HYDROGEOLOGIC INVESTIGATIONS OF FLOW IN FRACTURED TUFFS, RAINIER MESA, NEVADA TEST SITE

BY

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HYDROGEOLOGIC INVESTIGATIONS OF FLOW IN FRACTURED TUFFS, RAINIER MESA, NEVADA TEST SITE

by

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ABSTRACT

Rainier Mesa is located in the north central portion of the Nevada Test Site and consists of highly fractured and altered Tertiary Tuffs. Studies of the hydrogeologic regime of Rainier Mesa have become important as an increasing number of nuclear tests are conducted there. A hydrogeologic study is presented which attempted to determine the following parameters: the source of water found at the tunnel level, periods of principal recharge, ground-water travel time, period of hydrologic response to storm recharge, total amount of recharge entering Rainier Mesa, extent of mixing between fracture reservoirs, and the effects of nuclear testing on localized ground-water chemistry and discharge.

The data base consists of: the precipitation record, the discharge record of selected seeps within the system of adits used for weapons testing, chemical and stable isotopic compositions of water from these seeps, and two tracer studies from the top of the mesa.

Results have indicated the following: Rainier Mesa ground water is of recent meteoric origin, the period of principal recharge is from late fall to early spring. The

hydrologic response time is approximately four months and the total amount of recharge is approximately eight percent of the precipitation which falls on the mesa surface. It was also found that the active fracture systems are poorly interconnected, and the effect of nearby nuclear testing increases ground-water discharge through the generation of the seismic P waves which forces out interstitial water.

APPROVAL PAGE

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INTRODUCTION

Rainier Mesa is a tuffaceous plateau located in the north central portion of the Nevada Test Site. It is approximately 140 kilometers to the northwest of Las Vegas, Nevada.

Since 1957, nuclear testing has been conducted at Rainier Mesa within a series of adits which have been constructed on its eastern slopes. These adits, referred to as tunnels, extend nearly three kilometers into the Mesa, varying in elevation from 1717 m to 2013 m. The hydrogeology of the mesa is characterized by vadose zone fracture flow.

One rationale for studying Rainier Mesa is the relatively easy access to a vadose zone dominated by fracture flow. Few areas offer the accessibility to such an environment as do the tunnels mined into the mesa. Furthermore, these tunnels offer a unique opportunity to study radionuclide transport in such an environment. A second reason for studying Rainier Mesa is its similarity to Yucca Mountain, a possible site for the high level nuclear repository. Both consist of fractured tuffaceous rocks of the same formations situated within the vadose zone; however, for Rainier Mesa there exists ready access to study such an environment, whereas the opportunity to study Yucca Mountain is very limited. Rainier Mesa contrasts with Yucca Mountain by its greater elevation and increased precipitation.

Objectives

The objectives of this study were to quantitatively investigate hydrologic processes which occur within Rainier Mesa. The hydrogeologic objectives of concern were: origin of seep waters, average ground-water velocity, period of hydraulic response, total ground-water flux through Rainier Mesa, percentage of precipitation that enters the ground as recharge, period of principal recharge, extent of mixing between fracture reservoirs, and the effects of a nuclear test on ground-water chemistry and discharge.

Within Rainier Mesa, it has never been proven whether the seep water found in the tunnels are of recent meteoric origin, or ancient ground water from a pluvial period. Examination of the deuterium, and oxygen-18 isotope ratios, tritium concentrations, and seep discharge records, have the potential to indicate the source of the ground water found in the tunnel seeps.

The average velocity of the ground water is very important in determining the rate of radionuclide transport from the test areas to the underlying regional ground-water system. In efforts to estimate this parameter, two different tracer studies utilizing four tracers were conducted on the mesa top. The travel times and the distance travelled were calculated in order to estimate the average ground-water velocity. A comparison of the stable isotopic ratios between precipitation at the top of the mesa and discharge at the tunnel seeps has been conducted and analyzed with respect to a seasonal phase shift between the two sources. Finally, several tritium samples were taken in order to estimate the age of the ground water.

The period of hydraulic response is the time between a large recharge pulse entering the system which increases the head, and a corresponding increase in ground-water discharge. This process can have a very great effect on ground-water velocities and radionuclide transport. The hydraulic response time was determined by an examination of the precipitation and ground-water seep discharge records.

An important hydrogeologic parameter within Rainier Mesa is the total flux of ground water which passes through it. In order to quantitatively estimate this, the total discharge from U12n Tunnel has been monitored for nine months. These data coupled with humidity measurements in the tunnel and the surrounding environment, and the flux of air circulated through the ventilating system, was used to estimate the total ground-water discharge from this tunnel. A surface drainage area was estimated for U12n tunnel based upon tunnel extent and surface topography. These data, coupled with the precipitation record, were used to estimate the percentage of precipitation that recharges into Rainier Mesa.

Another important hydrologic parameter is the period during which the principal recharge occurs. This period was determined by a comparison of the stable isotopes in ground-water seeps to the corresponding isotopic ratio of the seasonal precipitation. The extent of mixing between fracture reservoirs was also determined. The methodology used was the examination of seasonal and spatial variance in the chemistry and isotopic signatures of different seeps within the tunnels.

The effects of an underground nuclear test on nearby discharge sources were examined. The results of these tests on the aquifer, and the resulting changes in aqueous chemistry, stable isotopic signatures, and discharge were closely investigated.

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 the aforementioned parameters. Johnson and Hubbard (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. Houser and Poole (1960), went on to examine 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 1961, Hinrichs and Orchild (1961), subdivide the Oak Spring Formation into eight members, and in 1962, Cattermole and Hansen published their report on the geologic effects of conventional high explosive tests on the U.S.G.S. 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 U.S.G.S. tunnel areas in Rainier Mesa. Sargent et al. (1965), and Orkild (1965), added further to the nomenclature of Rainier Mesa by naming the Indian Trail, Paintbrush and Timber Mountain formations. Since 1963 to the present, numerous technical letters and reports have been published by the U.S.G.S. These reports document the structure, stratigraphy, mineralogy, and physical properties of site specific locations in Rainier Mesa for their use in delineating working points for nuclear testing.

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. He derived a travel time of 0.8 to 6 years 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

Clebsch (1961), and Schoff and Moore (1964), several other geochemical studies have been done in relation to Rainier Mesa. Clebsch and Barker (1960) undertook the first chemical analysis of ground water from Rainier Mesa tunnel seeps. In the years after 1960, chemical analysis were done by the U.S.G.S. 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 occuring 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 effect 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.

ENVIRONMENTAL SETTING

Geography

At 2343 m, Rainier Mesa is the highest of a group of mesas, ridges, and low mountains which compose the Belted Range. The Belted Range lies approximately 140 km northwest of Las Vegas, Nevada, in the northern portion of the Nevada Test Site. It is located at approximately 116° 12'W 37° 12'N (Figure 1). The mesa trends roughly north-south, is 4.8 km long, 2.4 km wide, and includes 11.4 km^2 within the area of its caprock (Figure 2).

Rainier Mesa's caprock is characterized by a rolling topography in which the elevation ranges from 2250 to 2343 m. The caprock rises 60 to 210 m above the nearby highlands and is approximately 760 to 1060 m above Yucca Flat, which is a nearby intermontaine basin. The slopes of the mesa vary between 20° to 30°, with an upper and lower palisade just below the caprock. The two palisades are approximately 25 and 10 m in height respectively, with a steep slope of 40 m between them. The mesa acts as part of a drainage divide that seperates westerly drainage to the Forty Mile Canyon area, from easterly drainage to Yucca

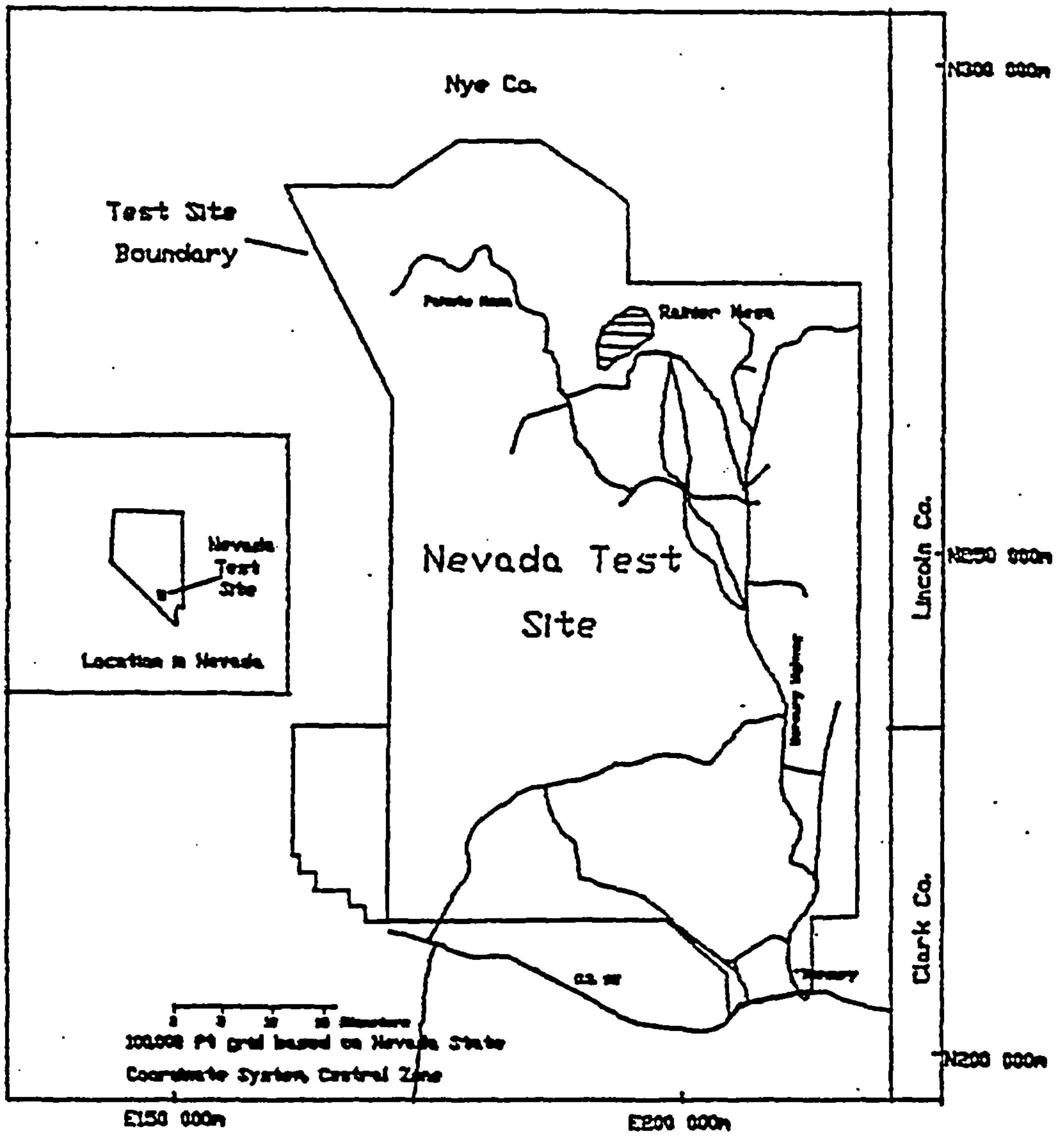

Figure 1. The Location of Rainier Mesa Relative to The Nevada Test Site and Vicinity

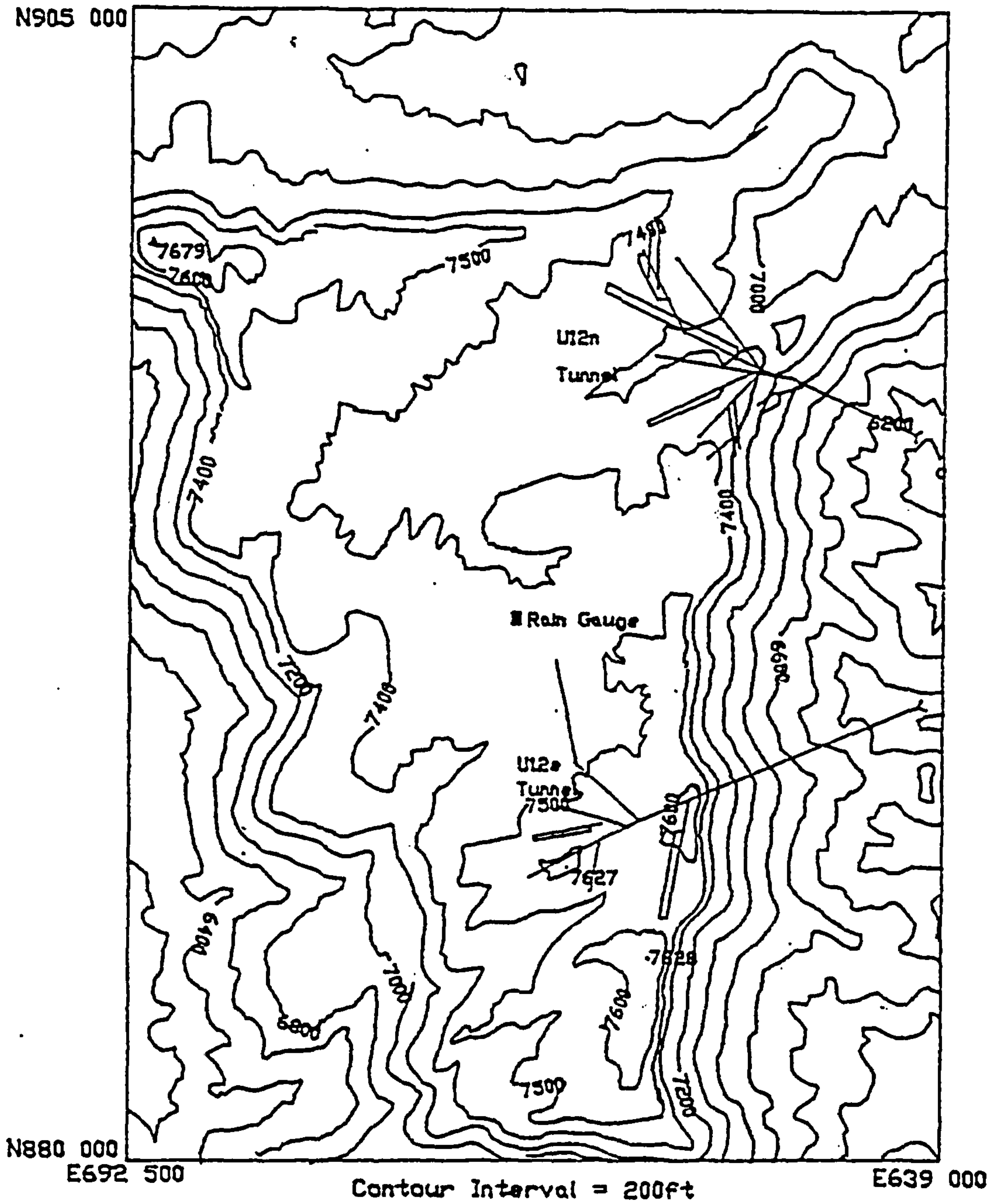

Figure 2. Rainier Mesa, U12n and U12e Tunnel Systems and Rain Station

Flat. Mined into Rainier Mesa on its western slopes, at an elevation range of 1720 to 2010 m, are a series of adits. Some of these adits, referred to as tunnels, penetrate nearly 3 km into the mesa and contain up to 13 km of tunnels. It is within these tunnels that nuclear tests are conducted. For this study, two tunnels were chosen for instrumentation, U12n and U12e. Three drifts within U12n Tunnel were instrumented for the purpose of recording hydrologic data, U12n.03, U12n.05, U12n.10, as well as the outside portal. U12e Tunnel was sealed against entry for safety reasons; however, the portal was monitored.

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 United States Department of Commerce Weather Service, Nuclear Support Office, Las Vegas. The mean precipitation amount is approximately 35 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

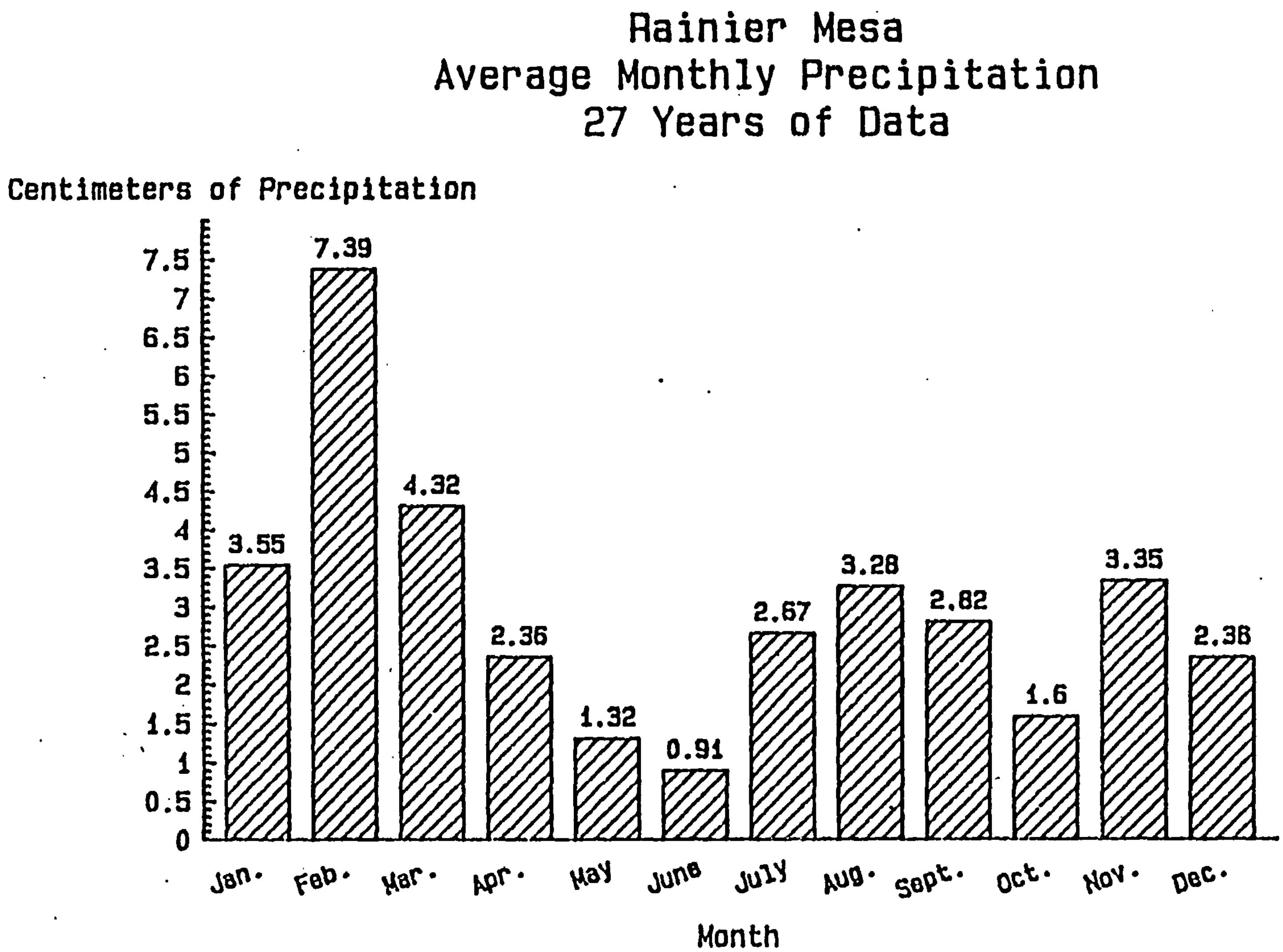

Figure 3. Rainier Mesa Average Monthly Precipitation

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.

Vegetation

Rainier Mesa supports an elevationally-zoned plant community. Above 1500 meters, the *Artemisia-Pinus-Juniperus* community exists (Beatley, 1976). Within this community, in deeper sandy soils, *Artemisia tridentata* (big sagebrush) thrive. In the the shallower soils *Artemisia nova* (black sagebrush) lives in mosaic with *A. Tridentata*. At approximately 1750 meters, *Pinus minophylla* (pinyon pine), and *Juniperus osteosperma* (Utah juniper) enter the *Artemisia* communities to form an open shrub-woodland environment. Within this community, though not as common, exist *Quercus gabelli* (scrub oak), *Rhus sp*. (snowberry), *Cowania sp*. (cliff rose), *Castilleja sp*. (indian paintbrush), *Grayia spinosa* (hopsage), *Chrysothamnus sp*. (rabbit brush), *Ephedra torreyana* (mormon tea), and *Purshia tridentata* (bitter bush). The tree-shrub community covers 34.8 to 43.9% of the land surface (Beatley, 1976). A herbaceous perrenial community also exists at this elevation. Most of this community consists of grasses such as Stipa comata, Stipa pinetorum, and Stipa thurberiana which compose 7.0 to 31.1% of the ground cover (Beatley, 1976).

