.19	3.19	3.14	2.61	2.56	2.56	2.61	2.61	2.61
8				3.31	3.31	3.31	2.86	2.86	2.92	3.19	3.19	3.19	2.56	2.56	2.61	2.66	2.66	2.66
9				3.31	3.31	3.31	2.92	2.92	2.92	3.14	3.14	3.14	2.61	2.66	2.66	2.61	2.61	2.61
10				3.31	3.31	3.31	2.92	2.92	2.92	3.14	3.14	3.14	2.61	2.61	2.61	2.61	2.61	2.61
11				3.31	3.31	3.31	2.97	2.97	3.03	3.14	3.14	3.14	2.61	2.61	2.61	2.61	2.56	2.56
12				3.31	3.31	3.31	2.97	2.97	2.92	3.08	3.08	3.08	2.61	2.66	2.66	2.56	--	2.86
13				3.31	3.31	3.31	2.92	2.92	2.92	3.08	3.08	3.08	2.66	2.61	2.66	2.66	2.61	2.56
14				3.31	3.31	3.31	2.92	2.92	2.92	3.03	3.03	3.03	2.71	2.76	2.81	2.56	2.61	2.66
15				3.31	3.31	3.31	2.92	2.92	2.97	3.08	3.08	3.03	2.81	2.76	2.71	2.81	2.76	2.71
16				3.31	3.31	3.31	2.97	2.97	3.03	2.97	2.97	2.97	2.66	2.97	2.81	2.61	2.56	2.56
17				3.31	3.31	3.31	3.03	3.08	3.08	2.92	2.92	2.97	2.71	2.66	2.61	2.56	2.56	2.56
18				3.31	3.31	3.31	3.03	3.03	2.97	2.97	2.97	2.97	2.56	2.56	2.61	2.56	2.56	2.56
19				3.31	3.31	3.31	2.97	2.97	2.97	2.97	2.97	2.97	2.61	2.61	2.61	2.56	2.56	2.56
20				3.31	3.31	3.31	2.97	3.03	3.08	2.92	2.92	2.92	2.66	2.92	2.92	2.56	2.56	2.56
21				3.31	3.31	3.31	3.08	3.08	3.08	2.92	2.92	2.92	2.81	2.76	2.71	2.51	2.51	2.56
22				3.31	2.61	2.61	3.08	3.08	3.08	2.92	2.92	2.92	2.66	2.61	2.76	2.56	2.56	2.56
23				2.61	2.61	2.66	3.08	3.08	3.08	2.92	2.92	2.86	2.61	2.61	2.61	2.56	2.56	2.61
24				2.66	2.66	2.66	3.08	3.08	3.08	2.86	2.86	2.86	2.61	2.61	2.61	2.61	2.56	2.56
25				2.66	2.71	2.71	3.14	3.14	3.14	2.86	2.86	2.86	2.61	2.56	2.61	2.61	2.61	2.61
26				2.71	2.71	2.71	3.14	3.14	3.14	2.86	2.86	2.86	2.61	2.61	2.61	2.56	2.56	2.56
27		3.54	3.19	2.71	2.76	2.76	3.08	3.03	3.03	2.86	2.81	2.81	2.66	2.66	2.66	2.56	2.56	2.56
28	3.25	3.25	3.25	2.76	2.76	2.76	3.08	3.08	3.08	2.76	2.81	2.81	2.66	2.71	2.71	2.61	2.61	2.61
29	3.19	3.19	3.14	2.76	2.76	2.76	3.14	3.14	3.14	2.76	2.76	2.76	2.66	2.66	2.71			
30	3.19	3.25	3.25	2.76	2.81	2.81	3.14	3.14	3.08	2.76	2.76	2.86	2.71	2.71	2.71			
31				2.81	2.81	2.81				2.81	2.76	2.71	2.66	2.66	2.66			

day	Mar 1986			Apr 1986			May 1986			Jun 1986			Jul 1986			Aug 1986		
	A.M.	noon	P.M.	A.M.	noon	P.M.	A.M.	noon	P.M.	A.M.	noon	P.M.	A.M.	noon	P.M.	A.M.	noon	P.M.
1	2.76	2.71	2.66	3.19	3.19	3.19	2.71	2.71	2.71	2.61	2.61	2.61	--	2.36	2.41	2.36	2.51	2.51
2	2.61	2.61	2.61	3.19	3.19	3.19	2.71	2.71	2.71	2.61	2.56	2.56	2.36	2.36	2.61	2.51	2.46	2.51
3	2.56	2.51	2.51	3.25	3.25	3.19	2.71	2.71	2.76	2.56	2.61	2.56	2.61	2.51	2.41	2.51	2.51	2.51
4	2.51	2.51	2.51	3.14	3.08	3.08	2.76	2.71	2.71	2.56	2.61	2.61	2.41	2.36	2.36	2.51	2.32	2.27
5	2.51	2.51	2.51	3.08	3.19	3.19	2.71	2.71	2.71	2.61	2.76	2.71	2.36	2.36	2.36	2.22	2.27	2.22
6	2.51	2.51	2.51	3.19	3.14	3.08	2.92	2.86	2.86	2.66	2.61	2.61	2.36	2.36	2.36	2.18	2.13	2.13
7	2.51	2.56	2.56	3.08	3.08	3.03	2.81	2.81	2.76	2.66	2.71	2.71	2.36	2.36	2.36	2.13	2.09	2.13
8	2.56	2.61	2.61	3.03	3.08	3.08	2.76	2.71	2.66	2.66	2.61	2.61	2.36	2.36	2.41	2.13	2.13	2.18
9	--	--	--	3.08	3.19	3.25	2.66	2.61	2.97	2.61	2.61	2.61	2.41	2.41	2.41	2.18	2.18	2.18
10	--	--	--	3.25	3.67	5.80	2.97	3.08	3.08	2.61	2.61	2.66	2.41	2.41	2.41	2.13	2.13	2.13
11	--	3.42	3.25	4.18	3.31	3.03	3.03	2.97	3.03	2.66	2.61	2.61	2.41	2.41	2.41	2.27	2.22	2.27
12	3.25	3.19	3.19	2.86	2.81	2.81	3.03	3.03	3.03	2.61	2.61	2.61	2.41	2.36	2.36	2.18	2.13	2.13
13	3.14	3.14	3.19	2.76	2.71	2.71	3.03	3.03	3.08	2.61	2.61	2.56	2.41	2.41	2.41	2.13	2.13	2.13
14	3.19	3.14	3.14	2.71	2.71	2.71	3.08	3.08	3.08	2.56	2.56	2.56	2.41	2.41	2.36	2.13	2.13	2.13
15	3.31	3.31	3.31	2.71	2.71	2.76	3.08	3.08	3.08	2.61	2.76	2.81	2.36	2.36	2.36	2.13	2.18	2.13
16	3.25	3.19	3.19	2.76	2.76	2.76	2.61	2.61	2.51	2.76	2.71	2.66	2.36	2.36	2.36	2.13	--	2.41
17	3.19	3.19	3.14	2.76	2.71	2.71	2.51	2.51	2.51	2.61	2.61	2.81	2.36	2.36	2.51	2.31	2.27	2.27
18	3.14	3.14	3.08	2.71	2.71	2.71	2.56	2.56	2.56	2.86	2.86	2.86	2.46	2.41	2.36	2.22	2.18	2.18
19	3.08	3.08	3.08	2.71	2.71	2.71	2.56	2.56	2.61	--	--	--	2.36	2.36	2.32	2.13	2.18	2.32
20	3.08	3.14	3.14	2.71	2.71	2.76	2.61	2.61	2.66	--	--	--	2.32	2.32	2.36	2.32	2.27	2.27
21	3.14	3.14	3.19	2.76	2.76	2.81	2.66	2.66	2.66	--	--	--	2.36	2.36	2.36	2.18	2.18	2.18
22	3.19	3.25	3.25	2.81	2.97	2.92	2.71	2.71	2.66	--	--	--	2.36	2.36	2.36	2.18	2.18	2.18
23	3.19	3.25	3.31	2.86	2.81	2.81	2.61	2.61	2.61	--	--	--	2.36	2.32	2.32	2.18	2.18	2.18
24	3.25	3.25	3.19	2.81	2.76	2.76	2.61	2.56	2.56	--	--	--	2.32	2.36	2.36	2.18	2.18	2.18
25	3.14	3.08	3.08	2.76	2.76	2.81	2.56	2.56	2.61	--	--	--	2.36	2.36	2.36	2.13	2.13	2.18
26	3.08	3.14	3.19	2.81	2.76	2.76	2.61	2.61	2.61	--	--	--	2.36	2.36	2.36	2.18	2.22	2.18
27	3.19	3.19	3.14	2.71	2.71	2.71	2.61	2.61	2.71	--	--	--	2.36	2.36	2.36	2.13	2.13	2.13
28	3.14	3.14	3.19	2.71	2.76	2.76	2.66	2.66	2.61	--	--	--	2.36	2.36	2.51	2.13	2.18	2.18
29	3.19	3.19	3.14	2.76	2.76	2.71	2.61	2.56	2.56	--	--	--	2.56	2.46	2.41	2.18	2.18	2.22
30	3.14	3.14	3.14	2.71	2.71	2.71	2.61	2.61	2.61	--	--	--	2.36	2.36	2.36	2.18	2.18	2.18
31	3.14	3.19	3.19				2.56	2.56	2.61				2.36	2.36	2.36	2.18	2.18	2.18