Below 1500 m exists a shrub-grassland community which is dominated by Atriplex confertifolia (shadscale), and Coleogyne sp. (Black Brush). This community extends to the upper reaches of Yucca flat where a gradation to a drier community occurs.

GEOLOGY

The geology of Rainier Mesa controls the occurrence, mode of transport and geochemistry of the ground water occurring 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 complexely faulted Cenozoic volcanics, Mesozoic granitic stocks, and Paleozoic sediments which unconformably overlay a Precambrian metamorphic complex. The Cenozoic section, which Rainier Mesa is a part of, is primarily composed of a 12,000 m thick, composite section of Tertiary volcanics. Within the region are large strike-slip faults, such as the Las Vegas Shear Zone which is to the south and south west of Rainier Mesa.

Rainier Mesa is the remnant of a volcanic plateau uplifted during an episode of tectonic extension during the middle to late Cenozoic. The mesa is composed of a series of nearly parallel, roughly planar Miocene Tuffs which dip 10° to 25° to the West (Hansen et al., 1963). These tuffs originated from a series of calderas to the west, south, and southwest of Rainier Mesa. One of these calderas, the Silent Canyon Caldera, borders Rainier Mesa on its western slopes.

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 and Townsend, 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., (1978).

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, this structural event affected the Gold Meadows Monzonite, the Wood Canyon Schist, the Stirling Quartzite, as well as older units.

During the middle to late Cenozoic, major block

TABLE 1. STRATIGRAPHY AND LITHOLOGY OF RAINIER MESA (Maldonado *et al.*, 1978)

Stratigraphic and Lithologic descriptions	Range of Thickness (meters)	Mean of Thickness (meters)	Present in # of Wells
Timber Mountain Tuff			
Rainier Mesa Member			
Miocene Tuff (9.5 ± 0.7 my), ash-flow, light brownish gray to pale red to pinkish gray, densely welded to partially welded, grades to nonwelded-----------	13.0 - 181.7	76.9	23
Paintbrush Tuff			
Miocene Tuff (11.3 ± 1.1 my), ash-fall, reworked ash-fall, and tuffaceous sandstone, very light gray to light gray to pale or dusky brown, thin to thick bedded, vitric in the upper part, grading to zeolitized in the lower portion of the formation, some welded beds exist, such as the Tiva Canyon Member, some slightly argillized zones also exist------------	34.4 - 219.5	157.2	22
Stockade Wash Tuff			
Miocene Tuff, ash-flow, white to very light gray, massive, nonwelded, zeolitized-------------------------------------	0.0 - 14.3	8.7	3
Bedded and Ash-Flow Tuffs of Area 20			
Miocene Tuff, ash-fall, reworked ash-fall, tuffaceous siltstone, very pale orange to dark yellowish brown to yellowish gray; thin bedded to massive, zeolitized---	0.0 - 63.4	40.7	3
Lava and Tuff of Dead Horse Flat			
Miocene Tuff, peralkaline ash-flow, densely welded to nonwelded, moderate brown to dusky brown, massive, (cont. next page)			

TABLE 1. STRATIGRAPHY AND LITHOLOGY OF RAINIER MESA (cont.)

Stratigraphic and Lithologic descriptions	Range of Thickness (meters)	Mean of Thickness (meters)	Present in # of Wells
basal conglomerate unit, interfingers with Bedded and ash-flow Tuffs of Area 20	0.0 - 39.3	14.6	3
Belted Range Tuff Grouse Canyon Member Miocene Tuff (13.8 my), peralkaline ash-fall and ash-flow, moderate brown to dusky brown, massive to bedded, welded to nonwelded, tuffaceous conglomerate at base	0.0 - 39.3	14.6	17
Indian Trails Formation Tunnel Bed Unit 5 Miocene Tuff, peralkaline ash-fall and reworked ash-fall, tuffaceous sandstone, medium to dark gray, dusky yellow green to grayish yellow green, thin to thick bedded, vitric grading to zeolitized in lowest part of interval, argillized in some sections	3.1 - 48.8	30.6	24
Indian Trails Formation Tunnel Bed Unit 4 Miocene Tuff, ash-fall, reworked ash-fall, and peralkaline ash-fall, tuffaceous sandstone, grayish yellow to moderate reddish brown, thin bedded to massive, thin lenses of isolated siltstone, zeolitized with some slightly silicified and argillized zones, consists of 8 subunits; AB, CD, E, F, G, H, J, K	0.0 -168.3	94.1	26

TABLE 1. STRATIGRAPHY AND LITHOLOGY OF RAINIER MESA (cont.)

Stratigraphic and Lithologic descriptions	Range of Thickness (meters)	Mean of Thickness (meters)	Present in # of Wells
Indian Trail Formation Tunnel Bed Unit 3 Miocene Tuff, ash-fall, and minor reworked ash-fall calc-alkaline ash-fall, and tuffaceous sandstone, grayish orange pink to pale dusky red, massive to thinly bedded, zeolitized with several silicified beds, consists of 3 subunits; A, BC, D--	22.9 - 96.3	49.4	21
Belted Range Tuff Tub Spring Member Miocene Tuff, peralkaline ash-flow, ash-fall, and reworked ash-fall, grayish yellow green, moderate reddish brown grayish yellow to light olive, thin to thick bedded, zeolitized, some argillized and silicified zones, dominately nonwelded--	0.0 - 20.7	6.5	21
Indian Trail Formation Tunnel Bed Unit 2 Miocene Tuff, ash-fall, reworked ash-fall, reworked peralkaline ash-fall, tuffaceous sandstone and siltstone, moderate reddish brown to grayish yellow to yellowish gray, and light brown, thin to thick bedded, zeolitized, some silicified and argillized intervals with pisolites included--------------------------------	0.0 - 68.3	44.0	21
Crater Flat Tuff Miocene Tuff, ash-flow, moderate reddish brown to mottled (cont. next page)			

TABLE 1. STRATIGRAPHY AND LITHOLOGY OF RAINIER MESA (cont.)

Stratigraphic and Lithologic descriptions	Range of Thickness (meters)	Mean of Thickness (meters)	Present in # of Wells
grayish orange pink, massive, nonwelded to very densely welded, phenocrysts are abundant, some sections are zeolitized--	0.0 - 68.3	10.6	21
Indian Trail Formation			
Tunnel Bed Unit 1			
Miocene Tuff, reworked ash-fall, tuffaceous sandstone and tuffaceous mudstone, yellowish gray to grayish orange pink to moderate reddish brown and pale red, dominately thin bedded, a few thick beds do exist, zeolitized, some thin silicified beds---------------------------------------	0.0 - 82.3	18.1	19
Red Rock Valley Tuffs			
Miocene Tuff (15.7 ± 0.6 my), ash-flow, grayish red to dark and moderate reddish brown, some pale red and grayish orange pink, nonwelded to partially welded--------------	0.0 - 15.2	9.6	3
Older Tertiary Tuffs			
Miocene tuffs, ash-flow, reworked ash-fall, and tuffaceous sandstone, pinkish gray to yellowish gray and very dark red stringers scattered throughout unit paralleling flow structure; slightly argillized, some thin silicified beds, some phenocryst rich areas, minor thick beds------------	0.0 - 36.3	19.2	4
Paleocolluvium			
Miocene Colluvium, granule to cobble size, angular, massive argillized, dark gray quartzite fragments in a tuffaceous (cont.)			

TABLE 1. STRATIGRAPHY AND LITHOLOGY OF RAINIER MESA (cont.)

Stratigraphic and Lithologic descriptions	Range of Thickness (meters)	Mean of Thickness (meters)	Present in # of Wells
Paleocolluvium cont. matrix, a few boulders of quartz monzonite are also present highly weathered, moderate reddish brown, some argillized zones	0.0 - 55.2	21.6	6
Gold Meadows Stock Cretaceous (91.8 ± 3.3 my) quartz monzonite, pinkish gray to moderate reddish brown, massive, highly altered	found in bottom 8m of 1 well		
Wood Canyon Formation Cambrian schist, contains micaceous siltstone, dark greenish gray to olive black	0.0 - 26.6	19.4	2
Stirling Quartzite Precambrian quartzite, dark gray, highly fractured with dark reddish brown material in fractures, minor amounts of micaceous schists are present, total thickness of the section is unknown in the area of Rainier Mesa, but is estimated at 300 m (Gibbons *et al.*, 1963)			

faulting occurred creating the Basin and Range province, which Rainier Mesa is a part of. 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 were common with displacements being measured up to six or seven km.

The most prominent 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 Aqueduct Syncline axis (Hansen et al., 1963). The Aqueduct Syncline and smaller folds are largely due to the settling of ash-flow 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.

Hansen et al. (1963), undertook a study of fractures within Rainier Mesa. He 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 from 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. A few of the fractures found within the tunnel beds are induration fractures caused by the extensive zeolitization which has occurred there.

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, 1963).

HYDROGEOLOGY

Physical Hydrogeology

For this study, the units of hydrologic interest are those formations which exist between the mesa surface, which is the suspected recharge area, and the lower Tunnel Beds where the sample sites exist. This section is approximately 450 m thick, starting at the top with the Rainier Mesa member of the Timber Mountain Tuff and extending down to Tunnel Bed Unit 2. An idealized cross section of this section and the areas of perched saturated ground-water flow are on Figure 4. Thordarson (1965), classified the Tunnel Beds and all of the units stratigraphically overlying it into three types of hydrogeologic units. These are the zeolitic bedded tuffs, friable bedded tuffs, and the welded and partially welded tuffs. The physical properties of these hydrogeologic units are summarized in Table 2.

The zeolitic bedded tuffs within Rainier Mesa are: the lower portions of the Paintbrush Tuff and Stockade Wash Tuff, some portions of the bedded and ash-flow tuffs of Area 20 of the Nevada Test Site, and some portions of the

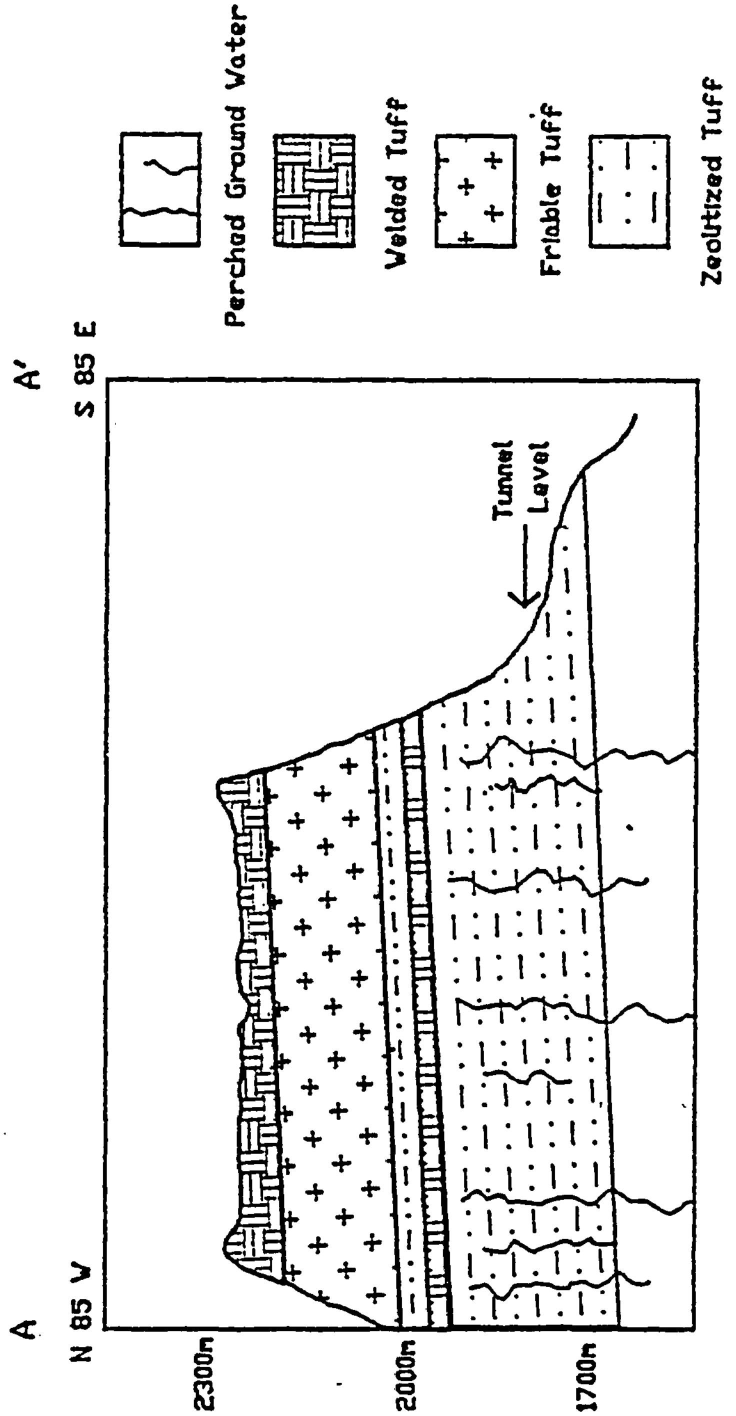

Figure 4. A Cross-section of Rainier Mesa showing the Three types of Hydrogeologic units found there and the Mode and Occurrence of Perched Ground-Water Lenses.

TABLE 2. FORMATIONS OF RAINIER MESA AND A SUMMARY OF THEIR HYDRAULIC PROPERTIES USING AVAILABLE DATA.

Formation and Member	Interstitial Permeability	Interstitial Porosity	Effective Permeability
Timber Mountain Tuff, Rainier Mesa Member	$4.72X10^{-9}m/s$	14%	Fracture
Paintbrush Tuff	$1.75X10^{-6}m/s$	40%	Interstitial
Belted Range Tuff, Grouse Canyon Member	$2.80X10^{-9}m/s$	19%	Fracture
Tunnel Bed Unit 4, Indian Trail Formation	$9.44X10^{-9}m/s$	38%	Fracture
Unit 3	$1.40X10^{-9}m/s$	35%	Fracture
Unit 2	----no data---	32%	Fracture
Unit 1	----no data---	25%	Fracture

Data from Thordarson, 1965.

lava and tuffs of Dead Horse Flat, as well as most sections of the Tunnel Bed units. The ash-flows and ash-falls which comprise the zeolitic bedded tuffs originally contained pumice and glass shards, which were subsequently altered in situ to the zeolites clinoptilolite, mordenite, and some analcime (Benson, 1980).

Core samples taken by Thordarson (1965) from the Tunnel Beds yielded an average interstitial porosity ranging from 25 to 38 percent. Byers (1961), determined the pore spaces found within the Tunnel Beds are close to 100 percent saturation. The uppermost zeolitized bedded tuff, which is in the lower section of the Paintbrush Tuff, contains an interstitial porosity of 27 to 29 percent (Diment et al., 1959a). Saturation in this unit was also found to be close to 100 percent.

The range of interstitial permeability for the Tunnel Beds are from 0.19×10^{-9} to 9.44×10^{-9} m/s. The mean interstitial permeability for the lower Paintbrush Tuff was found to be 9.44×10^{-9} m/s. The porosity values between these two units closely agree, yet the permeability values may vary up to an order of magnitude These values are thought to be a representative range for most zeolitized tuffs within Rainier Mesa.

Within the tunnels mined into the zeolitic bedded tuffs, a general absence of water on the walls is noted. This evidence, coupled with the presence of very low interstitial permeability, indicates that pore water is strongly held by capillary forces within these units. It is appropriate to assume that the interstitial waters travel extremely slow through these units. The above evidence does not preclude the possibility of the movement of interstitial waters into the tunnels by the process of evaporation. This hypothesis is supported by samples taken from the tunnel walls by Byers (1961), and Diment (1959a). The interstitial pores of these samples were saturated only 62 to 70 percent. If ground water is moving into the tunnels by evaporation from the pore spaces, then it is contributing to the total discharge derived from each tunnel. The extent of this contribution will be analyzed in a latter section.

Free flowing ground water is found primarily within the Tunnel Bed fracture system. The majority of these water-bearing fractures are normal faults characterized by several centimeters of displacement. A fracture analysis was undertaken by Thordarson (1965) within U12e tunnel. It was determined that 50 to 60 percent of all normal faults yielded fracture water, while only 2 percent of induration joints, cooling joints, and other types of fractures were water bearing. This phenomenon is most likely due to the greater extent and continuity of the normal faults.

Interspersed among the water-bearing fractures are dry fractures. It is assumed that the fracture system is poorly connected hydraulically. This hypothesis is supported by thermal variations of relatively close fracture seeps, and the extreme variation in initial discharge for these same seeps (Thordarson, 1965). Some fracture systems drain and are dry within a few weeks after mining. Others, which are relatively close by, have acted as continous seeps since the initial excavation, albeit at much lower discharge rates than initially recorded (Thordarson, 1965).

The top of the zone of saturation has been determined by numerous test holes drilled into Rainier Mesa. The elevation of the water table varies up to 100 meters owing to the poor hydraulic continuity of the water-bearing fractures. However, the mean elevation is approximately 1820 m, which is in Tunnel Bed Units 3 and 4 (Thordarson, 1965). The present water table elevation most likely reflects lowered levels due to extensive gravity drainage of the fractures by mining activities.

The friable bedded tuffs are composed of the lower part of the Grouse Canyon Member and the bulk of the Paintbrush Tuff. These units were deposited as an ash-fall which remained relatively unaltered and uncemented. The interstitial porosity and permeability of these units are relatively high in comparison to the other tuffs of Rainier Mesa. Samples from the Paintbrush Tuff indicate a porosity of 40 percent and a mean interstitial permeability of 1.7×10^{-6} m/s (Emerick and Houser, 1962). In the same study, it was determined that the interstitial spaces were saturated at an average of 64 percent. An examination of the fractures within the friable bedded tuffs by Thordarson (1965), revealed that most faults are rarely preserved in these units, yet those that exist are usually sealed by fault gouge to a considerable degree. The dominant form of transport is thought to be partially saturated interstitial flow, which is a result of the formation's relatively high permeability and porosity, and low fracture frequency.

The welded and partially welded tuffs are composed of the Tub Spring Member, and most of the Grouse Canyon Member of the Belted Range Tuff, the Stockade Wash and Tiva Canyon members of the Paintbrush Tuff, and the Rainier Mesa Member of the Timber Mountain Tuff. These Tuffs were formed as ash-flows which were welded together during deposition. Cooling joints and structural deformation fractures are abundant and well preserved in these formations.

The interstitial porosity of the Rainier Mesa and Grouse Canyon members average 14 and 19 percent respectively. The interstitial permeability of these units average 4.72×10^{-9} m/s (Thordarson, 1965). Owing to the high fracture frequency within the welded and partially welded tuffs and the low porosity and permeability of the matrix, fracture flow is thought to be the dominant form of transport within these units (Thordarson, 1965).

According to Thordarson (1965), ground water within Rainier Mesa occurs as a series of perched lenses within fractures of the zeolitic bedded tuffs of the Indian Trails Formation. The regional zone of saturation is at least 1000 m below the surface of the mesa and 500 meters below the tunnel level. The movement of ground water is downward from the recharge area at the top of the mesa, through the fractures of the Rainier Mesa Member, and then through the underlying friable Paintbrush Tuff. Vertical movement through these units is probably rapid, due to their relatively larger effective permeability. However, upon reaching the less permeable zeolitic bedded tuff, the ground water creates a series of perched lenses which slowly drain through the fracture system of the formation, or into the tunnel system. The friable bedded tuff of the overlying Paintbrush Tuff acts as a large perched aquifer supplying ground water to the fracture systems throughout the dry portions of the year. Once ground water has percolated past the tunnel level, movement continues downward until the regional water table is reached.

Chemical Hydrogeology

As ground water passes through Rainier Mesa, incongruent dissolution processes create a sodium bicarbonate water found within the fractures (White et al.,

1980) and a sodium silicate bicarbonate water within the interstitial pore spaces (Benson, 1976). The difference between the two waters is due to a longer residence time for the interstitial waters which provides enough time for silica saturation to occur.

A relatively dilute calcium bicarbonate type of precipitation recharges Rainier Mesa (John Hess, personal communication, January, 17 1986). The dominant reaction which occurs as the precipitation infiltrates the soil zone is the increase of bicarbonate due to the soil biota. As the water passes through the upper strata, incongruent dissolution of the tuffs occurs. The primary reactive components within these rocks are the volcanic glasses contained within the vitric tuffs, and the crystalline silicate minerals contained within the devitrified tuffs (Benson, 1976). Within Rainier Mesa, it has been found that dissolution of the tuffs preferentially releases sodium, calcium, and magnesium, and preferentially retains potassium (White et al., 1980).

According to Benson (1976), as dissolution continues, saturation with respect to certain minerals occurs. These minerals are the clays montmorillonite and illite, and the zeolites clinoptilolite, analcime, and mordenite. These minerals are predominately found within the altered zones of the Paintbrush and Indian Trails formations. Montmorillonite, which is the predominant clay mineral, occurs mainly within the Paintbrush Tuff and below. The predominant zeolite mineral present is clinoptilolite. Once past the tunnel beds, the ground water is incorporated into the regional flow system. Regional ground-water geochemistry has been documented by Thordarson and Winograd (1975). Within their studies it was determined that recharge passing through Rainier Mesa eventually discharges at Ash Meadows Basin within the Amargosa Valley, 50 km to the west of the Nevada Test Site.

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: the discharge record from U12n.03, U12n.05 and the portal seeps, the stable isotopic ratios of oxygen and hydrogen from the U12n tunnel seeps and Rainier Mesa precipitation, as well as the tritium concentrations and gross chemistry from these same seeps. A humidity record was also collected from within U12n tunnel, as was the 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 one 100 ml sample daily and integrate them over five days 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 (Figure 5). The recorded heads from these weirs were applied to the following equation from King and Brater (1963):

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

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. Due to the larger discharge, this recorder was set up on a 90° v-notch weir (Figure 5). The discharge equation for this wier was also derived from King and Brater (1963):

$$Q = 70.8\ H^{2.5}.$$

Within 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 combined 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 flourescent dye receptors consisting of pure cotton surrounded by fiberglass screening were emplaced. The receptors were

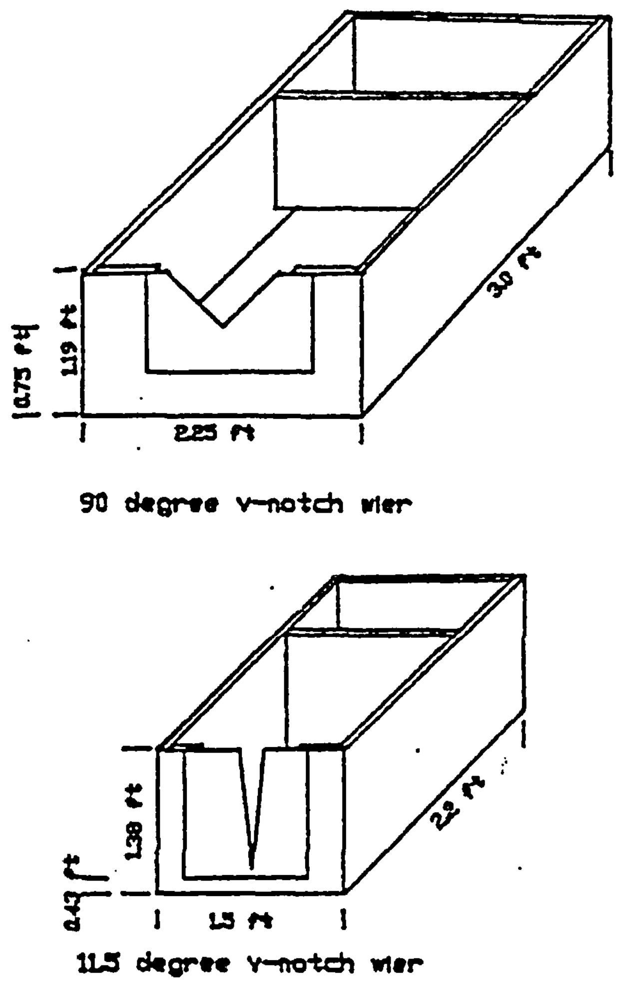

Figure 5. A Schematic Diagram for Wiers Installed in U12n.03, U12n.05 and U12n Portal

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 894300, E 634600 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 and 340 m above U12n.05 drift. This study was designed and directed by Howard Koltermann of Desert Research Institute and was later monitored by the author.

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 fluorecene dyes. Within a month, precipitation had pooled behind the berms facilitating infiltration of the dyes (John W. Hess, personal communication, January 31, 1986). 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

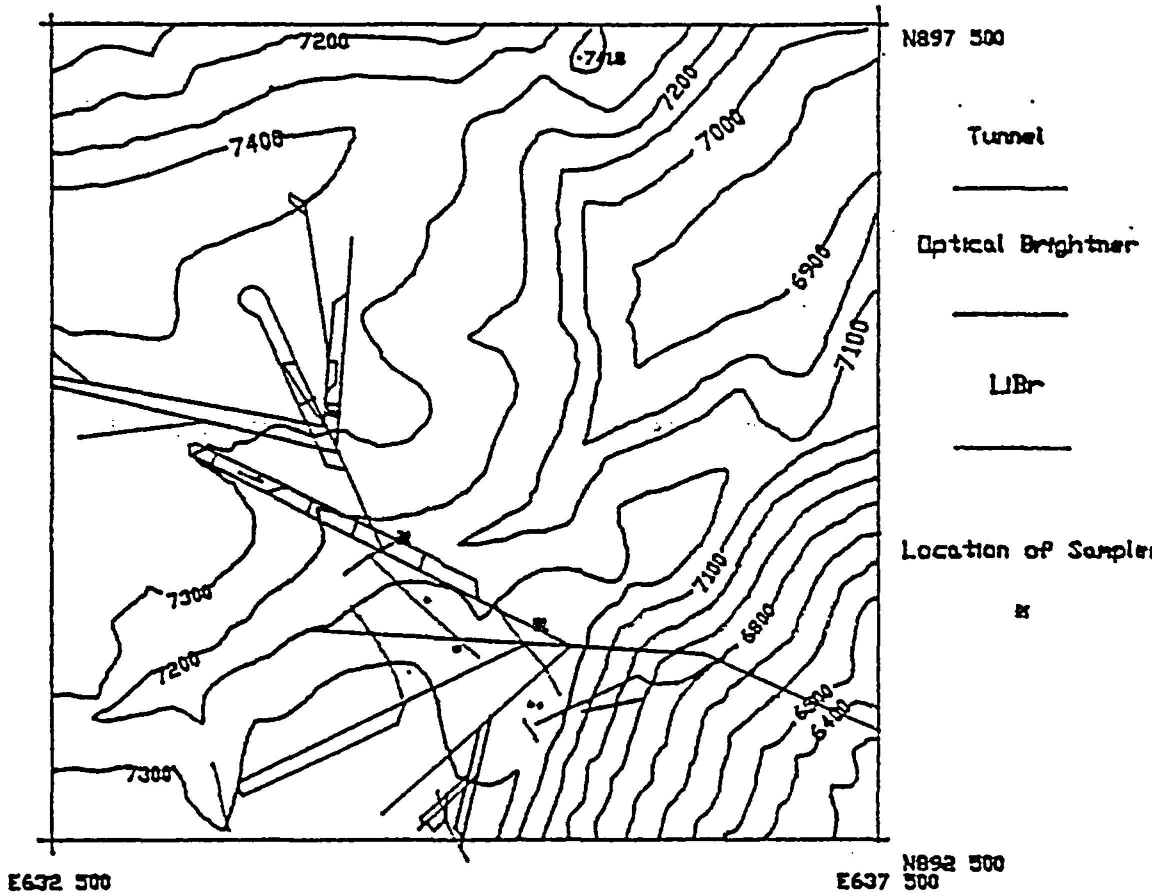

Figure 6. U12n Tunnel and Areas of LiBr and Optical Brightner Emplacement

determined that a point source tracer study was inadequate for an environment which 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 brightner. Both tracers have been used extensively before (Schmutzer et al, 1973).

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 on Figures 6 and 7. 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 were poured into a large fault trace which had been recently reactivated by nuclear testing. This was done in order to facilitate infiltration of the solution. The precipitation record was also monitered during this period to determine if and when infiltration occured.

On May 1, 1986 8 kg of Tinopal 5BM, a concentrated optical brightner, 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 Rainier Mesa surface, with 190 l of the tracer solution going into each fracture. The solution was pumped with a small

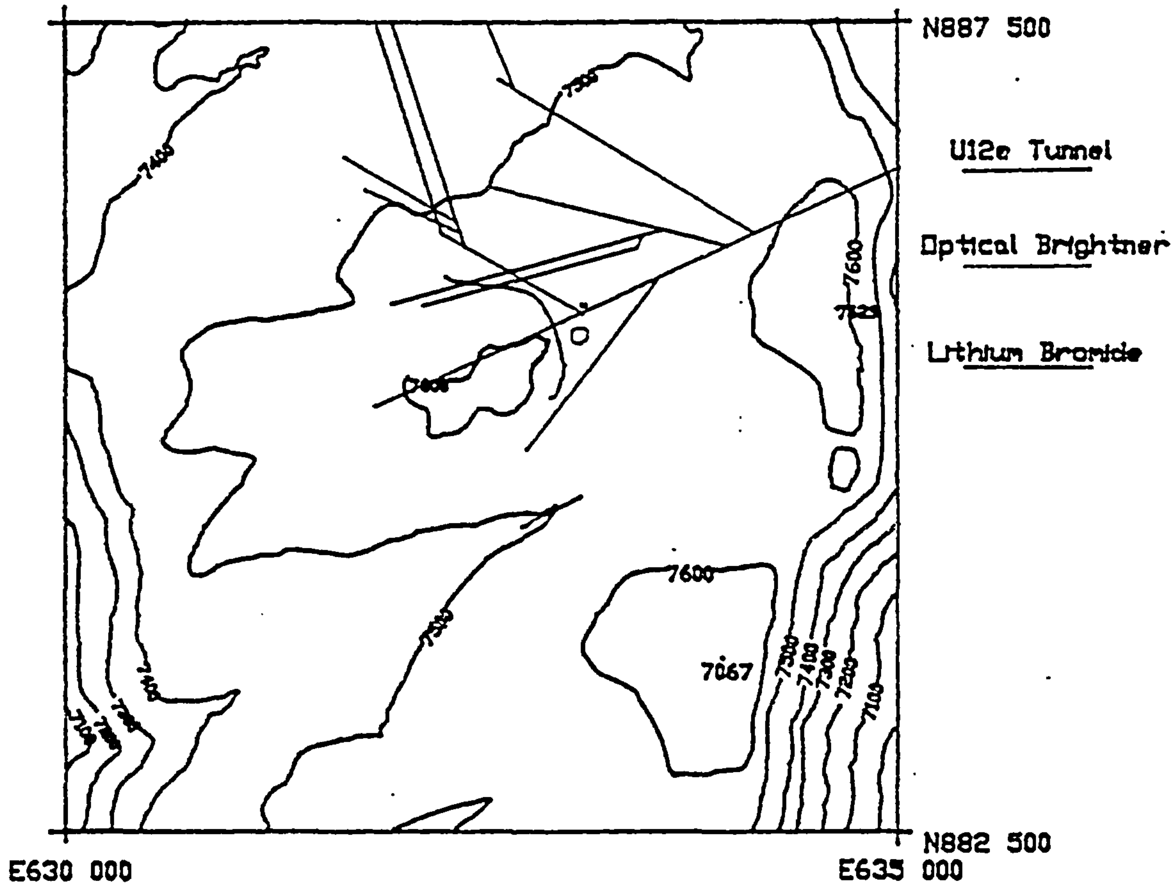

Figure 7. U12e Tunnel and Dye Emplacement Areas

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 fluorecene and direct yellow dyes, as well as the optical brightners. Water samples were also taken on a biweekly basis from both E and N tunnels and analyzed for LiBr concentrations.

Laboratory Methods

The majority of all laboratory analysis done for this study was undertaken by the Water Resources Center laboratories of the Desert Research Institute. Water samples taken from Rainier Mesa were analyzed for deuterium, oxygen-18, tritium, gross chemistry, lithium bromide, and fluorescent dye concentrations. The stable isotopes were analyzed by Desert Research Institute Environmental Isotope Laboratory in Las Vegas, Nevada. The deuterium samples were prepared according to the uranium method (Friedmund, 1953), and were run on a 3-60-HD Nuclide mass spectrometer. The oxygen-18 samples were prepared according to the quanidine method (Dugan et al, 1985), and were run on a 6-60-RMS Nuclide and a Finnigan Delta E mass spectrometer. Tritium samples were analyzed by the

Environmental Sciences Laboratory in Mercury, Nevada. The dilution methodology was used to prepare the samples for analysis. The concentrations of tritium were determined on a Beckman 1501 scintillation counter.

Gross chemistry and lithium bromide samples were prepared and analyzed by the Water Analysis Laboratory, Water Resources Center of Desert Research Institute, Reno, Nevada. All samples, except those indicated, were prepared according to methods found in "Methods for Chemical Analysis of Water and Wastes" (Environmental Monitoring and support laboratories, 1979). Appendix I lists the species which were analyzed for gross chemistry, the method of analysis, equipment used, and the appropriate references.

RESULTS AND DISCUSSION

In the following sections, the objectives of this study will be discussed: the origin of Rainier Mesa ground water, period of principal recharge, total recharge through U12n Tunnel and Rainier Mesa, the percent of precipitation which recharges the mesa, the extent of mixing, hydraulic response, travel time, and the effect of nuclear testing on ground-water chemistry and discharge. The data used to draw each conclusion will be analyzed and discussed as well.

Origin of the Ground Water Found in Rainier Mesa

There are two possible hypothesis concerning the origin of ground water found in Rainier Mesa. The first hypothesis states that recharge is not occurring and that all ground water found in Rainier Mesa is relict water from a pluvial period. The second hypothesis states that recharge is presently occuring, albeit in small amounts.

Evidence to support the relict water hypothesis was found during the mining of the tunnel systems. Almost all of the seeps intercepted during drilling operations were characterized by an initially large discharge which drop off fairly rapidly to little or no discharge Thordarson (1965). However, a few seeps have drained continuously since first being mined.

It is this evidence which brought about the hypothesis of modern precipitation which is recharging the tunnel seeps. In order to prove which hypothesis is correct, an examination of the tunnel discharge and the isotopic signatures of the tunnel seeps and Rainier Mesa precipitation was conducted. The discharge from U12n.05 tunnel is plotted on Figure 8. This graph illustrates an increase in discharge over the entire month. This seep is not the only seep which exhibits an increase in discharge, both the U12n.03 and portal wiers have recorded similiar increases during March. If the increase in discharge is a yearly event as is suspected, then it is best explained by present day precipitation recharging Rainier Mesa.

The isotopic ratios of the 03 and 05 drift seeps were compared to the isotopic ratios of the precipitation falling on Rainier Mesa. The information is plotted on Figure 9. This graph reveals that the precipitation tends to fall on the Craig meteoric water line. The isotopic ratios of the tunnel seeps plot on the meteoric water line as well, near the middle of the Rainier Mesa precipitation. Figure 9 indicates that the fracture water found within the Indian Trails Formation is isotopically similar to the precipitation which falls on Rainier Mesa. This piece of

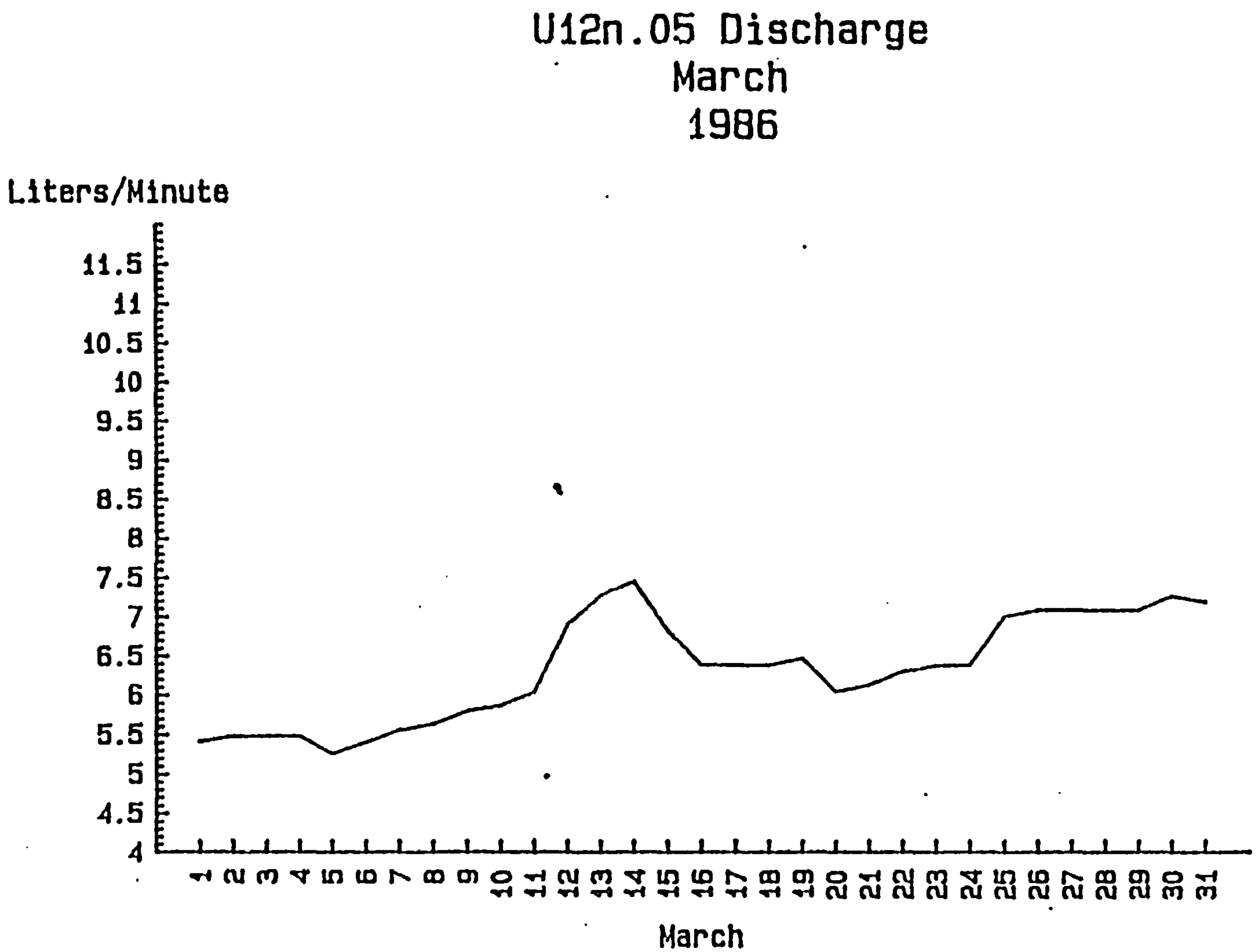

Figure 8. U12n.05 Drift Discharge for March, 1986

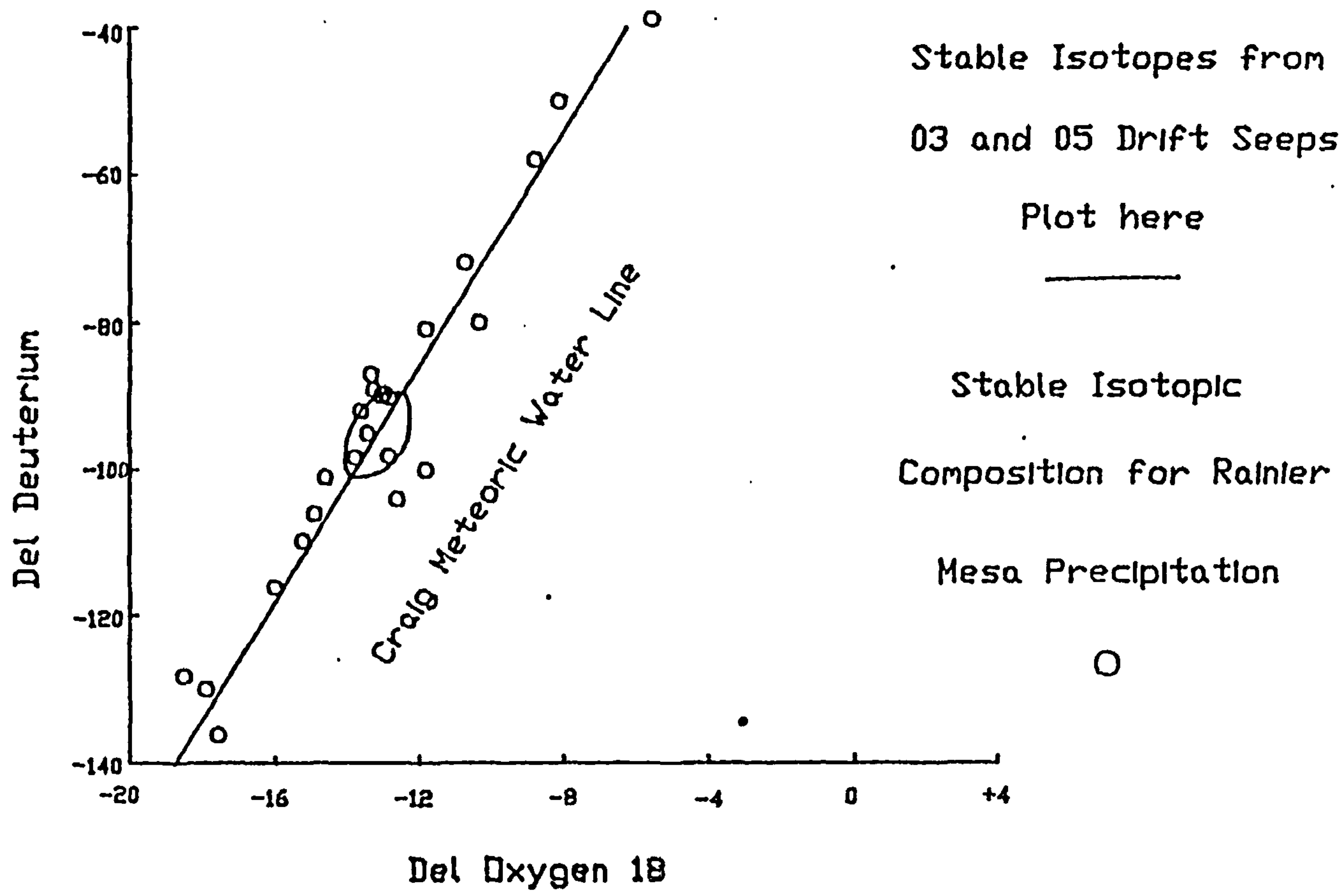

Figure 9. A Plot of the Isotopic Composition of Rainier Mesa Precipitation and Ground Water Found in U12n.03 and U12n.05 Drift Seeps

information coupled with the observation of an increase in discharge, indicates that the water found in the seeps of Rainier Mesa is derived from recent recharge.