day	Sep 1986		
	A.M.	noon	P.M.
1	2.18	2.18	2.18
2	2.18	2.18	2.36
3	2.31	2.22	--
4	--	--	--
5	--	2.27	

U12n.05 Discharge (l/min)

day	Dec 1985 A.M.	Dec 1985 noon	Dec 1985 P.M.	Jan 1986 A.M.	Jan 1986 noon	Jan 1986 P.M.	Feb 1986 A.M.	Feb 1986 noon	Feb 1986 P.M.	Mar 1986 A.M.	Mar 1986 noon	Mar 1986 P.M.	Apr 1986 A.M.	Apr 1986 noon	Apr 1986 P.M.	May 1986 A.M.	May 1986 noon	May 1986 P.M.
1				5.25	5.25	5.25	5.10	5.10	5.10	5.40	5.40	5.48	6.56	6.38	6.38	7.09	7.09	7.09
2				5.25	5.25	4.88	5.10	5.17	5.17	5.48	5.48	5.48	6.38	6.38	6.30	7.09	7.09	7.09
3				4.73	4.66	4.52	5.17	5.17	5.32	5.48	5.48	5.48	6.13	6.64	6.82	7.37	7.09	7.09
4		4.66	4.66	4.45	4.45	4.45	5.32	5.32	5.32	5.48	5.48	5.48	6.91	6.91	7.00	7.09	7.09	7.09
5	5.10	5.10	5.02	4.45	4.45	4.45	5.32	5.32	5.32	5.17	5.25	5.32	7.00	6.91	6.91	7.18	7.00	7.00
6	5.02	5.02	5.02	4.45	4.45	4.45	5.32	5.32	5.32	5.40	5.70	5.48	6.91	16.91	6.91	7.00	7.00	--
7	5.02	5.02	5.02	4.88	4.80	5.02	5.40	5.40	5.48	5.48	5.56	5.56	6.91	16.82	6.82	--	--	--
8	5.10	5.17	5.25	5.17	4.88	4.73	5.48	5.56	5.64	5.64	5.64	5.72	6.82	6.82	6.82	--	--	--
9	5.25	5.25	5.17	4.59	4.80	5.10	5.72	5.80	5.80	5.72	5.80	5.80	6.82	6.82	6.82	--	7.37	7.37
10	5.17	5.17	5.17	5.17	5.17	5.25	5.80	5.40	5.56	5.88	5.88	5.96	7.18	0.27	10.85	7.37	7.37	7.37
11	5.17	5.10	5.10	5.25	5.32	5.32	5.56	5.48	5.48	5.96	6.04	6.04	10.73	0.16	10.27	7.37	7.37	7.37
12	5.02	5.10	5.10	5.32	5.32	5.25	5.56	5.56	5.56	6.47	6.91	7.09	9.93	9.82	9.71	7.27	7.27	7.27
13	5.10	5.10	5.17	5.25	5.25	5.32	5.56	5.56	5.56	7.18	7.27	7.37	9.60	9.49	9.38	7.27	7.37	7.37
14	5.17	5.17	5.17	5.32	5.40	5.17	5.56	5.56	5.56	7.56	7.46	7.46	9.38	9.28	8.75	7.37	7.18	7.09
15	5.17	5.17	5.10	488	4.80	4.73	5.56	5.56	5.56	7.09	6.82	6.47	8.75	8.95	8.96	7.09	7.18	7.18
16	5.10	5.10	5.10	4.95	5.17	5.25	5.56	5.56	5.56	6.38	6.38	6.38	8.96	8.85	8.85	7.37	7.37	7.46
17	5.17	5.17	5.10	5.32	5.40	5.40	5.56	5.56	5.56	6.38	6.38	6.38	8.85	8.85	8.85	7.46	7.46	7.46
18	5.10	5.10	5.10	5.40	5.40	5.40	5.56	5.56	5.56	6.38	6.38	6.38	8.85	8.75	8.75	7.46	7.46	7.56
19	5.02	5.02	5.02	5.40	5.40	5.40	5.56	5.56	5.56	6.38	6.47	6.47	8.75	8.75	8.75	7.56	7.56	7.56
20	5.10	5.10	5.10	5.40	5.40	5.40	5.56	5.56	5.56	6.30	6.04	6.04	8.75	8.64	8.64	7.56	7.56	7.56
21	5.10	5.10	5.17	5.40	5.40	5.32	5.56	5.56	5.56	6.04	6.13	6.13	8.64	8.64	8.64	7.56	7.56	7.56
22	5.17	5.17	5.17	5.32	5.32	5.25	5.56	5.56	5.56	6.21	6.30	6.30	8.54	8.54	8.64	7.56	7.37	7.27
23	5.17	5.17	5.17	5.25	5.25	5.25	5.56	5.56	5.56	6.30	6.38	6.38	8.75	8.75	8.75	7.27	7.37	7.37
24	5.17	5.25	5.25	5.17	5.17	5.17	5.56	5.17	5.25	6.38	6.38	6.38	8.75	8.54	8.54	7.37	7.37	7.37
25	5.25	5.25	5.25	4.80	4.31	4.24	5.32	5.40	5.40	6.91	7.00	7.00	8.54	8.44	7.94	7.37	7.37	7.37
26	5.25	5.25	5.25	4.24	4.24	4.24	5.40	5.40	5.25	7.00	7.09	7.09	7.84	7.75	7.65	7.37	7.37	7.37
27	5.25	5.25	5.25	4.24	4.24	4.24	5.32	5.40	5.40	7.18	7.18	7.18	7.56	7.46	7.46	7.37	7.37	7.37
28	5.25	5.32	5.32	4.59	4.80	4.88	5.40	5.40	5.40	7.18	7.18	7.18	7.37	7.37	7.27	7.37	7.27	7.27
29	5.32	5.32	5.32	4.95	5.02	5.02				7.18	7.18	7.18	7.27	7.18	7.18	7.27	7.27	7.27
30	5.32	5.32	5.32	5.10	5.10	5.10				7.18	7.27	7.27	7.18	7.18	7.18	7.27	7.27	7.18
31	5.25	5.25	5.25	5.10	5.10	5.10				7.27	7.18	7.09				7.18	7.18	7.18