Period of Principal Recharge

The precipitation regime of Rainier Mesa is characterized by a winter maximum and early summer minimum (Figure 10), with a mean summer temperature of 36° C higher than the mean winter temperature. These observations tend to indicate that winter is the primary period of recharge. However, the factors previously mentioned are not the only processes which control infiltration and recharge rates; the extent of overland flow, precipitation intensity and duration, and the rate of snowmelt also affect recharge rates. Summer storms within southern Nevada are of short duration and extreme intensity, and seem just as likely to recharge Rainier Mesa as the longer term winter storm systems.

In order to solve this problem, the deuterium composition of the ground-water seeps were compared to that of the precipitation. The deuterium values for Rainier Mesa precipitation and ground water are shown on Figure 11. The available ground-water isotopic record ranges from -89 to -101 per mil del deuterium. Summer precipitation del deuterium values range from -39 to -116 per mil and winter precipitation ranges from -80 to -104 per mil. The

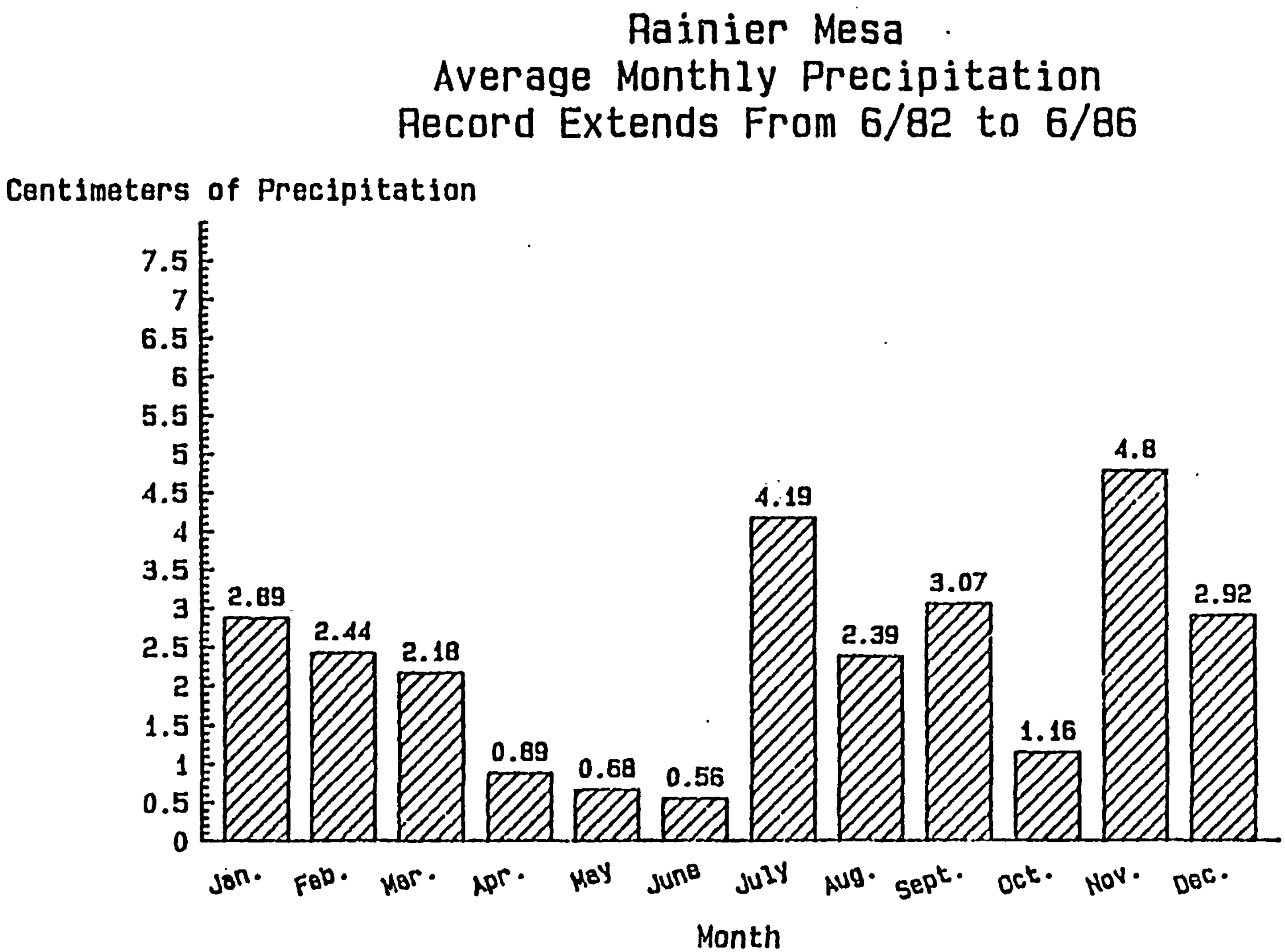

Figure 10. Average Monthly Precipitation of Rainier Mesa for the last four years.

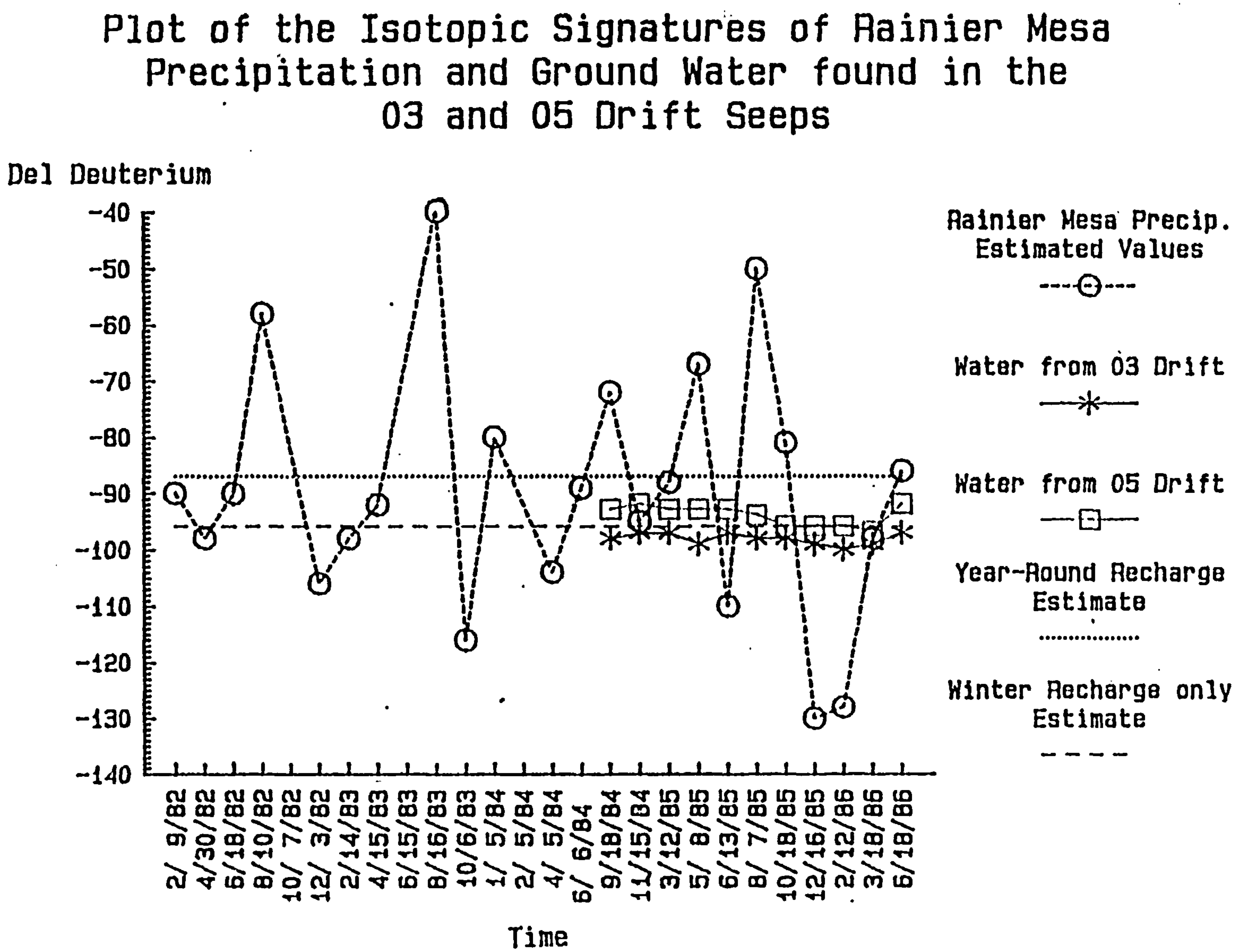

Figure 11. A Plot of the Isotopic Signatures of Rainier Mesa Precipitation and Ground Water Found in U12n.03 and U12n.05 Drift Seeps

ground-water isotopic ratios tend to better fit the winter precipitation isotopic range. Oxygen-18 shows a similiar best fit to the winter isotopic range. Oxygen-18 fractionates to a lesser degree than deuterium, thus the comparison between the precipitation and ground-water isotopic composition is best shown by using only deuterium. Since there is a large overlap between summer and winter isotopic ranges, a simple mixing model will be used to determine the period of principal recharge.

The model excludes the exceedingly light precipitation for the winter of 1985-86 and later dates. This is justifiable if it is assumed that the water from this period of precipitation is still in transit. The model uses the precipitation record of the last four years, divided on the lines of periods between isotopic samplings. The resulting total precipitation values for each period are weighted by their isotopic content, added together, and divided by the total precipitation record. This model yields a rough estimate of the isotopic content of the seep waters if year-round precipitation from the period of record, recharged Rainier Mesa. The data and results are presented in Table 3. The same model was used to calculate a hypothetical isotopic ratio of the tunnel seeps if only late fall and winter precipitation recharged into Rainier Mesa. The data and results of this model are presented in Table 4.

Comparison of the two models reveals that the winter

TABLE 3. THE ESTIMATED ISOTOPIC CONTENT OF RAINIER MESA GROUND WATER IF YEAR ROUND RECHARGE OCCURRED

Period of Time Represented	Total Precip (cm)	del Deuterium Ratio	Weighted del Deuterium Ratio
12/ 1/81 - 2/ 9/82	3.45	-90	-310.50
2/ 9/82 - 4/30/82	6.88	-98	-674.24
4/30/82 - 6/18/82	3.35	-90	-301.50
6/18/82 - 8/10/82	2.46	-58	-142.68
8/10/82 - 12/ 3/82	15.34	-106	-1626.04
12/ 3/82 - 2/14/83	10.46	-98	-1025.08
2/14/83 - 4/15/83	1.45	-92	-133.40
4/15/83 - 8/16/83	4.04	-39	-157.56
8/16/83 - 10/ 6/83	5.51	-116	-639.16
10/ 6/83 - 1/ 5/84	6.27	-80	-501.60
1/ 5/84 - 4/ 5/84	2.11	-104	-219.44
4/ 5/84 - 6/ 6/84	0.53	-89	- 47.17
6/ 6/84 - 9/18/84	15.95	-72	-1148.40
9/18/84 - 11/15/84	1.12	-95	-106.4
11/15/84 - 3/12/85	9.96	-88	-876.48
3/12/85 - 5/ 8/85	1.35	-67	- 90.45
5/ 8/85 - 6/13/85	1.57	-110	-172.70
6/13/85 - 8/ 7/85	5.18	-50	-259.00
8/ 7/85 - 10/15/85	2.06	-81	-166.86
Totals	99.04		-8598.66

Average isotopic signature = -87 per mil del deuterium

TABLE 4. THE ESTIMATED ISOTOPIC CONTENT OF RAINIER MESA GROUND WATER IF ONLY WINTER RECHARGE OCCURRED

Period of Time Represented	Total Precip (cm)	del Deuterium Ratio	Weighted del Deuterium Ratio
12/ 1/81 - 2/ 9/82	3.45	-90	-310.50
2/ 9/82 - 4/30/82	6.88	-98	-674.24
8/10/82 - 12/ 3/82	15.34	-106	-1626.04
12/ 3/82 - 2/14/83	10.46	-98	-1025.08
2/14/83 - 4/15/83	1.45	-92	-133.40
10/ 6/83 - 1/ 5/84	6.27	-80	-501.60
1/ 5/84 - 4/ 5/84	2.11	-104	-219.44
9/18/84 - 11/15/84	1.12	-95	-106.40
11/15/84 - 3/12/85	9.96	-88	-876.48
Totals	57.04		-5473.18

Average isotopic signature = -96 per mil del deuterium recharge model best approximates the present isotopic signature found in Rainier Mesa tunnel seeps (Figure 11). Thus winter is the primary period of recharge for the Mesa. Summer precipitation can recharge but only as a minor component of total flux into the mesa.

Ground-Water Mass Balance for U12n Tunnel

The three components for a ground-water mass balance for U12n Tunnel can be stated as:

$$T = D + R + E$$

where D is equal to the amount of liquid water passing through the U12n Tunnel portal discharge point, R is equal to the quantity of tunnel water which infiltrates back into the fracture system before reaching the tunnel portal, E is equal to the quantity of water removed by the tunnel circulation system by evaporation processes, and T is the total water which enters the tunnel.

D has been measured for nine months at U12n Tunnel portal, and the results are presented in Appendix II. These data have been analyzed in order to eliminate the effects of mining activities on the total discharge. The result is the estimated base discharge from December 1985, to July 1986, which is shown on Figures 12 and 13. The mean discharge was calculated using only those data points taken when mining effluent was not disrupting the base

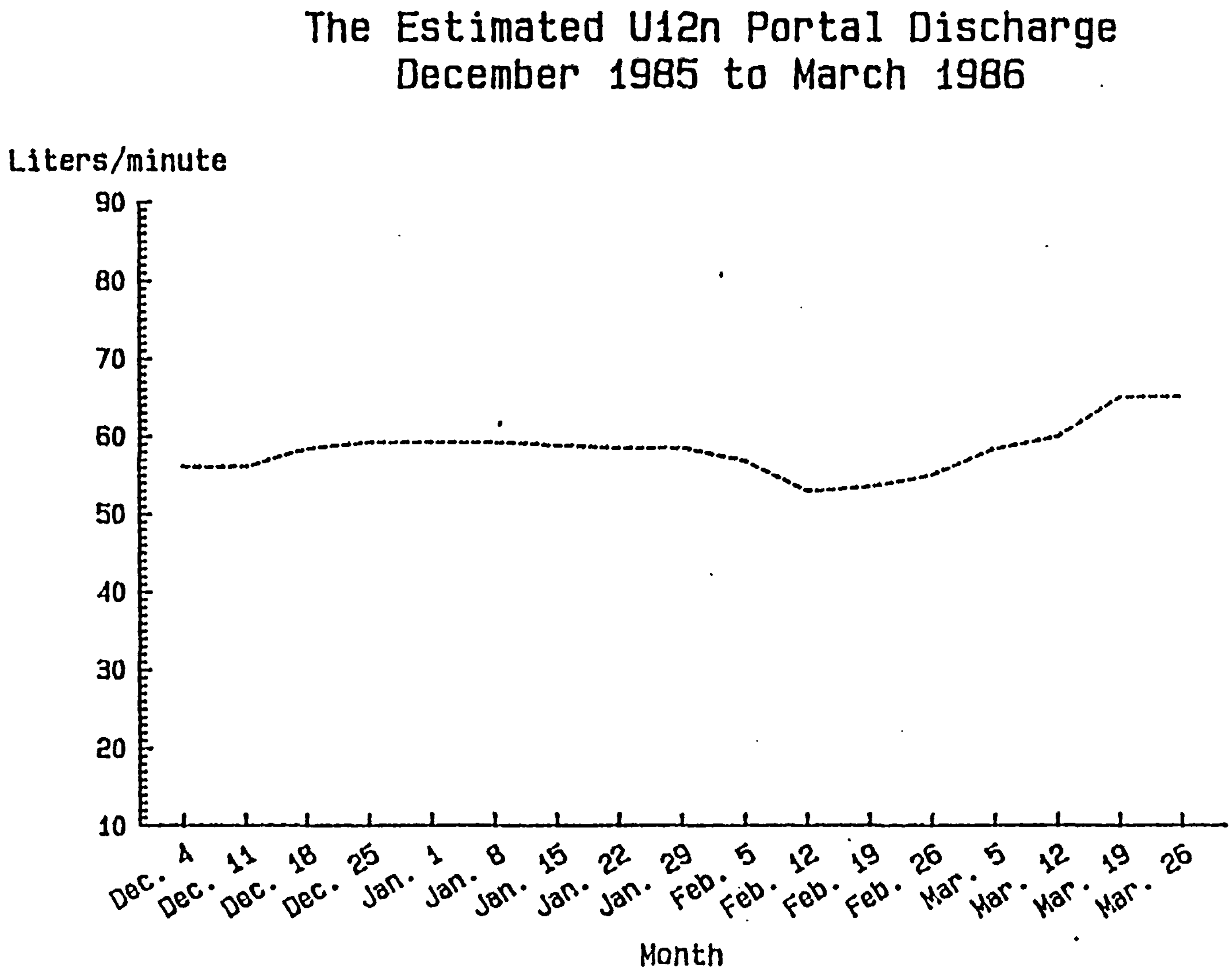

Figure 12. The Estimated U12n Portal Discharge for December 1985 to March 1986

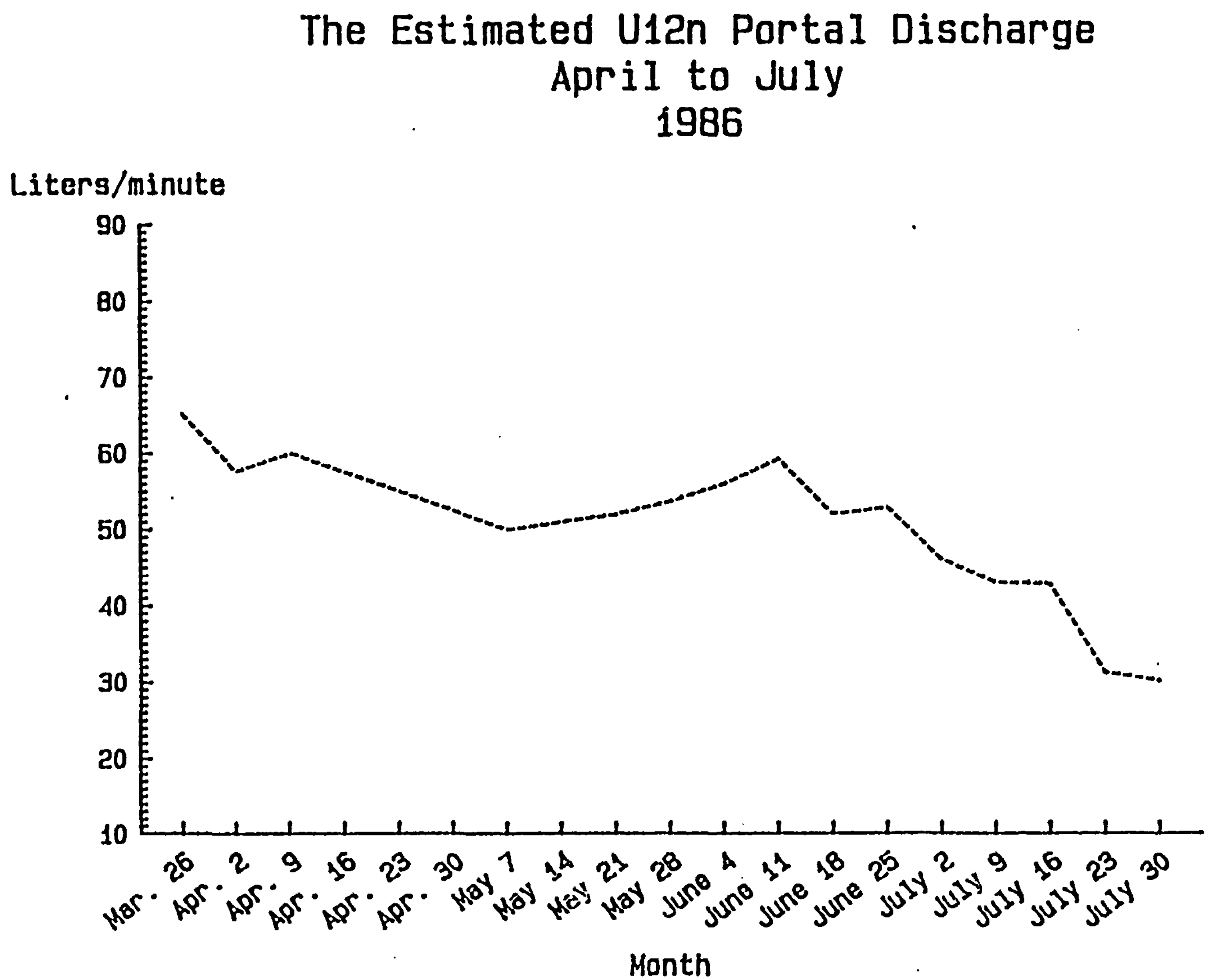

Figure 13. The Estimated U12n Portal Discharge for April to July 1986

discharge. The result was a mean discharge of 53 ± 9 liters per minute derived from the 89 data points indicated in the portal discharge data of Appendix II. Using this number, a yearly discharge of 27,900 ± 4700 m^3/yr was calculated. The discharge record is rather short for the use of estimating an accurate yearly discharge from U12n Tunnel. Monitoring of the total discharge should continue to improve the accuracy of this estimate.

For the tunnel systems, R is an unknown quantity. It is assumed that the U12n Tunnel drainage system removes the ground water before a significant portion can recharge back into the fracture network. For the purpose of this report, that quantity is assumed to be zero.

E has been quantified by measurements of both relative humidity and temperature inside and outside U12n Tunnel, and by a knowledge of the flux of air passing from the tunnel to the outside environment. The raw temperature and humidity data are presented in Appendix III, with the mean relative humidity, and the mean temperature for each drift in Table 5. Table 6 presents the mean relative humidity change between the tunnel and the surrounding outside environment. The mean relative humidity change for the entire tunnel is 38 ± 13%. When this value is taken into account with the mean temperature within the tunnels, one can calculate the amount of water being transported by each cubic meter of tunnel air to the outside environment. The

TABLE 5. TEMPERATURE AND RELATIVE HUMIDITY DATA FOR U12N TUNNEL.

Mean Relative Humidity	Mean Temperature	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	

TABLE 6. CALCULATIONS FOR GROUND-WATER TRANSPORT BY EVAPORATION FROM U12n TUNNEL

Temperature (°C)	Mean Relative Humidity	Wieght in gm of a 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 Amount of Water per m^3 of Tunnel Air			
18.9	59%	16.12	9.5
Least Amount of Water per m^3 of Tunnel Air			
18.3	14%	15.65	2.1

*Values from Weast, R. C. (1981)

calculations for the greatest and least measured amount of water being transported, as well as the mean, are on Table 6.

There are two ventilation systems circulating air through U12n Tunnel, the tunnel system which moves 2180 m^3 per minute, and the portal system which moves 1000 m^3 per minute, creating a combined total of 3180 m^3 per minute passing through U12n Tunnel, 24 hours a day, five days a week (Frank Clingan, personal communication, September 29, 1986). The quantity of air which circulates through the tunnel on a yearly basis is approximately 1.19×10^9 m^3 per year.

From Table 6, one can see that the average quantity of water being removed from U12n Tunnel by a cubic meter of air is 5.8 ± 2.0 gm/m^3. This translates into a total of:

$$3180\ m^3/min \times 5.8 \pm 2.0\ gm/m^3 = 18.4 \pm 6.4\ kg/min$$

which is equal to 18.4 ± 6.4 l/min or approximately $7,000 \pm 2,400$ m^3/year. If the following calculation is made:

$$\frac{E \times 100}{(D + E)} = C$$

Then the component of total flow contributed by evaporation processes, which is C, can be calculated;

$$7000 \pm 2400\ m^3/yr \times 100 \div (7000 \pm 2400\ m^3/yr + 27900 \pm 4700\ m^3/yr) = 20 \pm 16\%$$

The large standard deviation of this estimate is an expression of the standard deviation of the variables. There are other problems which are inherent to this estimated component of flow. The percent contributed by various sources from which water is evaporated is not known. These sources are: evaporation of interstitial waters from the tunnel walls, evaporation derived from puddles of water emanating from tunnel seeps, or in the worst case, evaporation of water which is artificially introduced by mining activites.

Examination of the portal discharge charts reveals that water from mining activites often supplies the largest component of flow from U12n Tunnel. The same is not true for the evaporation component; mine slurry is quickly removed to the tunnel drainage system before significant evaporation can occur. The majority of evaporated water is most likely derived from evaporation of interstitial water from the portal walls.

A third problem is the limited nature of the data; most of the humidity and temperature data were taken during the summer months, a period of time when the greatest amount of evaporation would occur. Thus the results are skewed towards a larger evaporation component than what would actually occur on a yearly basis, also the accuracy of the estimate is in doubt due to the limited time during which humidity and temperature data were taken. Yet even with the above problems, a given percentage of the total flow of ground water is being contributed by evaporation processes and removal by the ventilation system. This component is certainly no greater than the 20 ± 16% calculated here. This estimate shall be used in calculating the upper limit for total flow:

$$T = D + E$$

$$(27900 + 7000 \pm ((4700)^2 + (2400)^2))^{.5}$$

$$= 34900 \pm 5300 \ m^3/yr$$

Assuming that there is not a substantial recharge process (R), ccurring within the tunnels, the total discharge emanating from U12n Tunnel is estimated at 34,900 ± 5,300 m^3 per year.

Estimated Total Recharge Passing Through Rainier Mesa Caprock

An estimated 34,900 ± 5,300 m^3 of water per year discharges from U12n Tunnel. Since U12n Tunnel acts as the discharge point for a certain recharge basin on the mesa surface, it is assumed that the boundaries for this recharge basin can be estimated if the following are true: (1) the aquifer matrix within Rainier Mesa acts as a storage unit rather than a conduit for ground-water transport; (2) all fracture systems within U12n Tunnel recharge basin discharge into U12n Tunnel; (3) the Rainier Mesa fracture system is fairly uniform throughout the mesa in its ability to transmit ground water; (4) the recharge basin for U12n Tunnel is controlled more by proximity to the tunnel than topography; and (5) precipitation and infiltration are uniform over Rainier Mesa. Through the above assumptions, the portion of the mesa which acts as a recharge basin for U12n Tunnel can be estimated, and from this it can be determined how much ground water is actually passing through the mesa.

Some of the above assumptions are difficult to defend while others are more obvious. For the aquifer matrix to act as storage, the hydraulic conductivity must be very low to inhibit interstitial flow. The hydraulic conductivity for the zeolitic bedded tuffs range from 0.19×10^{-9} to 9.44×10^{-9} m/s. These values are so low that the fracture system within Rainier mesa is easily the dominant form of transport, thus interstitial transport may be assumed to be zero. Assumption 2 which states that all fracture systems in the U12n recharge basin discharge into U12n Tunnel, is not as easily justified. If all areas of the recharge basin lie directly over a portion Of U12n Tunnel, then most fractures will discharge into it. This assumption will be a guiding principal in determining the exact placement of the recharge basin.

The assumption that the fracture system is uniform through out the mesa is also not completely justifiable, but an accurate fracture study over all of Rainier Mesa is beyond the scope of this study. Since the major lithologic units are fairly uniform within the Mesa, they should impart some degree of uniformity to the fracture density and continuity as well. Assumption 4 is fairly accurate. The topography on top of Rainier Mesa is gentle and rolling, and is not a dominant control on the fracture system which carries the ground water, whereas tunnel proximity to the water-bearing fractures is more important. Assumption 5, which states that precipitation and infiltration are uniform throughout the mesa, is also not completely accurate. However, this only applies to the sporadic thundershowers of summer precipitation. Since the dominant recharge source is the more uniform winter precipitation, this assumption is justifiable. If we assume that precipitation is uniform, and the fracture system is also, then recharge can be considered to be uniform throughout the mesa.

The above methodology will not determine a unique number for recharge; however it will arrive at a conservative estimate. The recharge basin will be estimated as large as reasonably possible to achieve a conservative recharge value per unit area, which will be used to determine a conservative estimate of total recharge through Rainier Mesa.

Through the use of the above guidelines, Figure 14 was constructed showing a best estimate recharge area for U12n Tunnel. The dominant controls for creating this basin are proximity to the tunnel and topographic controls. From Figure 14 it has been determined that the U12n Tunnel

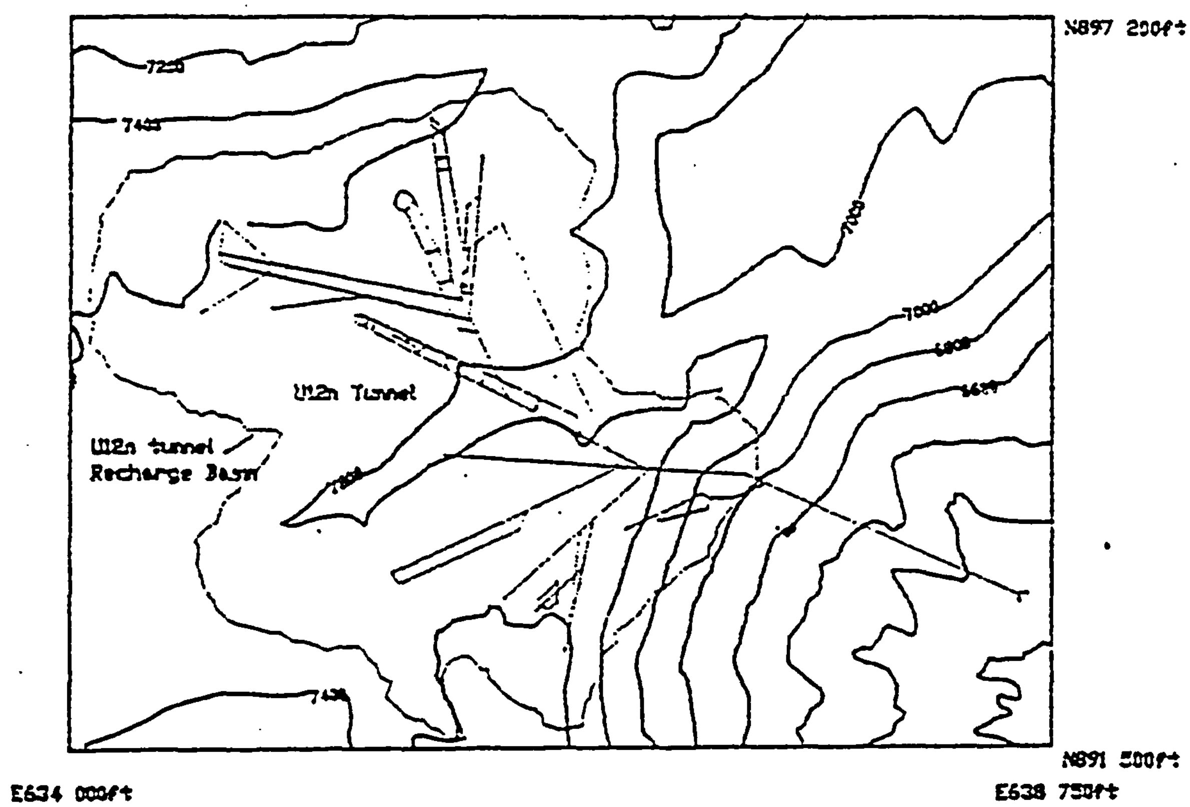

Figure 14. The Estimated U12n Tunnel Recharge Area

catchment basin is $1.47X10^6$ m^2. It is possible that the actual size of the recharge basin is considerably different than this estimate, but by how great of a deviation is unknown. If we arbitrarily assign an error estimate of 20%, then the area of the U12n Tunnel catchment basin becomes $1.47X10^6 \pm 2.94X10^5 m^2$. This error estimate is large enough to account for most variations in size of the recharge basin.

The caprock of Rainier Mesa covers approximately 11.4 km^2. If the amount of precipitation, recharge, and the fracture systems are uniform throughout Rainier Mesa then:

$$\frac{R}{U} = \frac{Rg}{Ug}$$

where U is equal to the catchment basin area of U12n Tunnel, R is equal to the total area of Rainier Mesa caprock Ug is equal to the amount of ground water passing through U12n catchment basin, and Rg is equal to the amount of ground water passing through the caprock of Rainier Mesa. Thus;

$$\frac{R\ X\ Ug}{U} = Rg$$

where;

$$1.14X10^7\ m^2\ (34900 \pm 5300 m^3/yr) \div 1.47X10^6 \pm 294000\ m^2$$
$$= 271000 \pm 141000 m^3/yr$$

Thus a rough estimate of 241,000 ± 125,000 m^3 of ground water recharges through the Rainier Mesa caprock each year. The slopes of the mesa were not included in the calculations for several reasons. The first is the slopes are steep enough that surficial runoff is as important as infiltration. Thus it is impossible to tell how much infiltration occurs on the slopes relative to the caprock. The second reason is that the precipitation regime in such an elevationally zoned environment as the slope is not uniform, nor would the infiltration rates be so. Finally, and most importantly, the testing conducted within Rainier Mesa is conducted under the caprock, and not the slopes.

Percent of Total Precipitation Recharging into Rainier Mesa

A daily precipitation record extending from January 1959 to the present, exists for Rainier Mesa, the last four years of which are included in Appendix IV. Utilizing this record, the average yearly precipitation for the period of June 1982 to may 1986 was determined to be 27.9 ± 5.9 cm/year. Using this data, the area of the catchment basin of U12n tunnel, and the total discharge per year, the percentage of precipitation that recharges Rainier Mesa may be calculated.

It will be assumed that the total discharge calculation of 34,900 ± 5300 m^3/yr derived in the previous section is precise enough to accurately determine the percentage of precipitation which recharges Rainier Mesa. If the preceding assumption is true, then 27.9 ± 5.9 cm/yr multiplied by the total area of U12n catchment basin will result in the total amount of water which fell on the basin.

$$1.47X10^6 \pm 2.94X10^5 \ m^2 \ X \ .279 \pm .059 \ m/yr$$
$$= 4.10X10^5 \pm 2.39X10^5 \ m^3/yr$$

If the amount of water which is discharged from U12n tunnel is divided by the total amount of water which fell on U12n Tunnel catchment basin, then the percentage of precipitation which recharges the mesa may be calculated:

$$34900 \pm 5300 \ m^3/yr \ X \ 100 \div 410000 \pm 239000 \ m^3$$
$$= 8.5 \pm 21.5\%$$

This value falls near the 7% estimate of Thordarson, (1965) for precipitation which recharges through the caprock of Rainier Mesa. The estimate is accurate only if the estimates for the area of the catchment basin, the total discharge from U12n Tunnel, and the average yearly precipitation over Rainier Mesa are accurate.

Extent of Mixing Between the 03 and 05 Drift Seeps

A potential problem for contaminant transport within Rainier Mesa concerns how interconnected the fracture reservoirs are. 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 chemistry of the two seeps, and the isotopic ratios. A Stiff diagram of the chemistry of the U12n.03 drift is presented in Figure 15 and a similiar diagram for the U12n. 05 geochemistry is presented in Figure 16. Four samples were used in order to delineate the differences in geochemistry between the 03 and 05 seeps. However, 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. Another possibility exists; that the two fractures reservoirs are not well connected. It is similar geochemical processes which create the similar ground-water chemistries.