day	Jun 1986 A.M.	Jun 1986 noon	Jun 1986 P.M.	Jul 1986 A.M.	Jul 1986 noon	Jul 1986 P.M.	Aug 1986 A.M.	Aug 1986 noon	Aug 1986 P.M.	Sep 1986 A.M.	Sep 1986 noon	Sep 1986 P.M.
1	7.18	7.18	7.18	9.38	9.38	9.38	10.05	10.05	10.05	9.38	9.38	9.38
2	7.18	7.18	7.18	9.49	9.49	9.49	10.05	10.05	10.05	9.38	9.17	9.17
3	7.18	7.18	7.18	9.49	9.49	9.49	10.05	10.05	10.05	9.17	9.17	9.17
4	7.18	7.18	7.27	9.49	9.49	9.49	10.05	10.05	10.05	9.17	9.17	9.17
5	7.27	7.37	7.37	9.49	9.49	9.60	10.05	10.05	10.05	9.17	9.17	
6	7.37	7.46	7.46	9.60	9.60	9.60	10.05	10.05	10.05			
7	7.46	7.46	7.46	9.60	9.60	9.60	10.05	10.05	10.05			
8	7.46	7.46	7.46	9.60	9.60	9.60	10.05	10.05	10.05			
9	7.46	7.46	7.46	9.60	9.60	9.60	10.05	10.05	10.05			
10	7.46	7.46	7.46	9.60	9.60	9.60	10.05	10.05	10.05			
11	7.46	7.46	7.46	9.60	9.71	9.71	10.05	10.05	10.05			
12	7.56	7.56	7.56	9.71	9.71	9.71	10.05	10.05	10.05			
13	7.56	7.75	7.75	9.71	9.71	9.82	10.05	10.05	10.05			
14	7.84	7.84	7.84	9.82	9.93	9.93	9.82	9.49	9.38			
15	7.94	7.94	7.94	9.93	9.93	9.93	9.28	9.17	9.17			
16	8.04	8.04	8.04	9.93	9.93	9.93	9.17	12.45	8.96			
17	8.04	8.04	10.39	9.93	9.93	10.16	8.64	8.44	8.34			
18	9.82	9.60	9.38	10.16	10.16	10.16	8.34	8.34	8.44			
19	9.17	8.96	8.96	10.16	10.16	10.05	8.44	8.44	8.54			
20	9.06	9.17	9.17	10.05	10.05	10.05	8.85	9.06	9.17			
21	9.17	9.17	9.17	10.05	9.93	9.93	8.96	9.06	9.17			
22	9.17	9.17	9.17	9.93	9.93	9.93	9.17	9.28	9.28			
23	9.17	9.17	9.17	9.93	9.93	9.93	9.28	9.38	9.38			
24	9.17	9.17	9.17	10.05	10.05	9.93	9.38	9.38	9.38			
25	9.17	9.17	9.17	9.93	10.05	10.05	9.38	9.49	9.49			
26	9.17	9.17	9.17	10.05	10.05	10.05	9.49	9.49	9.49			
27	9.17	9.17	9.17	10.05	10.05	10.05	9.49	9.49	9.49			
28	9.28	9.28	9.28	10.05	10.05	10.05	9.49	9.49	9.49			
29	9.28	9,28	9.38	10.05	10.05	10.05	9.49	9.38	9.38			
30	9.38	9.38	9.38	10.05	10.05	10.05	9.38	9.38	9.38			
31				10.05	10.05	10.05	9.38	9.38	9.38			

U12n Portal Discharge (l/min)

day	Dec 1985 A.M.	noon	P.M.	Jan 1986 A.M.	noon	P.M.	Feb 1986 A.M.	noon	P.M.	Mar 1986 A.M.	noon	P.M.	Apr 1986 A.M.	noon	P.M.	May 1986 A.M.	noon	P.M.
1					59.21*			61.69			45.57			58.39*			--	
2					119.87			66.84			64.24			57.59*			--	
3					59.21*			65.10			62.53			60.03*			--	
4		55.99*			59.21*			78.87			61.69			60.03*			--	
5		55.99*			59.21*			67.73			62.53			60.03*			--	
6		59.88			65.10			56.78*			61.69			69.51			--	
7		57.59			59.21			55.99			58.39*			65.10			--	
8		54.21*			10.85			52.88*			60.85*			--			--	
9		73.17			63.38			52.88*			56.78*			--			54.42	
10		68.62			73.17			52.88*			65.97			--			53.65	
11		91.05			73.17			56.78			72.24			--			49.88*	
12		55.99*			59.21*			59.21			65.10			--			50.62*	
13		55.20*			59.21*			61.69			72.27			--			54.42	
14		55.20*			75.04			63.38			70.42			--			43.50	
15		83.82			68.62			60.85			66.84*			--			50.62	
16		76.94			80.83			72.24			72.24			--			53.65	
17		58.39*			75.04			65.10			70.42			--			51.36*	
18		54.42			62.53			55.20			75.99			--			51.36*	
19		58.39			61.69			43.50			65.10*			--			56.78	
20		77.90			58.39*			16.28			67.73			--			54.42	
21		58.39*			58.39*			18.23			65.10*			--			52.88	
22		58.39*			63.38			52.12			65.10*			--			54.42	
23		59.21*			61.69			61.69			67.73			--			53.65*	
24		82.82			63.38			59.21			69.51			--			50.62*	
25		69.51			64.24			58.39			68.62			--			50.62*	
26		60.03*			62.53			58.39			67.73			--			50.62*	
27		59.21*			62.83			53.65			66.84			--			53.65*	
28		59.21*			58.39*			42.15			65.10*			--			53.65	
29		59.21*			58.39*						65.10*			--			54.42	
30		59.21*			63.38						63.38*			--			50.62*	
31		59.21*			64.24						63.38*						52.88*	

day	Jun 1986 A.M.	noon	P.M.	Jul 1986 A.M.	noon	P.M.	Aug 1986 A.M.	noon	P.M.	Sep 1986 A.M.	noon	P.M.
1		49.88*			60.85			82.82				
2		57.59*			53.65							
3		55.99*			63.38							
4		54.42			42.82*							
5		51.36			44.87*							
6		67.73			53.65							
7		62.53*			49.14							
8		62.53*			50.62							
9		67.73			49.88							
10		67.73			53.65							
11		64.24			45.57							
12		65.10			42.15							
13		64.24			49.88							
14		55.99*			52.88							
15		50.62*			42.82*							
16		51.36*			42.82*							
17		60.85			42.15*							
18		57.59			42.15*							
19		58.39			42.15*							
20		54.42*			28.44							
21		52.88*			49.14							
22		47.69*			15.18							
23		47.87			31.15*							
24		56.78			32.28*							
25		52.88*			30.60*							
26		53.65*			30.60*							
27		53.65*			31.71*							
28		49.88*			30.05*							
29		49.88*			30.05*							
30		51.36			30.05*							
31					29.51*							

*Denotes just baseflow emanating from U12n tunnel portal.