To further investigate this problem, the isotopic ratios of the two seeps were examined. This information is plotted on Figure 17. On this Figure, the 03 seep del deuterium is generally two to three per mil depleted with respect to the 05 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

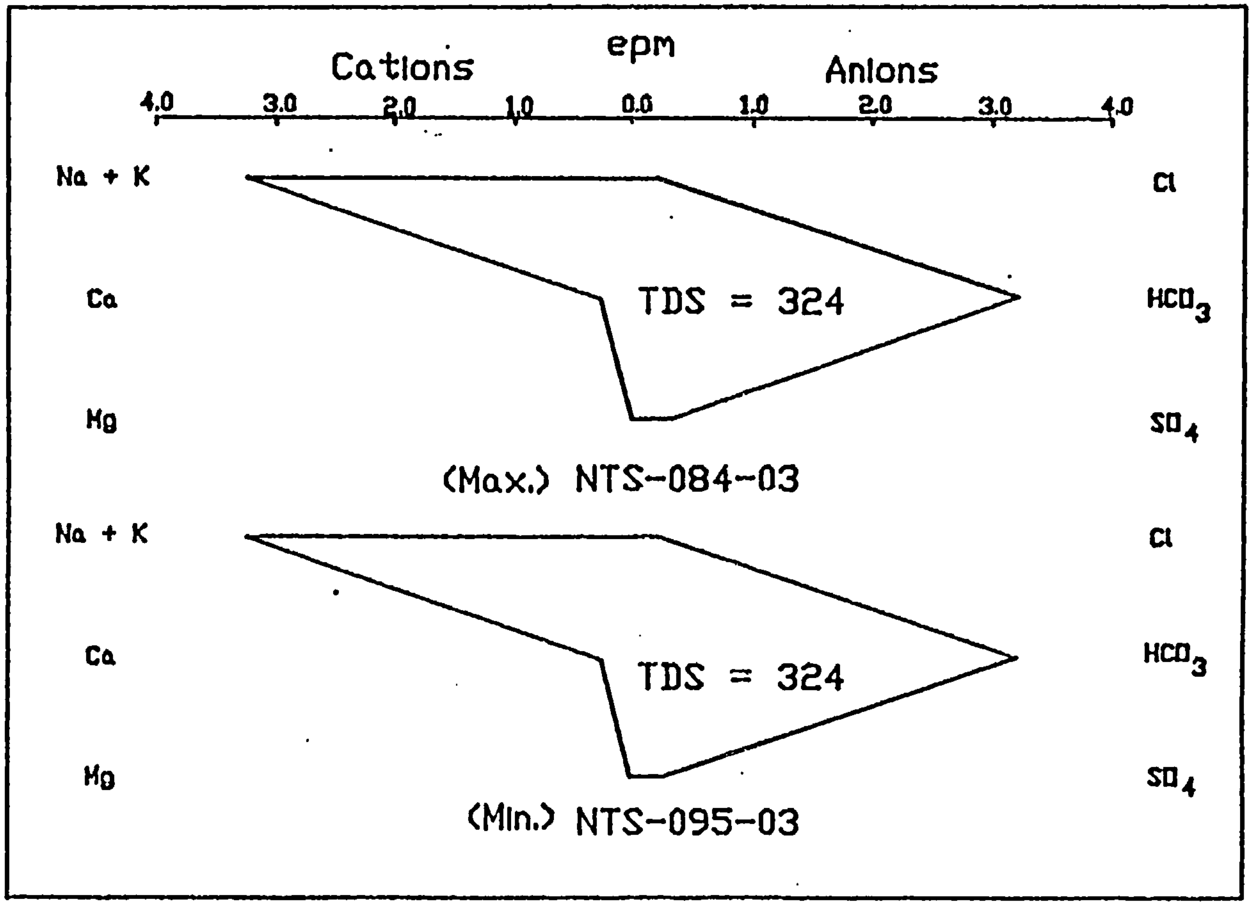

Figure 15. Stiff Diagrams of U12n.03 Seep at Maximum and Minimum Flows

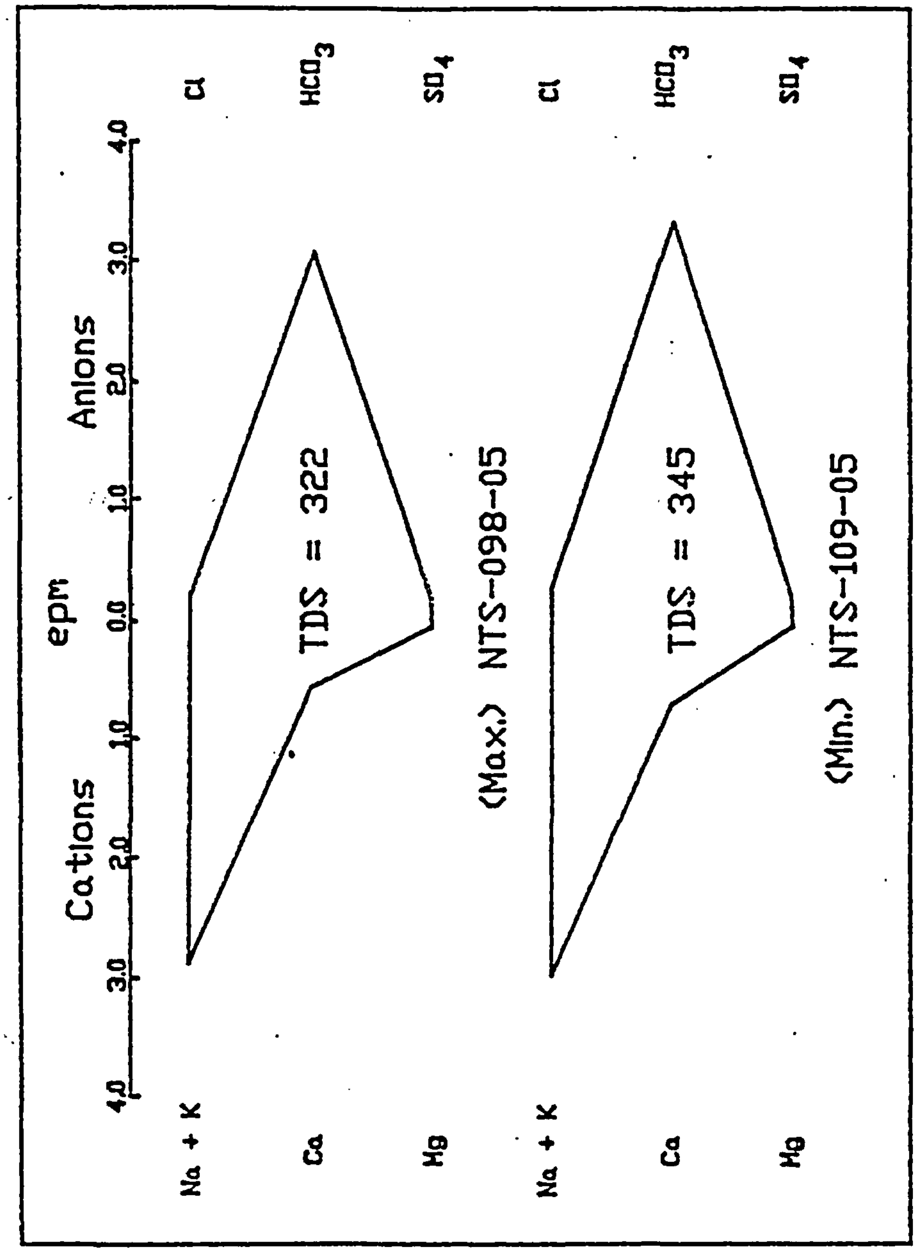

Figure 16. Stiff Diagrams of U12n.05 Seep at Maximum and Minimum Flows

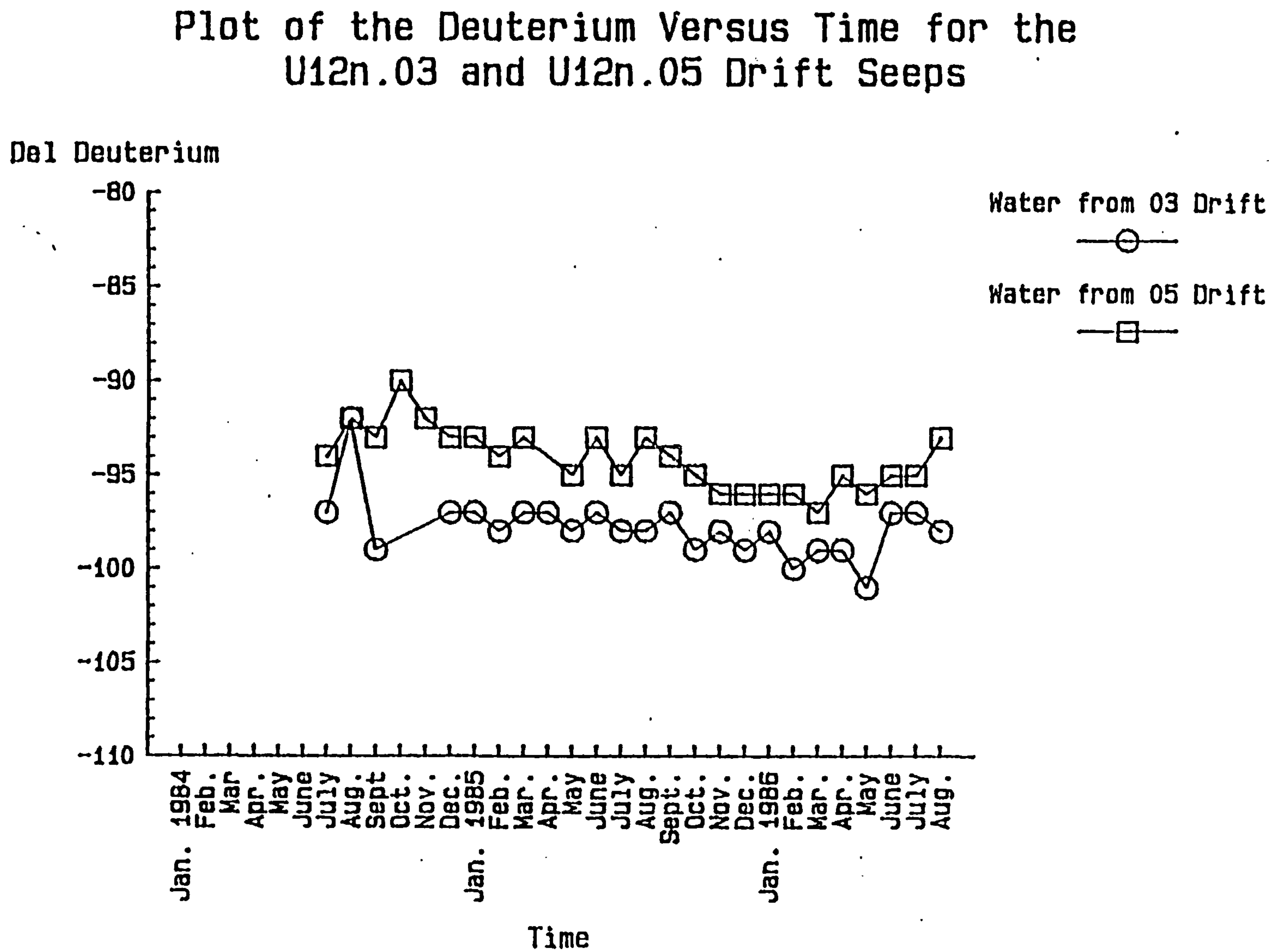

Figure 17. A Plot of Deuterium Versus Time for the U12n.03 and U12n.05 Drift Seeps

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 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 1.2-4 per mil del deuterium per 100 m are considered average. Using this gradient and the 3-4 per mil del deuterium difference between the two seeps, it can be concluded that since the 05 drift seep is 3-4 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 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. The second possibility deals with a variation in seasonal recharge due to each fracture systems 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 it relative flatness. Since summer recharge is heavier isotopically than winter recharge and the 05 fracture system is located in an area which is conducive to a relatively greater amount of summer recharge, then the 05 fracture water should be isotopically heavier than the 03 fracture water. This observation can be verified on Figures 17 and 18. A third possibility also exists. An examination of the tritium data in Appendix V reveals that the 05 drift has a concentration of 13,000 T.U. while the 03 drift has 237 T.U. Thus the 05 drift has undergone a greater degree of contamination 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 18 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 .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,

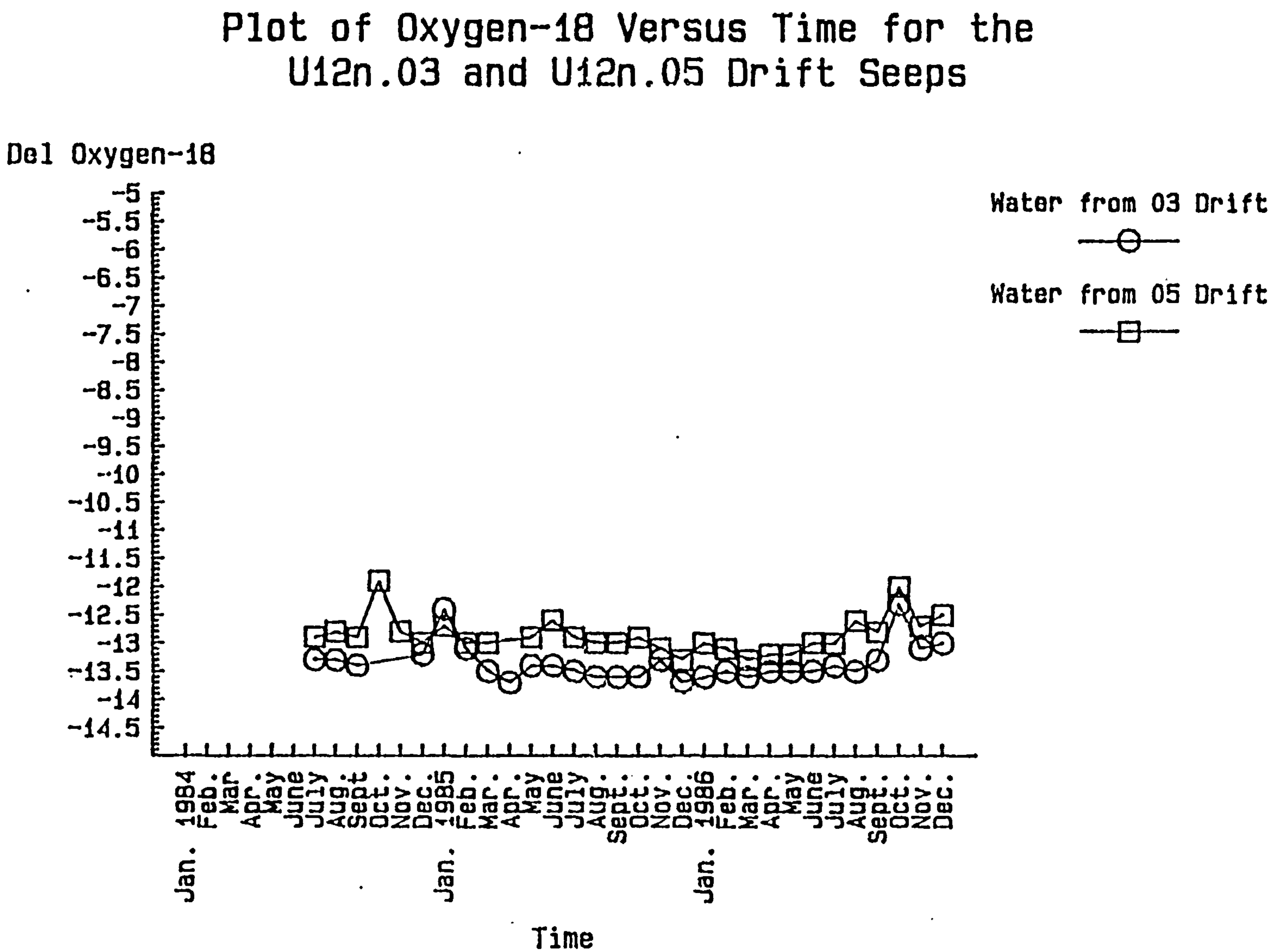

Figure 18. A Plot of Oxygen-18 Versus Time for the U12n.03 and U12n.05 Drift Seeps

and there has been contamination of the 05 drift, perhaps it is a combination of these three factors which create the enriched waters of U12n.05 fracture reservoir.

Hydraulic Response

The ground-water discharge from an unconfined aquifer or perched ground-water lens increases when a given precipitation event recharges that aquifer. This increase in flow is not necessarily due to the actual precipitation flowing out as discharge. As is often the case, the recharging precipitation increases the hydraulic head of a system which creates a pressure response, which in turn increases discharge. This phenomenon is called the hydraulic response to a given precipitation event. The period of time between the precipitation event and the corresponding increase in ground-water discharge is known as the period of hydraulic response. The period of hydraulic response is an important parameter for a ground-water system, especially in an environment where ground-water contaminant transport is a concern.

In order to delineate the period of hydraulic response for Rainier Mesa, two important pieces of information were required. The first is a complete precipitation record for the mesa, the second is a discharge record from a seep within the mesa. The precipitation record used is from the period of September 1, 1983 to August 31, 1986. The data are presented in Appendix IV. The discharge data were obtained from the Stevens recorders in U12n.03, U12n.05, and U12n portal. These three discharge records extend from September 27, 1985 for the 03 and 05 drifts, and December 4, 1985 for the portal discharge, to August 31, 1986. The data are presented in Appendix II.

The period of hydraulic response was determined by averaging the 03, 05, and portal discharge records from suspected recharge events using a simple averaged response technique (Robert Kinnison personal communication, August 8, 1986). This methodology uses a number of raw time series which record an event that will occur within a variable time period after a stimulus is applied. The technique averages the time from stimulus to response for n records and determines an average response time.

A total of six discharge records were obtained for two precipitation events which were recorded at all three wiers. The suspected recharge events occurred on November 11 and 12, 1985 and January 30, 1986. The six discharge events are presented on Figures 19 and 20 as discharge versus the number of days after the recharge event. The resultant plot of the average response is on Figure 21. By inspection, a hydraulic response for each recharge event begins to manifest itself at approximately 120 days, or more appropriately, at four months.

In the plot of the average response, an increase in discharge is noted at approximately 30 days and lasting for

Plot of the U12n.03, U12n.05, and U12n Portal Discharge following the Precipitation Event of Nov. 11, 1985

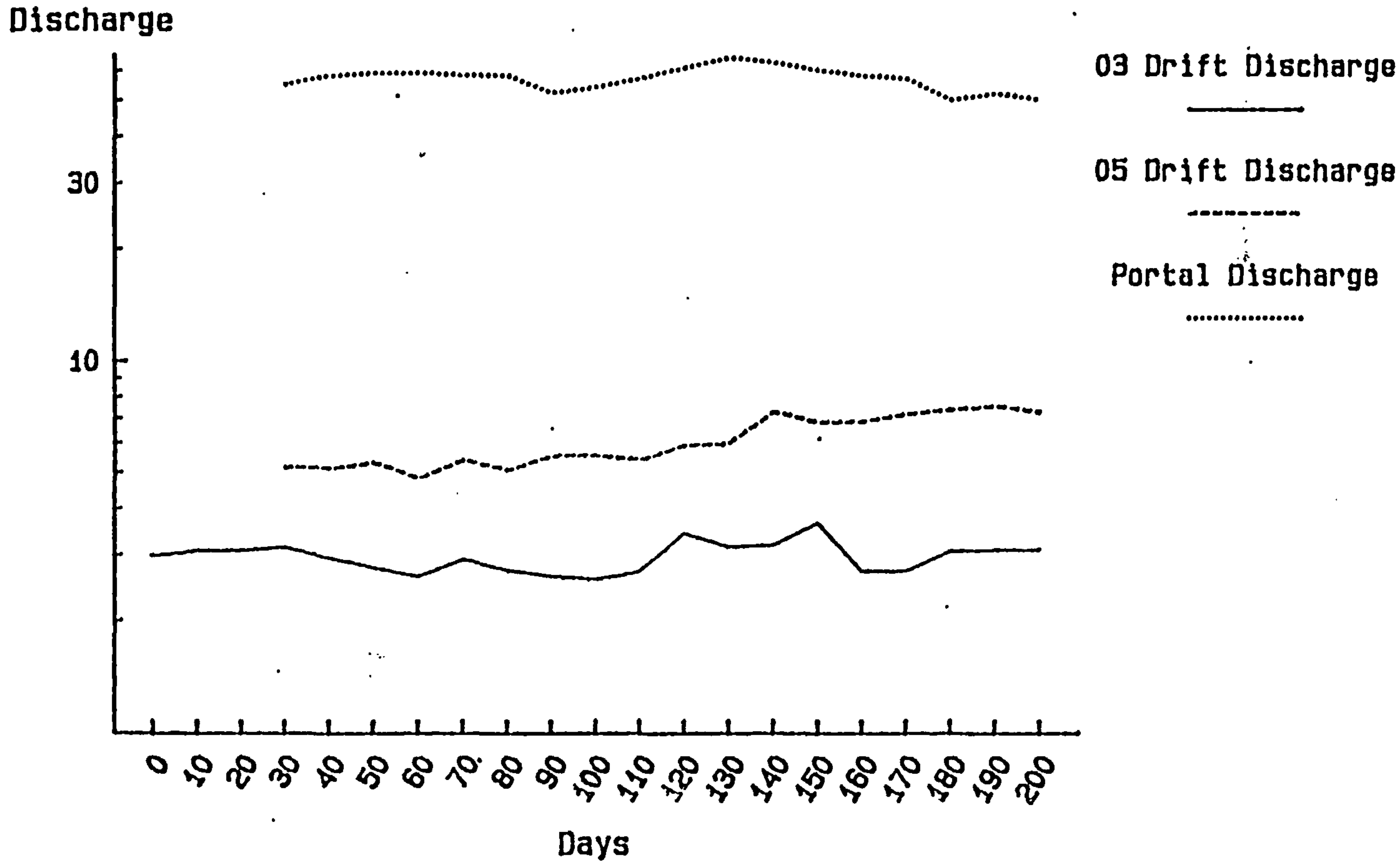

Figure 19. A Plot of the U12n.03, 05 and Portal Discharges Following the Precipitation Event of Nov. 11, 1985

Plot of the U12n.03, U12n.05, and U12n Portal Discharge following the Precipitation Event of Jan. 29, 1986

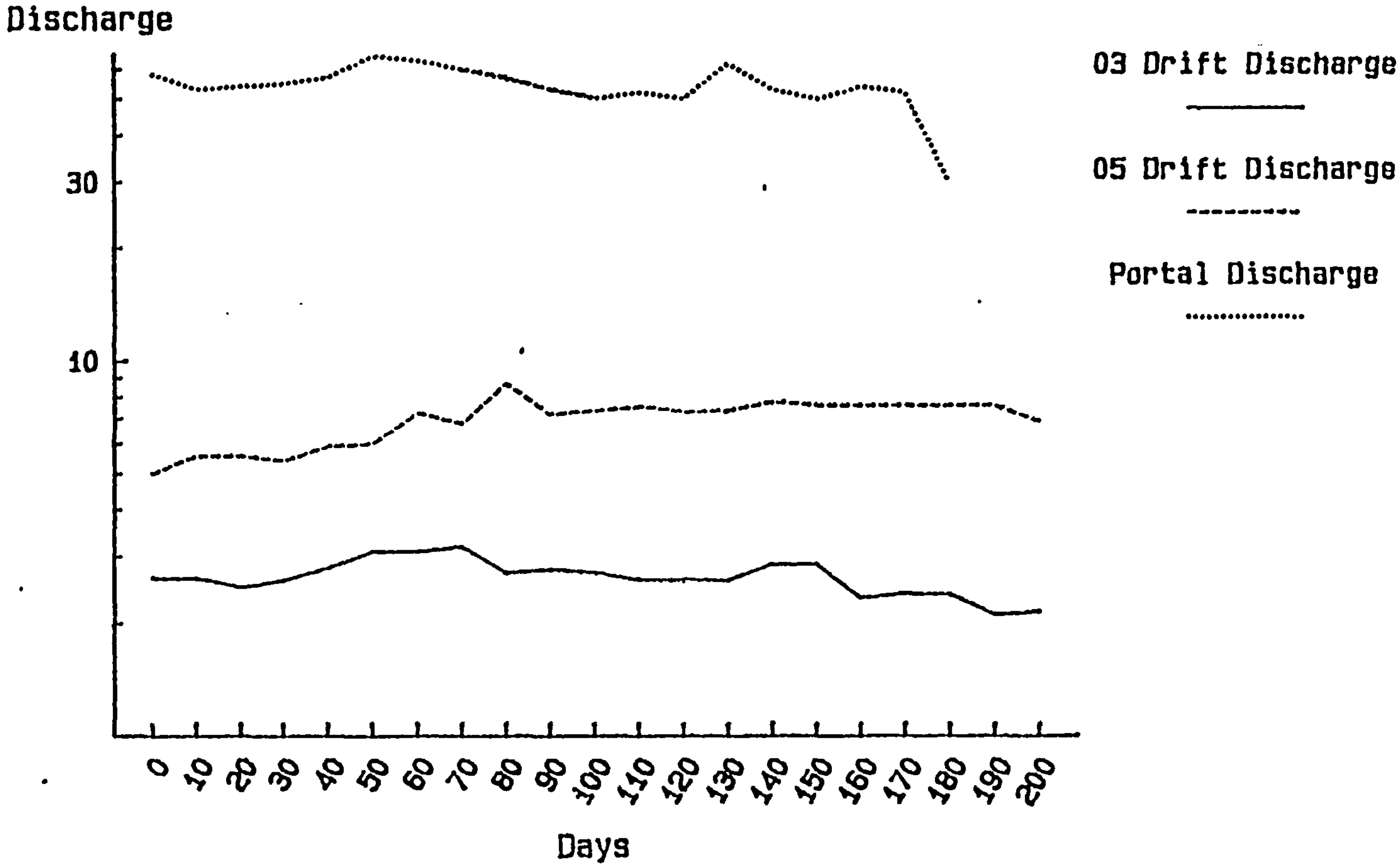

Figure 20. A Plot of the U12n.03, 05 and Portal Discharges Following the Precipitation Event of Jan. 29, 1986

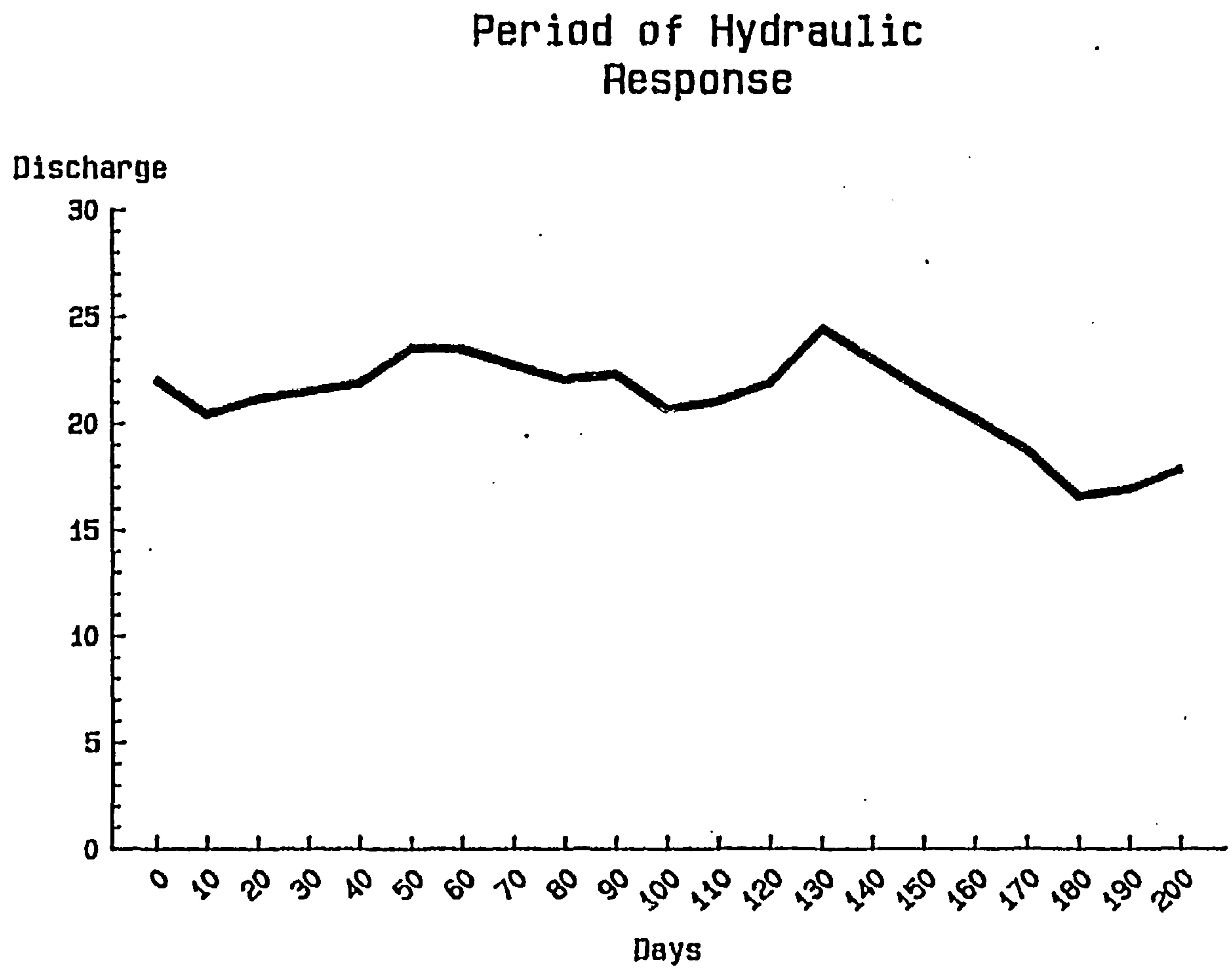

Figure 21. The Averaged Response of Six Discharge Events From U12n Tunnel Seeps

70 days after the recharge event. There are two reasons for this. The first reason is due to the nature of the average response technique and the relative closeness of the two recharge events. The individual discharge records on Figures 18 and 19 are 200 days long. The two recharge events are seperated by 78 days. The discharge records on Figure 20 exhibit the hydraulic response of both storms, one at 30 days and the other at 110 days. When averaged into the response plot, the two storms recorded on Figure 20 were expressed on Figure 21. The second reason for the slight increase is a nuclear test which occurred on April 9, 1986. This test caused an increase in discharge which was reflected at 70 days on Figures 20 and 21.

Travel Time

Several methodologies were attempted in order to determine the ground-water travel time in the Rainier Mesa. The first methodology incorporated the tracer studies described in the Methodology section. The direct yellow and fluorescene dyes used during the point source test of June 24, 1984 were never detected at the tunnel system level. The lithium bromide and optical brightner used in the diffused test were not detected either, as of September 9, 1986. Several possibilities could account for this. The most obvious is that travel times are longer than the two and a half years since the first dye test was conducted. Two previous studies from Clebsch (1960), and Henne (1982) indicate travel times of less than two and a half years. A likely possibility is that both tracer tests failed to infiltrate the active fracture transport system. The fracture system of Rainier Mesa is anisotropic and heterogenous. It is hard to determine whether the fractures on which the tracers were applied are hydrologically connected to the seeps presently being monitored within U12n Tunnel. Another possibility may pertain to the tracers applied on March 23, 1986. A large recharge event did not occur until late 1986, thus the tracers may have remained on the mesa surface until the winter precipitation events of 1986-1987. The monitoring for these tracers will continue. A final possibility is that some of the tracers are not conservative within an environment like Rainier Mesa. This applies to fluorescene, direct yellow, and optical brightner; however, lithium bromide has been used sucsessfully in a tuffaceous environment (Schmotzer et al., 1973). Most likely the tracers were simply not applied to the proper fractures for them to be transported to the tunnel system.

Tritium studies were also attempted within U12n Tunnel. Due to contamination from nuclear tests, the tritium levels within the tunnel systems are far above background levels. The lowest level of tritium found was 267 T. U. within the 03 drift and the highest was 697,000 T.U. at U12n Tunnel portal. This level of contamination effectively blocks the use of tritium to age date the water.

A third method was also attempted. The stable isotopic signatures of both the precipitation and the ground-water seeps were plotted versus time. These graphs were analyzed for changes that could be correlated between the precipitation and ground-water isotopic signatures. Both auto-correlation and cross-correlation methods were attempted on these data sets, but the results were not statistically significant. The most plausible reason for this is that the isotopic ratios of the U12n Tunnel seeps are very homogenous with respect to time. The homogeneity is a reflection of the fairly uniform isotopic composition for the last four years of precipitation. It is also a reflection of the extent of mixing which occurs within individual fracture systems. If pulses of ground water traveled through the system, then some variation of the isotopic ratios would be seen. If mixing of these recharge events occurred within the perched ground-water lenses, then the isotopic composition would be relatively constant as is shown on Figures 17 and 18.

The isotopic composition for precipitation has been uniform except for the winter of 1985-86. The isotopic composition for that season's precipitation is a weighted average of approximately 129 per mil del deuterium. There is the possibility that this anamoly will be reflected in the ground water of U12n Tunnel System, thus the monitoring of the isotopic ratios of the ground water will continue.

A simple conservative mixing calculation predicts that when this precipitation reaches the tunnel seeps, a depletion of at least six per mil del deuterium is expected. If this depletion is detected, then an approximate travel time for the ground water within Rainier Mesa may be established.

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., 1963, 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).

This study documents the effects of a nuclear explosion on local ground-water discharge and chemistry. During the course of the 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 on Figure 22. An announced nuclear test was conducted on April 10, 1986, corresponding with 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 eighteen days. Other announced tests have been

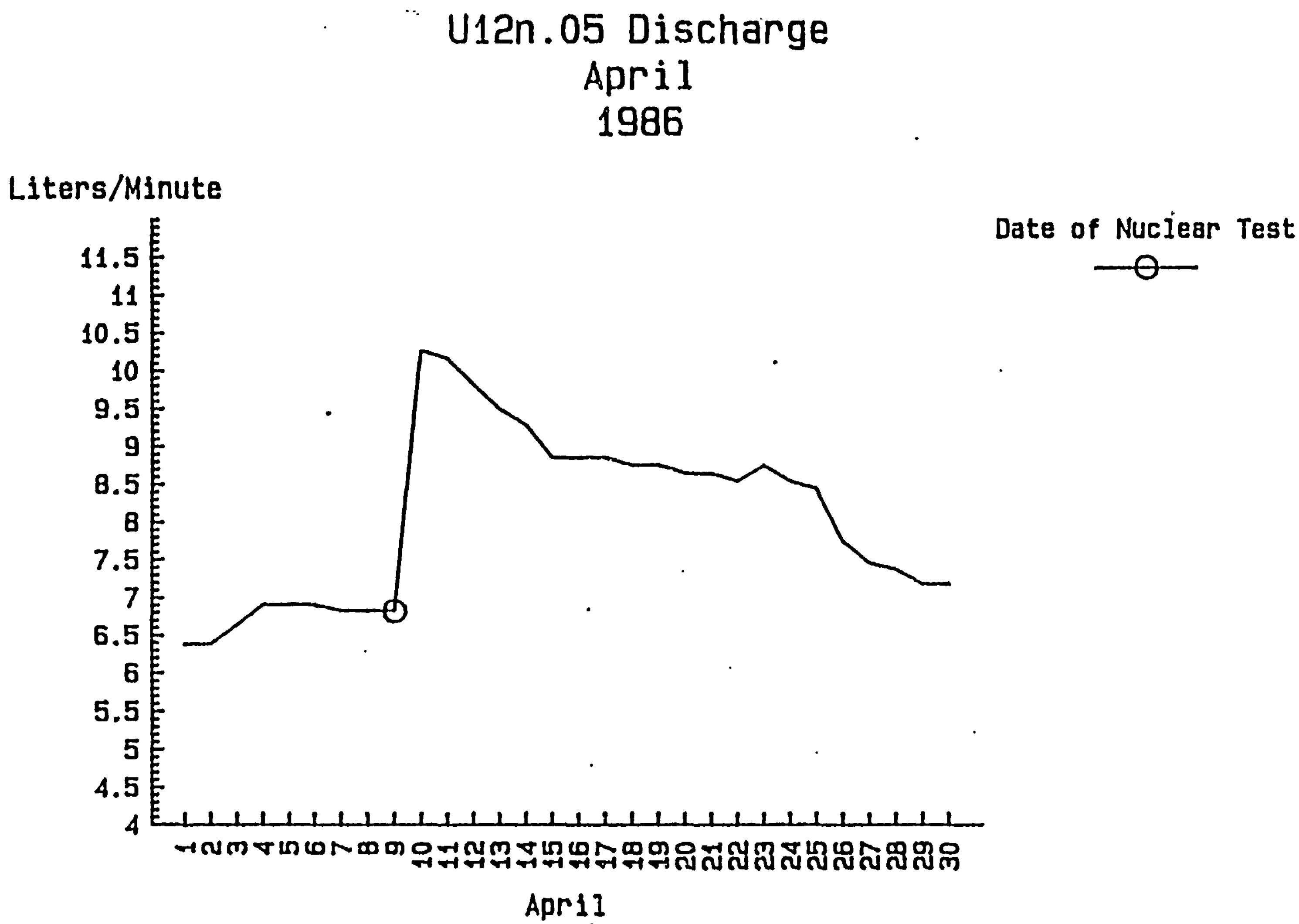

Figure 22. A Plot of Increased Discharge Due to a Nuclear Test

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 in the 03 drift, and Figures 25 and 26 are for a test conducted on April 10, 1986 as recorded in 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 which has a longer residence time within the formations of Rainier Mesa. This would most certainly be the interstitial water, which owing to the low effective permeability of the matrix, has a much 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 for the before and after cases are presented in the Stiff diagrams of Figures 27 and 28. Normal discharge waters are already elevated in

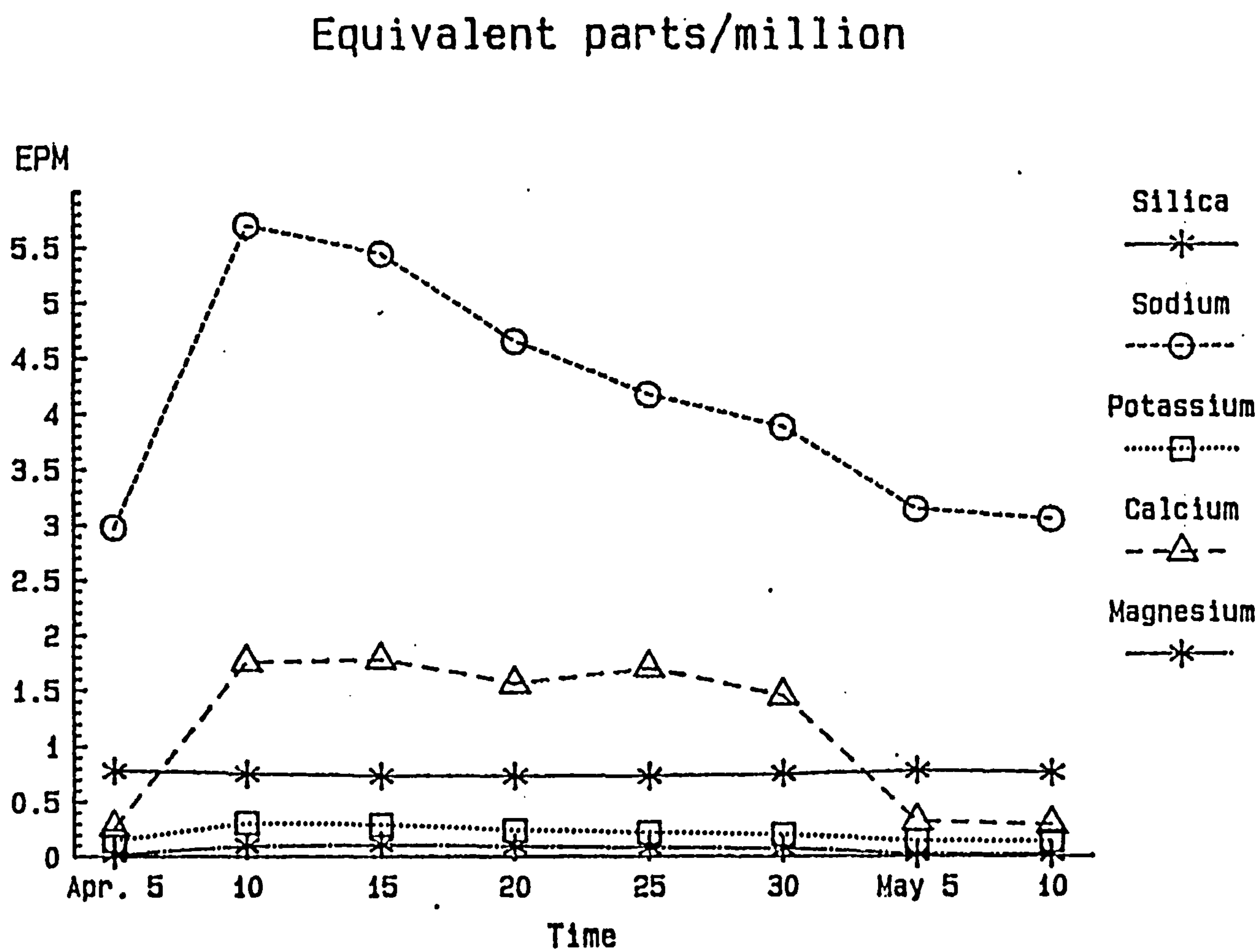

Figure 23. A Plot of SiO_2, Na, K, Ca, and Mg versus Time Following a Nuclear Test Conducted on April 6, 1985