APPENDIX II
U12n Tunnel Humidity and Temperature

U12n TUNNEL HUMIDITY AND TEMPERATURE

03 Drift

Date taken	Dry Bulb T °C	Wet Bulb T °C	Relative Humidity
07/01/86	17.8	13.9	66%
07/23/86	18.9	16.1	76%
08/01/86	20.6	13.9	49%
08/15/86	18.9	16.1	76%
09/05/86	18.9	14.4	62%
09/18/86	18.3	13.9	61%

05 Drift

Date taken	Dry Bulb T °C	Wet Bulb T °C	Relative Humidity
07/01/86	15.0	11.1	63%
07/23/86	16.1	13.3	73%
08/01/86	15.0	11.1	63%
08/15/86	17.2	13.9	70%
09/05/86	16.7	13.3	74%
09/18/86	15.0	12.2	73%

10 Drift

Date taken	Dry Bulb T °C	Wet Bulb T °C	Relative Humidity
07/01/86	ND	ND	ND
08/01/86	16.9	12.2	59%
08/15/86	18.9	14.4	61%
09/05/86	17.8	15.0	74%
09/18/86	18.3	14.4	66%

Outside

Date taken	Dry Bulb T °C	Wet Bulb T °C	Relative Humidity
07/01/86	30.0	15.0	13%
07/23/86	28.9	19.4	42%
08/01/86	35.5	20.5	25%
08/15/86	31.1	16.7	17%
09/05/86	28.9	15.5	23%
09/18/86	20.5	13.9	47%

APPENDIX III
Rainier Mesa Precipitation Record
January 1983 — January 1986

RAINIER MESA PRECIPITATION RECORD (inches)

day	1983 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.0	0.0	0.0*	0.0	1.14	0.0	0.0	0.0	0.0	1.32	0.0	0.0
2	0.0	0.13	0.0*	0.0	0.03	0.0	0.0	0.0	0.0	0.03	0.0	0.03
3	0.0	0.38	0.0*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.89
4	0.0	0.0*	0.0*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0*	0.0*	0.0	0.05	0.0	0.0	0.61	0.0	0.0	0.0	0.0
6	0.0	0.0*	0.0*	0.0	0.0	0.0	0.0	0.0*	0.0	0.0	0.0	0.0
7	0.0	0.0*	0.0*	0.0	0.0	0.0	0.0	0.0*	0.0	0.0	0.0	0.0
8	0.0	0.0*	0.0*	0.0	0.0	0.0	0.0	0.0*	0.0	0.0	0.0	0.0
9	0.0	0.0*	0.0	0.0	0.0	0.0	0.0	0.0*	0.0	0.0	0.0	0.0
10	0.0	0.0*	0.0	0.0	0.0	0.0	0.0	0.76	0.0	0.0	0.0	0.05
11	0.0	0.0*	0.0	1.30	1.0	0.0	0.0	0.03	0.0	0.0	0.0	0.0
12	0.0	0.0*	0.0*	0.15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0*	0.0*	0.0*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0*	0.0*	0.0*	0.0	0.0	0.0	0.43	0.0	0.0	0.0	0.0
15	0.0	0.0*	0.0*	0.0*	0.0	0.0	0.0	0.15	0.0	0.0	0.0	0.0
16	0.81	0.0*	0.0*	0.0*	0.0	0.0	0.0	3.02	0.0	0.0	0.0	0.0
17	0.18	0.0*	0.0*	0.0*	0.0	0.0	0.0	0.56	0.0	0.0	0.03	0.0
18	0.0	0.0*	0.0*	0.0*	0.0	0.0	0.0	0.0*	0.0	0.0	0.0	0.0
19	1.04	0.0*	0.0*	0.0*	0.0	0.0	0.0	0.0*	0.0	0.0	0.0	0.0
20	0.0	0.0*	0.0*	0.0*	0.0	0.0	0.0	0.0	0.0	0.0	0.68	0.0
21	0.0	0.0*	0.0*	0.0*	0.0	0.0	0.0	0.0*	0.0	0.0	0.0	0.0
22	0.33	0.0*	0.0*	0.0*	0.0	0.0	0.0	0.0*	0.0	0.0	0.0	0.0
23	0.08	0.0*	0.0*	0.08	0.0	0.0	0.0	0.0*	0.0	0.0	0.0	0.0
24	0.86	0.0*	0.0*	0.0*	0.0	0.0	0.0	0.0*	0.0	0.0	1.45	0.81
25	0.0	0.0*	0.0*	0.0*	0.0	0.0	0.0	0.0	0.28	0.0	0.13	2.01
26	0.0	0.0*	0.0*	0.0*	0.0	0.0	0.0	0.0	1.52	0.0	0.0	0.20
27	1.35	0.0*	0.0*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0*	0.0*	0.0	0.0	0.0	0.0	0.0	0.05	0.0	0.0	0.0
29	2.82		0.0*	0.0	0.0	0.0	0.0	0.0	0.83	0.0	0.0	0.0
30	0.0		0.0*	0.84	0.0	0.0	0.0	0.0	0.91	0.0	0.0	0.0
31	0.0		0.0*		0.0		0.0	0.0		0.0		0.0

day	1984 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.0	0.0	0.0	0.51	0.0	0.0	0.0	0.0	0.25	1.32	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	1.12	0.0	0.30	0.03	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.41	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.08	1.10
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.58	0.0	0.0	0.0	0.0	0.0	0.03	0.0	0.0	0.0	0.18
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.03	0.0	0.0	0.23
12	0.08	0.0	0.0	0.0	0.0	0.0	0.03	0.0	0.0	0.0	0.0	0.15
13	0.0	0.0	0.0	0.0	0.0	0.0	0.13	0.0	0.0	0.0	0.15	0.0
14	0.0	0.07	0.0	0.0	0.0	0.15	0.03	1.42	0.0	0.0	0.0	0.0
15	0.0	0.0	0.08	0.0	0.0	0.0	0.25	1.01	0.0	0.0	0.0	0.71
16	0.0	0.41	0.0	0.0	0.0	0.0	0.08	0.05	0.46	0.0	0.0	1.57
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.33	0.10	0.0	0.0	0.13
18	0.0	0.0	0.0	0.0	0.0	0.0	0.23	0.18	0.81	0.0	0.0	0.71
19	0.0	0.0	0.0	0.13	0.0	0.0	1.63	0.76	0.0	0.0	0.0	0.0*
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.23	0.30	0.0	0.0	0.0*
21	0.05	0.0	0.0	0.0	0.0	0.0	0.23	0.03	0.0	0.0	0.23	0.0*
22	0.0	0.0	0.0	0.0	0.0	0.0	1.90	0.0	0.0	0.0	2.36	0.0*
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.02	0.0*
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.07	0.0*
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.46	0.0	0.0	0.0	0.0*
26	0.0	0.0	0.0	0.0	0.0	0.0	0.46	0.0	0.0	0.0	0.0	0.0*
27	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.0	0.0	0.0	0.0	0.0*
28	0.0	0.0	0.0	0.0	0.0	0.0	0.66	0.0	0.0	0.0	0.0	0.0*
29	0.0		0.10	0.0	0.0	0.0	0.03	0.0	0.0	0.0	0.0	0.0*
30	0.0		0.0	0.0	0.0	0.0	0.18	0.0	0.0	0.0	0.0	0.0*
31	0.0		0.10		0.0		0.48	0.0	0.05	0.0		0.0*

*Denotes estimated record.

RAINIER MESA PRECIPITATION RECORD (inches)

1985

day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.0*	0.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0*	0.20	0.18	0.0	0.0	0.10	0.0	0.0	0.0	0.0	0.0	0.86
3	0.0*	0.05	0.0	0.0	0.0	0.99	0.0	0.0	0.0	0.0	0.0	0.25
4	0.0*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0*	0.0	0.0	0.0	0.0	0.0	0.05	0.0	0.0	0.15	0.0	0.0
7	0.0*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.25	0.0	0.0
8	0.0*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.05	0.0	0.0
9	0.0*	0.0*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0*	0.0*	0.0	0.0	0.48	0.0	0.0	0.0	0.0	0.13	0.0	0.22
11	0.0*	0.0	0.20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.33	0.0
12	0.0*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.26	0.0
13	0.0*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.41	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	1.04	0.0	0.0	0.0	0.71	0.0	0.94	0.0	0.0	0.0
19	0.0	0.0	0.05	0.0	0.0	0.0	2.21	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	1.65	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.05	0.0	0.0	0.13	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.41	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.10	0.0	0.0	0.0	0.0	0.20	0.0
25	0.05	0.0	0.0	0.05	0.0	0.0	0.0	0.0	0.28	0.0	0.48	0.0
26	0.51	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.52	0.0	0.0	0.03
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.53	0.0	0.0	0.03
28	0.05	0.0	0.15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.03
29	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.94	0.03
30	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.05	0.03
31	0.0		0.0		0.0		0.0	0.0		0.0		0.03

1986

day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.0	0.0	0.0	0.03	0.0	0.0						
2	0.0	0.0	0.10	0.0	0.0	0.0						
3	0.0	0.13	0.0	0.0	0.0	0.0						
4	0.0	0.0	0.0	0.0	0.13	0.0						
5	0.08	0.0	0.0	0.0	0.0	0.0						
6	0.36	0.0	0.0	0.96	0.23	0.0						
7	0.0	0.0	0.0	0.33	0.0	0.0						
8	0.0	0.0	0.51	0.18	0.0	0.0						
9	0.0	0.0	0.0	0.0	0.0	0.0						
10	0.0	0.0	1.12	0.0	0.0	0.0						
11	0.0	0.0	0.10	0.0	0.0	0.0						
12	0.0	0.03	0.0	0.0	0.0	0.0						
13	0.0	0.28	0.76	0.0	0.0	0.0						
14	0.0	1.70	0.03	0.0	0.0	0.0						
15	0.0	1.50	0.79	0.0	0.0	0.0						
16	0.0	0.0	0.94	0.05	0.0	0.0						
17	0.0	0.0	0.13	0.0	0.0	0.0						
18	0.0	0.0	0.0	0.0	0.0	0.0						
19	0.0	0.10	0.0	0.0	0.0	0.0						
20	0.0	0.0	0.0	0.0	0.0	0.0						
21	0.0	0.0	0.0	0.0	0.0	0.0						
22	0.0	0.0	0.0	0.0	0.0	0.0						
23	0.0	0.0	0.0	0.0	0.0	0.0						
24	0.0	0.0	0.0	0.0	0.0	0.0						
25	0.0	0.0	0.0	0.0	0.0	0.0						
26	0.0	0.0	0.0	0.0	0.0	0.0						
27	0.0	0.0	0.0	0.0	0.0	0.0						
28	0.0	0.0	0.0	0.0	0.0	0.0						
29	0.0		0.03	0.0	0.0	0.0						
30	2.72		0.0	0.0	0.0	0.0						
31	0.25		0.08		0.0							

*Denotes estimated record.

APPENDIX IV
U12N Tunnel Dye Receptor and Tritium Concentration

U12n TUNNEL DYE RECEPTOR AND TRITIUM CONCENTRATION

Rainier Mesa Dye Receptors

Sample No.	Date Taken	Dates Represented	Results
NTS-B01-03	08/08/84	08/08/84 and previous	negative
NTS-B02-03	08/30/84	08/08/84 to 08/30/84	negative
NTS-B03-03	10/25/84	08/30/84 to 10/25/84	negative
NTS-B04-03	12/06/84	10/25/84 to 12/06/84	negative
NTS-B05-03	01/03/85	12/06/84 to 01/03/85	negative
NTS-B06-03	02/22/85	01/03/85 to 02/22/85	negative
NTS-B07-03	03/26/85	02/22/85 to 03/26/85	negative
NTS-B08-03	05/01/85	03/26/85 to 05/01/85	negative
NTS-B09-03	06/04/85	05/01/85 to 06/04/85	negative
NTS-B10-03	07/19/85	no bug found	-----
NTS-B11-03	10/22/85	07/19/85 to 10/22/85	negative
NTS-B12-03	11/22/85	10/22/85 to 11/22/85	negative
NTS-B13-03	12/11/85	11/22/85 to 12/11/85	negative
NTS-B14-03	01/02/86	12/11/85 to 01/02/86	negative
NTS-B15-03	charcoal bug terminated		
NTS-B01-05	08/30/84	08/30/84 and previous	negative
NTS-B02-05	10/25/84	08/30/84 to 10/25/84	negative
NTS-B03-05	12/06/84	10/25/84 to 12/06/84	negative
NTS-B04-05	01/03/85	12/06/84 to 01/03/85	negative
NTS-B05-05	02/22/85	01/03/85 to 02/22/85	negative
NTS-B06-05	03/26/85	02/22/85 to 03/26/85	negative
NTS-B07-05	05/01/85	no bug found	-----
NTS-B08-05	06/04/85	05/01/85 to 06/04/85	negative
NTS-B09-05	07/19/85	06/04/85 to 07/19/85	negative
NTS-B10-05	10/22/85	07/19/85 to 10/22/85	negative
NTS-B11-05	11/22/85	10/22/85 to 11/22/85	negative
NTS-B12-05	12/11/85	11/22/85 to 12/11/85	negative
NTS-B13-05	01/02/86	12/11/85 to 01/02/86	negative
NTS-B14-05	charcoal bug terminated		
NTS-B01-10	06/28/84	06/28/84 and previous	negative
NTS-B02-10	08/30/84	06/28/84 to 08/30/84	negative
NTS-B03-10	10/25/84	no bug found	-----
NTS-B04-10	12/06/84	10/25/84 to 12/06/84	negative
NTS-B05-10	01/03/85	12/06/84 to 01/03/85	negative
NTS-B06-10	02/22/85	01/03/85 to 02/22/85	negative
NTS-B07-10	03/26/85	02/22/85 to 03/26/85	negative
NTS-B08-10	05/01/85	03/26/85 to 05/01/85	negative
NTS-B09-10	06/04/85	no bug found	-----
NTS-B10-10	07/19/85	06/04/85 to 07/19/85	negative
NTS-B11-10	11/05/85	07/19/85 to 11/05/85	negative
NTS-B12-10	12/11/85	11/05/85 to 12/11/85	negative
NTS-B13-10	01/02/86	12/11/85 to 01/02/86	negative
NTS-B14-10	charcoal bug terminated		

Rainier Mesa Dye Receptors (continued)

Sample No.	Date Taken	Dates Represented	Results
OU12n.031	05/09/86	05/09/86 and previous	negative
OU12n.032	06/04/86	05/09/86 to 06/04/86	negative
OU12n.033	06/13/86	06/03/86 to 06/13/86	negative
OU12n.034	07/01/86	06/13/86 to 07/01/86	negative
OU12n.035	07/23/86	07/01/86 to 07/23/86	negative
OU12n.036	08/01/86	07/23/86 to 08/01/86	negative
OU12n.037	08/15/86	08/01/86 to 08/15/86	negative
OU12n.038	09/05/86	08/15/86 to 09/05/86	negative
OU12n.039	09/18/86	09/05/86 to 09/18/86	negative
OU12n.0310	10/24/86	09/18/86 to 10/24/86	negative
OU12n.0311	12/18/86	10/24/86 to 12/18/86	trace
OU12n.0312	02/05/87	12/18/86 to 02/05/87	negative
OU12n.0313	03/13/87	02/05/87 to 03/13/87	negative
OU12n.0314	04/16/87	03/13/87 to 04/16/87	negative
OU12n.0315	05/07/87	04/16/87 to 05/07/87	negative
OU12n.0316	06/05/87	05/07/87 to 06/05/87	negative
OU12n.0317	07/21/87	06/05/87 to 07/21/87	negative
OU12n.051	05/09/86	05/09/86 and previous	negative
OU12n.052	06/04/86	05/09/86 to 06/04/86	negative
OU12n.053	06/13/86	06/03/86 to 06/13/86	negative
OU12n.054	07/01/86	06/13/86 to 07/01/86	negative
OU12n.055	07/23/86	07/01/86 to 07/23/86	negative
OU12n.056	08/01/86	07/23/86 to 08/01/86	negative
OU12n.057	08/15/86	08/01/86 to 08/15/86	negative
OU12n.058	09/05/86	08/15/86 to 09/05/86	negative
OU12n.059	09/15/86	09/05/86 to 09/18/86	negative
OU12n.0510	10/24/86	09/18/86 to 10/24/86	negative
OU12n.0511	12/18/86	10/24/86 to 12/18/86	negative
OU12n.0512	02/05/87	12/18/86 to 02/05/87	trace
OU12n.0513	03/13/87	02/05/87 to 03/13/87	trace
OU12n.0514	04/16/87	03/13/87 to 04/16/87	trace
OU12n.0515	05/07/87	04/16/87 to 05/07/87	negative
OU12n.0516	06/05/87	05/07/87 to 06/05/87	negative
OU12n.0517	07/21/87	06/05/87 to 07/21/87	trace
OU12n.101	05/09/86	05/09/86 and previous	negative
OU12n.102	06/04/86	05/09/86 to 06/04/86	negative
OU12n.103	06/13/86	06/03/86 to 06/13/86	negative
OU12n.104	07/01/86	06/13/86 to 07/01/86	negative
OU12n.105	07/23/86	07/01/86 to 07/23/86	negative
OU12n.106	08/01/86	07/23/86 to 08/01/86	negative
OU12n.107	08/15/86	08/01/86 to 08/15/86	negative
OU12n.108	09/05/86	08/15/86 to 09/05/86	negative
OU12n.109	09/18/86	09/05/86 to 09/18/86	negative
OU12n.110	missing		
OU12n.111	02/05/87	12/18/86 to 02/05/87	negative

Rainier Mesa Dye Receptors (continued)

Sample No.	Date Taken	Dates Represented	Results
OU12n.112	03/13/87	02/05/87 to 03/13/87	negative
OU12n.113	06/05/87	05/07/87 to 06/05/87	negative
OU12n.P1	05/09/86	05/09/86 and previous	negative
OU12n.P2	06/04/86	05/09/86 to 06/04/86	negative
OU12n.P3	06/13/86	06/03/86 to 06/13/86	negative
OU12n.P4	07/01/86	06/13/86 to 07/01/86	negative
OU12n.P5	07/23/86	07/01/86 to 07/23/86	negative
OU12n.P6	08/01/86	07/23/86 to 08/01/86	negative
OU12n.P7	08/15/86	08/01/86 to 08/15/86	negative
OU12n.P8	09/05/86	08/15/86 to 09/05/86	negative
OU12n.P9	09/18/86	09/05/86 to 09/18/86	negative
OU12e.P1	05/09/86	05/09/86 and previous	negative
OU12e.P2	06/04/86	05/09/86 to 06/04/86	negative
OU12e.P3	06/13/86	06/03/86 to 06/13/86	negative
OU12e.P4	07/01/86	06/13/86 to 07/01/86	negative
OU12e.P5	07/23/86	07/01/86 to 07/23/86	negative
OU12e.P6	08/01/86	07/23/86 to 08/01/86	negative
OU12e.P7	08/15/86	08/01/86 to 08/15/86	negative
OU12e.P8	09/05/86	08/15/86 to 09/05/86	negative
	09/18/86 no sample taken, water could not be reached		

Rainier Mesa Tritium

Sample No.	Date Taken	Tritium Concentration
03T.1	07/01/86	237
05T.1	07/01/86	13000
E. portal	07/01/86	770000
N. portal	07/01/86	690000

APPENDIX V
Ground–Water Chemistry

U12n. 03 Gross Chemistry

Species	NTS-038-03	NTS-039-03	NTS-040-03	NTS-041-03	NTS-042-03	NTS-043-03	NTS-044-03	NTS-045-03	NTS-097-03	NTS-084-03	NTS-095-03
pH	8.42	8.32	8.34	8.36	8.25	8.32	8.43	8.55	8.23	7.66	7.73
sp cond. — (μmhos/cm)	328	812	769	645	620	555	340	333	325	334	328
Anions (in ppm)											
SiO_2	47	45	44	44	44	45	47	46	47	47	48
HCO_3	182	231	236	228	226	215	193	189	191	196	195
CO_3	3.40	0.90	1.30	1.70	ND	0.70	3.00	5.50	ND	ND	ND
Cl	6.60	23.10	16.40	11.50	8.80	8.10	730	6.70	6.60	7.10	6.70
SO_4	15.10	141.00	160.00	120.00	120.00	99.20	14.00	13.80	13.20	11.90	11.10
F	ND*	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
NO_3	1.02	45.20	11.61	3.19	0.09	1.24	<0.04	1.11	1.50	<0.04	<0.04
NO_2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cations (in ppm)											
Na	68.60	131.00	125.00	107.00	96.00	89.20	72.10	70.20	68.60	70.50	70.70
K	5.75	12.30	11.50	9.51	8.77	7.92	5.38	5.35	5.40	6.59	6.44
Ca	5.47	35.30	35.70	31.20	34.10	29.10	6.42	5.84	5.69	5.80	5.69
Mg	0.26	1.28	1.31	1.08	1.00	0.88	0.28	0.25	0.25	0.28	0.27
NH_4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

U12n. 05 Gross Chemistry

Species	NTS-109-03	NTS-110-03	NTS-111-03	NTS-112-03	NTS-113-03	NTS-114-03	NTS-115-03	NTS-116-03	NTS-117-03	NTS-098-05	
pH	8.31	8.22	8.23	8.38	8.26	8.26	8.22	8.52	8.50	7.72	
sp cond. — (μmhos/cm)	348	355	423	434	416	391	367	367	362	316	
Anions (in ppm)											
SiO_2	51	51	51	51	51	51	51	ND	51	54	
HCO_3	205	208	242	241	236	224	212	195	201	187	
CO_3	0.60	ND	ND	2.40	ND	ND	ND	6.30	4.80	ND	
Cl	8.40	9.90	10.20	9.90	9.70	9.40	8.60	10.00	8.80	7.80	
SO_4	11.50	12.90	22.90	25.00	23.10	20.10	17.40	18.90	17.20	8.80	
F	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
NO_3	0.53	1.02	<0.04	<0.04	<0.04	0.62	0.13	ND	0.84	<0.04	
NO_2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
Cations (in ppm)											
Na	63.00	65.90	78.10	79.50	76.80	73.50	69.70	70.80	68.30	60.70	
K	7.68	7.82	9.51	9.81	9.43	8.95	8.48	8.77	8.38	8.05	
Ca	13.90	13.00	17.20	17.94	16.80	15.50	13.70	13.40	12.80	10.80	
Mg	0.41	0.41	0.43	0.41	0.35	0.34	0.34	0.50	0.40	0.40	
NH_4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	

*ND – Not Determined

APPENDIX VI
Ground-Water and Precipitation Isotopic Composition

GROUND WATER AND PRECIPITATION ISOTOPIC COMPOSITION

Sample No.	Date Represented	Del deuterium (SMOW)	Del oxygen (SMOW)	Li	Br (mg/l)
		*Precipitation Isotope Data**			
NTS-019	12/03/81 - 02/09/82	-90	-12.8		
NTS-020-S†	12/03/81 - 02/09/82	-87	-13.3		
NTS-049	02/09/82 - 04/30/82	-98	-13.7		
NTS-083	04/30/82 - 06/18/82	-90	-13.0		
NTS-103	06/18/82 - 08/10/82	-58	-8.8		
NTS-155	08/10/82 - 12/03/82	-106	-14.9		
NTS-156-S	08/10/82 - 12/03/82	-101	-14.6		
NTS-175	12/03/82 - 02/14/83	-98	-12.8		
NTS-185	12/03/82 - 02/15/83	-100	-11.8		
NTS-197	02/14/83 - 04/15/83	-92	-13.6		
NTS-198-S	02/15/83 - 04/15/83	-72	-14.6		
NTS-247	04/15/83 - 08/16/83	-39	-5.5		
NTS-277	08/16/83 - 10/06/83	-116	-16.0		
NTS-319	10/06/83 - 01/05/84	-80	-10.3		
NTS-369	01/05/84 - 04/05/84	-104	-12.6		
NTS-387	04/05/84 - 06/06/84	-89	-13.2		
NTS-430	06/06/84 - 09/18/84	-72	-10.7		
NTS-462	09/18/84 - 11/15/84	-95	-13.4		
NTS-520	11/15/84 - 03/12/85	-88	-13.0		
NTS-562	03/12/85 - 05/08/85	-67	-9.1		
NTS-576	05/08/85 - 06/13/85	-110	-15.3		
NTS-611	06/13/85 - 08/07/85	-50	-8.1		
NTS-652	08/07/85 - 10/08/85	-81	-11.8		
NTS-659-S	10/08/85 - 11/14/85	-127	-18.6		
NTS-688	11/14/85 - 12/16/85	-130	-17.9		
NTS-705	12/16/85 - 01/15/86	-136	-17.6		
NTS-725	01/15/86 - 02/12/86	-128	-18.5		
NTS-743	02/12/86 - 03/18/86	-98	-13.7		
NTS-744	02/12/86 - 03/18/86	-90	-13.1		
NTS-784	03/18/86 - 05/28/86	-87	-11.8		
NTS-811	05/28/86 - 06/18/86	-86	-10.8		

Samples taken directly above U12n tunnel at 2200 m.
†S - *snow sample.*

Sample No.	Date Represented	Del deuterium (SMOW)	Del oxygen (SMOW)	Li	Br (mg/l)
		U12n.03 Isotope Data			
NTS-001-03	07/02/84	-97	-13.3		
NTS-002-03					
NTS-003-03					
NTS-004-03					
NTS-005-03					
NTS-006-03					
NTS-007-03					
NTS-008-03	08/06/84	-92	-13.3		
NTS-009-03					
NTS-010-03					
NTS-011-03					
NTS-012-03					
NTS-013-03					
NTS-014-03	09/05/84	-99	-13.4		
NTS-015-03					
NTS-016-03					
NTS-017-03					
NTS-018-03	09/25/84	-98	-13.5		
NTS-019-03	12/10/84	-97	-13.2	0.05	0.06
NTS-020-03					
NTS-021-03	01/03/85	-92	-12.4		
NTS-022-03					
NTS-022-03					
NTS-023-03	01/20/85	-97	-13.2		
NTS-024-03					
NTS-025-03					
NTS-026-03	02/04/85	-96	-13.1		
NTS-027-03					
NTS-028-03					
NTS-029-03					
NTS-030-03	02/24/85	-98	-13.5		
NTS-031-03					
NTS-032-03					
NTS-033-03					

U12n.03 Isotope Data (continued)

Sample No.	Date Represented	Del deuterium (SMOW)	Del oxygen (SMOW)	Li Br (mg/1)
NTS-034-03				
NTS-035-03	03/21/85	-97	-13.5	
NTS-036-03				
NTS-037-03	03/31/85	-99	-13.4	
NTS-038-03	04/05/85	-97	-13.7	
NTS-039-03	04/10/85	-95	-12.8	
NTS-040-03	04/15/85	-94	-13.2	
NTS-041-03	04/20/85	-94	-12.7	
NTS-042-03	04/25/85	-95	-13.5	
NTS-043-03	04/30/85	-97	-13.5	
NTS-044-03	05/05/85	-98	-13.4	
NTS-045-03	05/10/85	-99	-13.5	
NTS-046-03	06/08/85	-95	-12.8	0.04 0.05
NTS-047-03	06/13/85	-97	-13.4	
NTS-048-03	06/18/85	-98	-13.4	
NTS-049-03				
NTS-050-03				
NTS-051-03	07/03/85	-98	-13.5	
NTS-052-03				
NTS-053-03				
NTS-054-03	07/18/85	-98	-13.6	
NTS-055-03				
NTS-056-03				
NTS-057-03				
NTS-058-03	08/06/85	-98	-13.5	
NTS-059-03				
NTS-060-03				
NTS-061-03	08/19/85	-98	-13.6	
NTS-062-03	08/24/85	-99	-13.5	
NTS-063-03				
NTS-064-03	09/09/85	-97	-13.6	
NTS-065-03				
NTS-066-03	09/19/85	-99	-13.6	
NTS-067-03				
NTS-068-03	10/01/85	-99	-14.2	
NTS-069-03				
NTS-070-03				
NTS-071-03	10/26/85	-98	-13.6	
NTS-072-03				
NTS-073-03				
NTS-074-03				
NTS-075-03	11/12/85	-98	-13.3	
NTS-076-03	11/23/85	-99	-13.6	
NTS-077-03				
NTS-078-03	12/10/85	-99	-13.7	
NTS-079-03	12/25/85	-99	-13.7	
NTS-080-03	01/06/86	-98	-13.6	
NTS-081-03				
NTS-082-03				
NTS-083-03				
NTS-084-03				
NTS-085-03				
NTS-086-03				
NTS-087-03				
NTS-088-03	01/31/86	-97	-13.6	
NTS-089-03				
NTS-090-03	02/07/86	-98	-13.5	
NTS-091-03	02/12/86	-100	-13.4	
NTS-092-03				
NTS-093-03	03/20/86	-99	-13.6	
NTS-094-03				
NTS-095-03	03/30/86	-100	-13.6	
NTS-096-03	04/03/86	-99	-13.5	
NTS-097-03	05/09/86	-101	-13.5	
NTS-098-03				
NTS-099-03				
NTS-100-03	06/17/86	-97	-13.5	
NTS-101-03	07/05/86	-97	-13.4	
NTS-102-03	08/05/86	-98	-13.5	
NTS-103-03				
NTS-104-03				
NTS-105-03	08/16/86	-97	-13.5	

Sample No.	Date Represented	Del deuterium (SMOW)	Del oxygen (SMOW)	Li	Br (mg/l)
		U12n.05 Isotope Data			
NTS-001-05	07/02/84	-94	-12.9		
NTS-002-05					
NTS-003-05					
NTS-004-05					
NTS-005-05					
NTS-006-05					
NTS-007-05					
NTS-008-05	08/06/84	-92	-12.8		
NTS-009-05					
NTS-010-05					
NTS-011-05					
NTS-012-05					
NTS-013-05					
NTS-014-05	09/05/84	-93	-12.9		
NTS-015-05					
NTS-016-05					
NTS-017-05					
NTS-018-05					
NTS-019-05					
NTS-020-05	10/05/84	-90	-11.9		
NTS-021-05					
NTS-022-05					
NTS-023-05					
NTS-024-05					
NTS-025-05					
NTS-026-05	11/04/84	-92	-12.8		
NTS-027-05					
NTS-028-05					
NTS-029-05				0.04	0.035
NTS-030-05	12/12/84	-93	-13.0		
NTS-031-05	01/07/85	-93	-12.7		
NTS-032-05					
NTS-033-05					
NTS-034-05					
NTS-035-05					
NTS-036-05	02/01/85	-94	-13.0		
NTS-037-05					
NTS-038-05					
NTS-039-05	02/16/85	-94	-13.2		
NTS-040-05					
NTS-041-05					
NTS-042-05	03/03/85	-93	-12.8		
NTS-043-05					
NTS-044-05					
NTS-045-05					
NTS-046-05	03/23/85	-95	-13.0		
NTS-047-05	05/05/85	-93	-12.9		
NTS-048-05					
NTS-049-05					
NTS-050-05					
NTS-051-05					
NTS-052-05	05/26/85	-95	-12.5		
NTS-053-05	06/08/85	-93	-12.5		
NTS-054-05				0.04	0.05
NTS-055-05					
NTS-056-05					
NTS-057-05	06/28/85	-93	-13.0		
NTS-058-05	07/03/85	-94	-13.0		
NTS-059-05					
NTS-060-05	07/13/85	-97	-12.9		
NTS-061-05	07/23/85	-95	-12.9		
NTS-062-05					
NTS-063-05					
NTS-064-05	07/07/85	-94	-13.1		
NTS-065-05					
NTS-066-05					
NTS-067-05	08/19/85	-93	-13.0		
NTS-068-05					
NTS-069-05	08/28/85	-93	-12.8		
NTS-070-05	09/28/85	-94	-13.0		
NTS-071-05					
NTS-072-05					
NTS-073-05					
NTS-074-05					
NTS-075-05					
NTS-076-05	10/01/85	-95	-13.1		
NTS-077-05	10/06/85	-96	-12.9		

U12n.05 Isotope Data (continued)

Sample No.	Date Represented	Del deuterium (SMOW)	Del oxygen (SMOW)	Li (mg/l)	Br (mg/l)
NTS-078-05	11/05/85	-96	-13.1		
NTS-079-05					
NTS-080-05					
NTS-081-05					
NTS-082-05					
NTS-083-05	12/06/85	-96	-13.3		
NTS-084-05					
NTS-085-05					
NTS-086-05					
NTS-087-05					
NTS-088-05					
NTS-089-05					
NTS-090-05	01/11/86	-94	-13.0		
NTS-091-05					
NTS-092-05					
NTS-093-05					
NTS-094-05	01/31/86	-96	-12.9		
NTS-095-05					
NTS-096-05	02/07/86	-96	-13.1		
NTS-097-05					
NTS-098-05					
NTS-099-05					
NTS-100-05					
NTS-101-05	03/04/86	-97	-13.3		
NTS-102-05					
NTS-103-05					
NTS-104-05					
NTS-105-05					
NTS-106-05					
NTS-107-05					
NTS-108-05					
NTS-109-05					
NTS-110-05	04/12/86	-94	-13.0		
NTS-111-05	04/17/86	-95	-13.1		
NTS-112-05	04/22/86	-95	-13.2		
NTS-113-05	04/27/86	-95	-13.2	0.05	0.07
NTS-114-05	05/02/86	-96	-13.2		
NTS-115-05	05/07/86	-96	-13.3		
NTS-116-05	05/08/86	-96	-13.4		
NTS-117-05	05/12/86	-97	-12.9	0.04	0.07
NTS-118-05					
NTS-119-05					
NTS-120-05	06/17/86	-92	-13.0		
NTS-121-05	06/22/86	-95	-13.0		
NTS-122-05	06/27/86	-96	-13.1		
NTS-123-05					
NTS-124-05					
NTS-125-05	07/10/86	-94	-13.0		
NTS-126-05					
NTS-127-05	07/20/86	-95	-13.0		
NTS-128-05					
NTS-129-05					
NTS-130-05					
NTS-131-05	08/16/86	-93	-12.6		