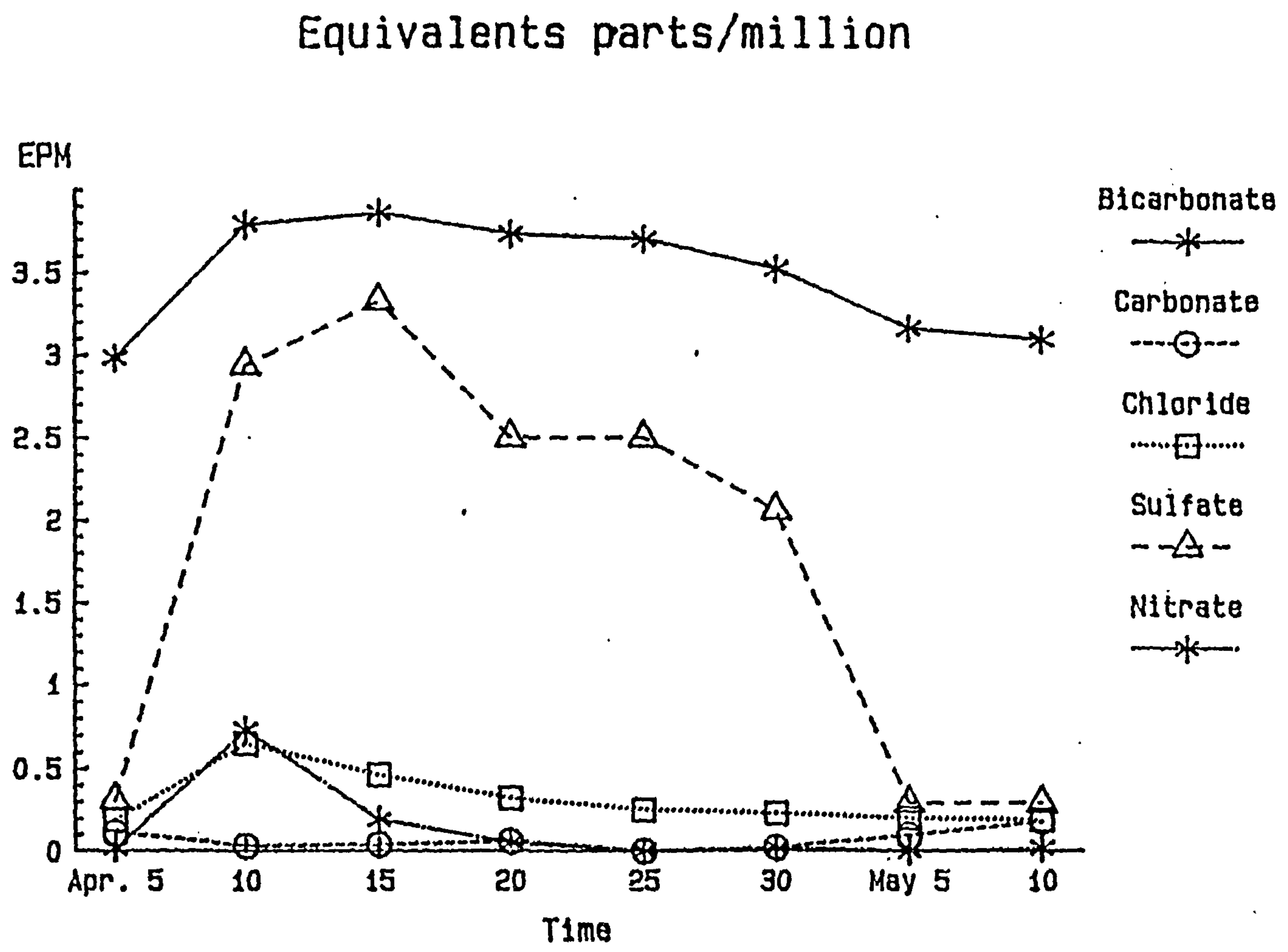

Figure 24. A Plot of HCO_3, CO_3, Cl, SO_4, and NO_3 Versus Time Following a Nuclear Test Conducted on April 6, 1985

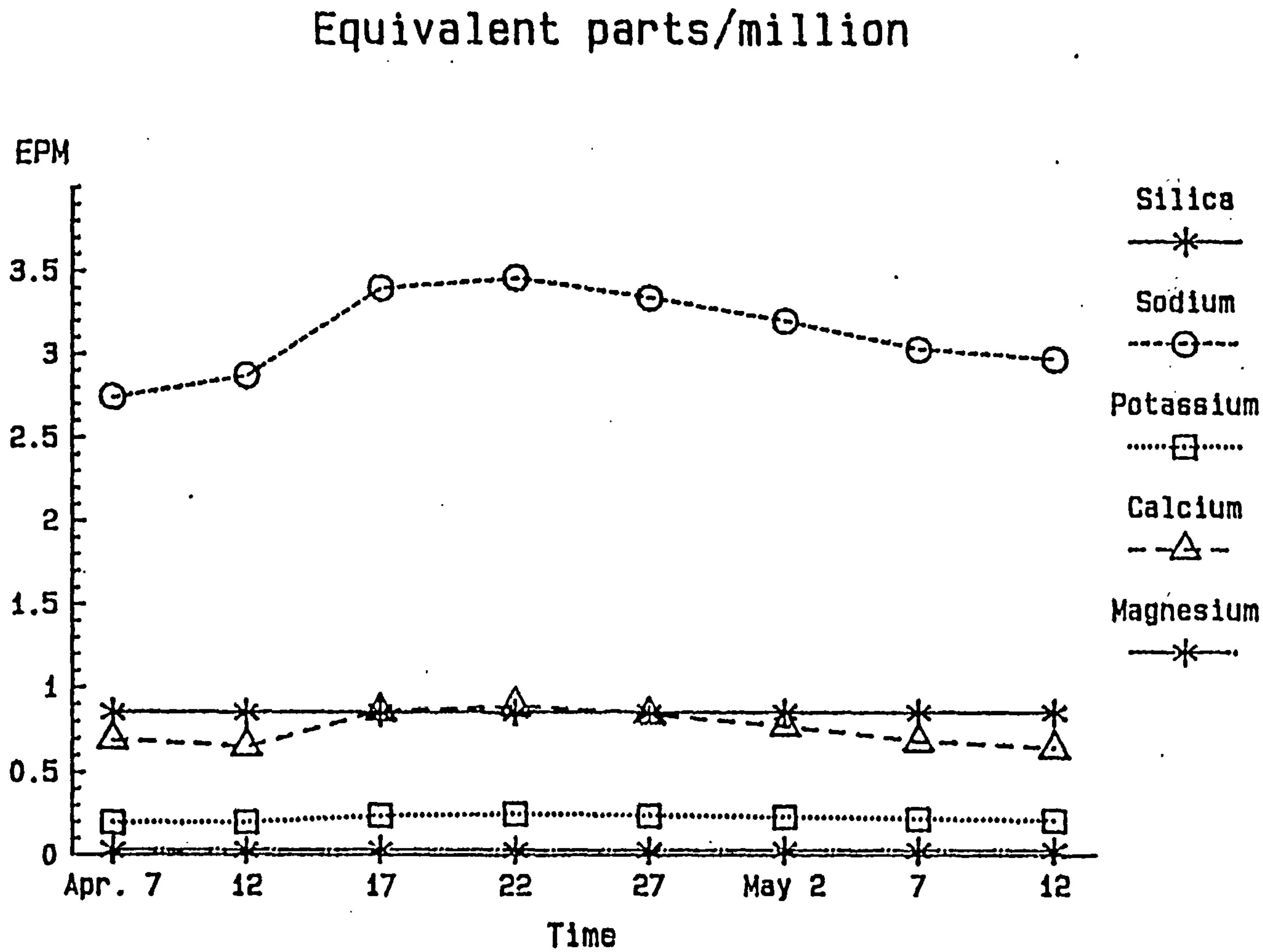

Figure 25. A Plot of SiO_2, Na, K, Ca, and Mg versus Time Following a Nuclear Test Conducted on April 10, 1986

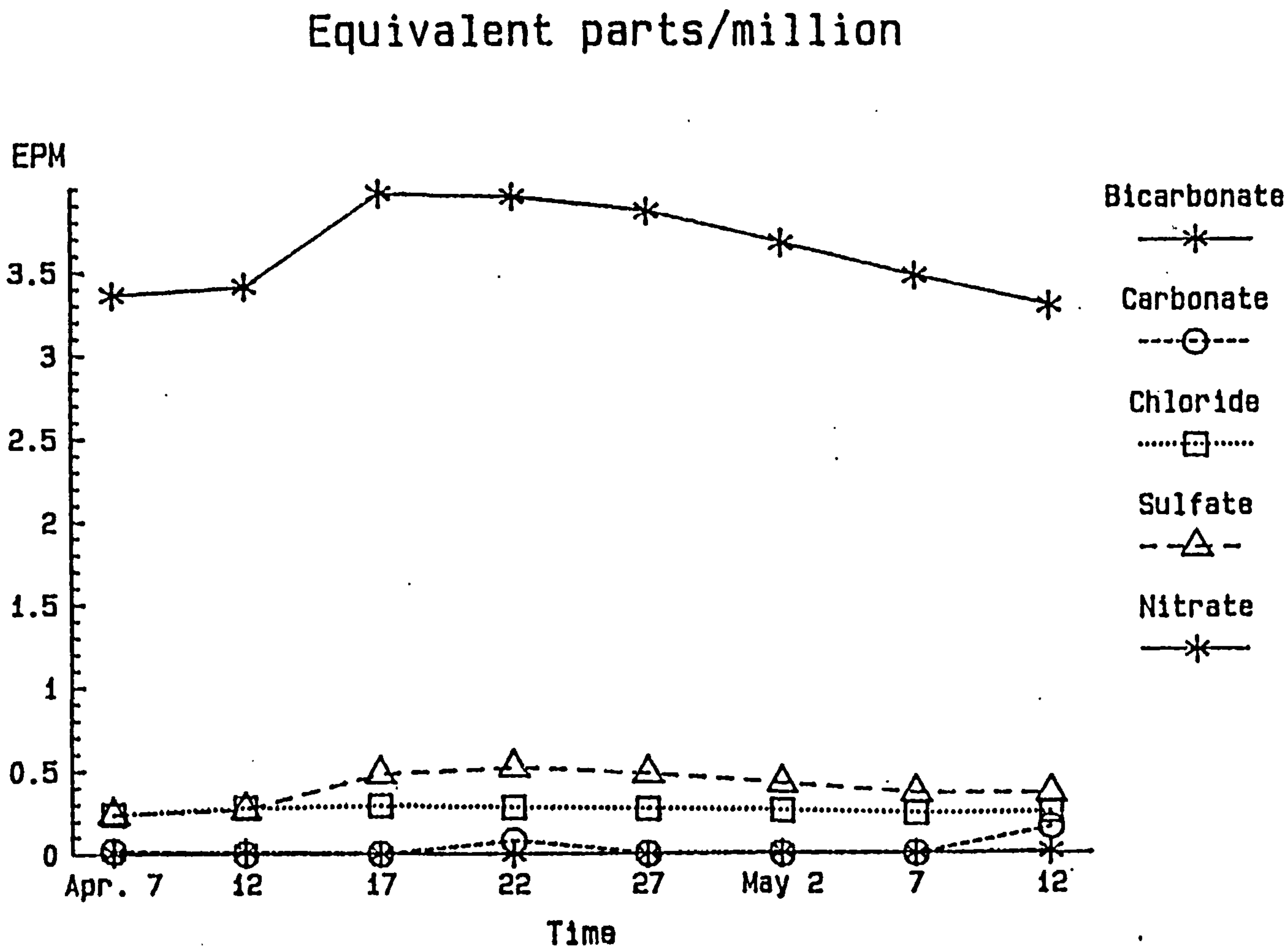

Figure 26. A Plot of HCO_3, CO_3, Cl, SO_4, and NO_3 versus Time Following a Nuclear Test Conducted on April 10, 1986

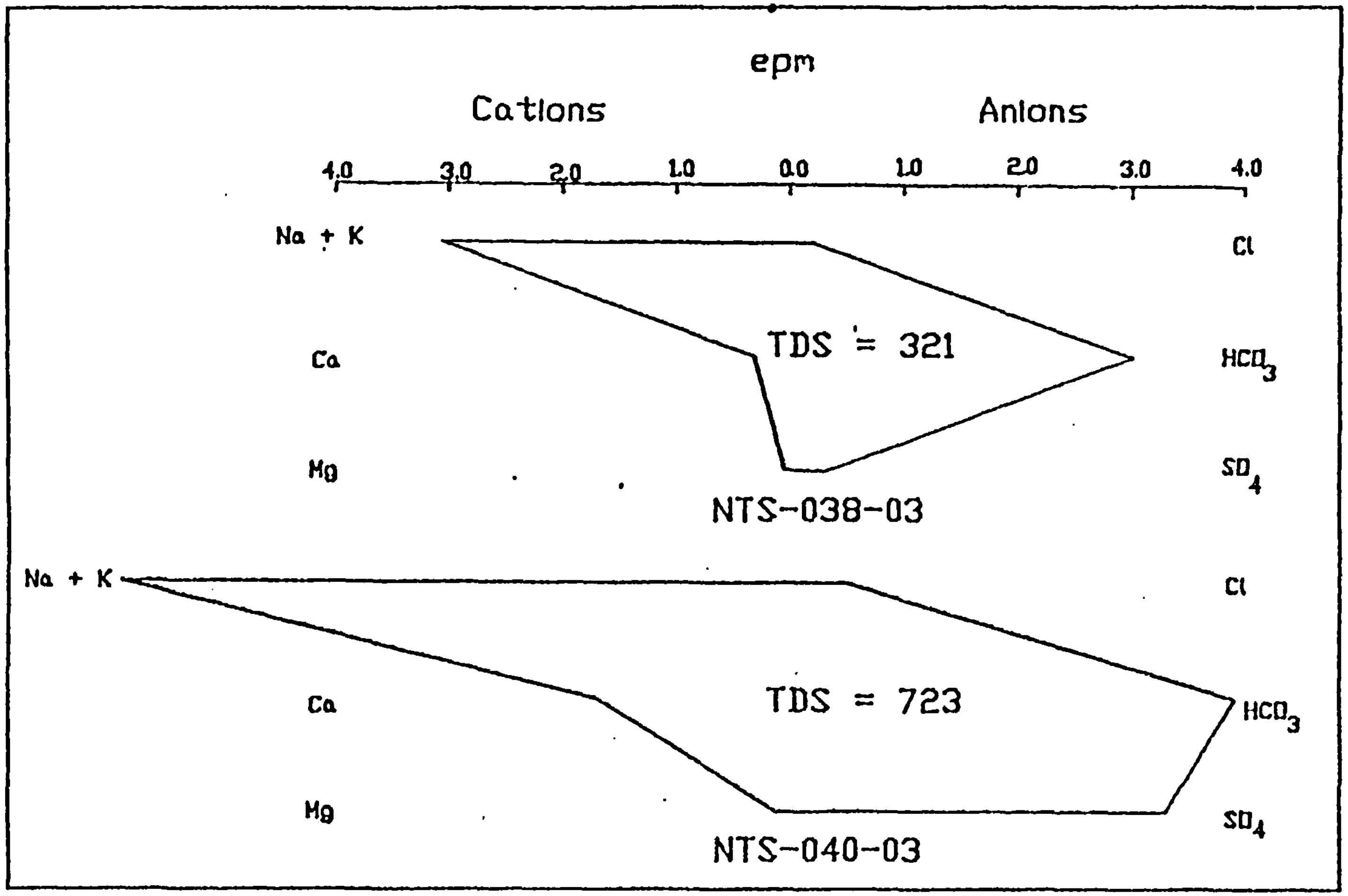

Figure 27. Stiff Diagrams of Before and After The April 6, 1985 Nuclear Test.

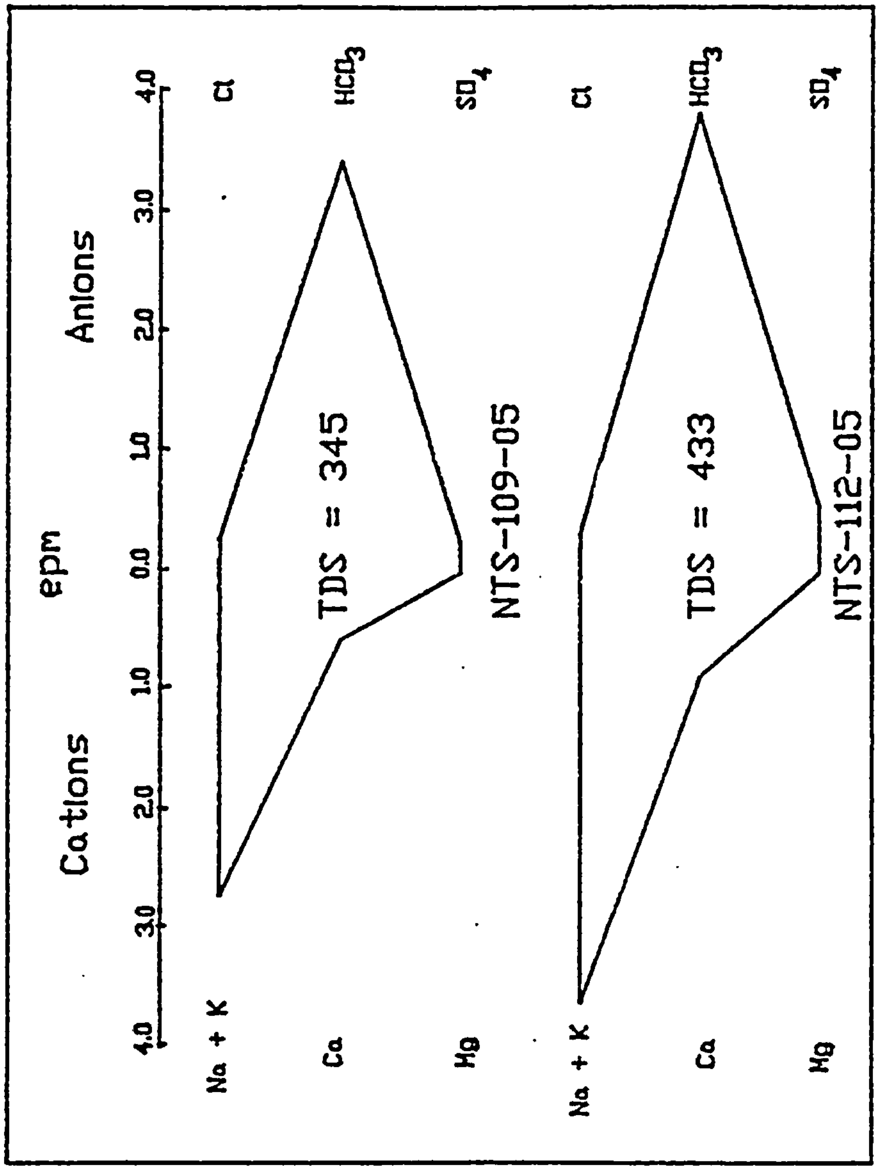

Figure 28. Stiff Diagrams of Before and After The April 10, 1986 Nuclear Test.

sodium and bicarbonate as described by White _et al_. (1978). Within the bomb pulses the sodium and bicarbonate are increased in concentration, but so is sulfate. The Stiff diagrams reveal that the April 6, 1985 bomb pulse has a much greater increase in the concentraion 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.

The large increase in sulfate for these waters are anomalous because the presence of even small quantities of sulfate minerals or their weathering products have never been reported within the formations of Rainier Mesa. There are only a few possibilities which can explain the elevated sulfate concentration within the interstitial waters of Rainier Mesa. One is that the multiple drilling projects within the mesa have contaminated the interstitial waters; however, this is not likely due to the low hydraulic conductivity of the formations which would inhibit the dissemination of the contaminant. Another hypothesis noted by White _et al_. (1978) is the presence of a relict water high in sulfate which remains from the time of deposition of the formations. Supporting this hypothesis are the traces of crossbedding and reworking in both the Paintbrush and Indian Trail Formations indicative of a fluvial or lacustrine environment prior to lithification. Thus it is a good possibility that a relict water high in sulfate resides as an interstitial water in the Indian Trail Formation.

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 similiar chemically to that of interstitial waters samples. The following variables are used:

Q_1 = prebomb 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

C_t = species concentration for Q_t

Where:

$$Q_t - Q_1 = Q_2$$

and:

$$Q_t C_t = Q_1 C_1 + Q_2 C_2$$

thus:

$$(Q_t C_t - Q_1 C_1)/Q_2 = C_2$$

Only for the April 10, 1986 bomb pulse, does the required chemistry and discharge variables exist. For 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 3. The concentrations of dissolved species for this time are recorded on Table 7 under column C_i. 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 7 under column C_t. Solving for Q_2:

$$Q_t - Q_1 = Q_2$$

$$8.54 - 6.82 = 1.72 \text{ l/min}$$

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 given in Table 7 under the heading of C_2. A Stiff diagram for the resultant water is on Figure 29, included are a comparative (sample #3) and an average (sample #16) interstitial sample from Benson (1976). The calculated C_2 water is similiar 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.

An interesting point is the comparison of Benson's sample #16 and sample #3 to the calculated C_2 water type. Sample #16 suggests that the chemistry for the interstitial water is not constant throughout Rainier Mesa, or that

TABLE 7. VARIABLES AND RESULTS OF MIXING CALCULATIONS USED TO DISCOVER THE COMPOSITION OF INTERSTITIAL WATER CONTRIBUTED DURING A NUCLEAR TEST AS RECORDED IN THE 05 DRIFT.

Q_1 = 6.82 l/min

Q_2 = 1.72 l/min

Q_3 = 8.54 l/min

(all concentrations given in ppm)

Species	C_1	C_t	C_2
pH	8.31	8.38	8.65
TDS	348	434	775
Bicarbonate	205	241	383
Sulfate	11.5	25.0	78.5
Flouride	0.0	0.0	0.0
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

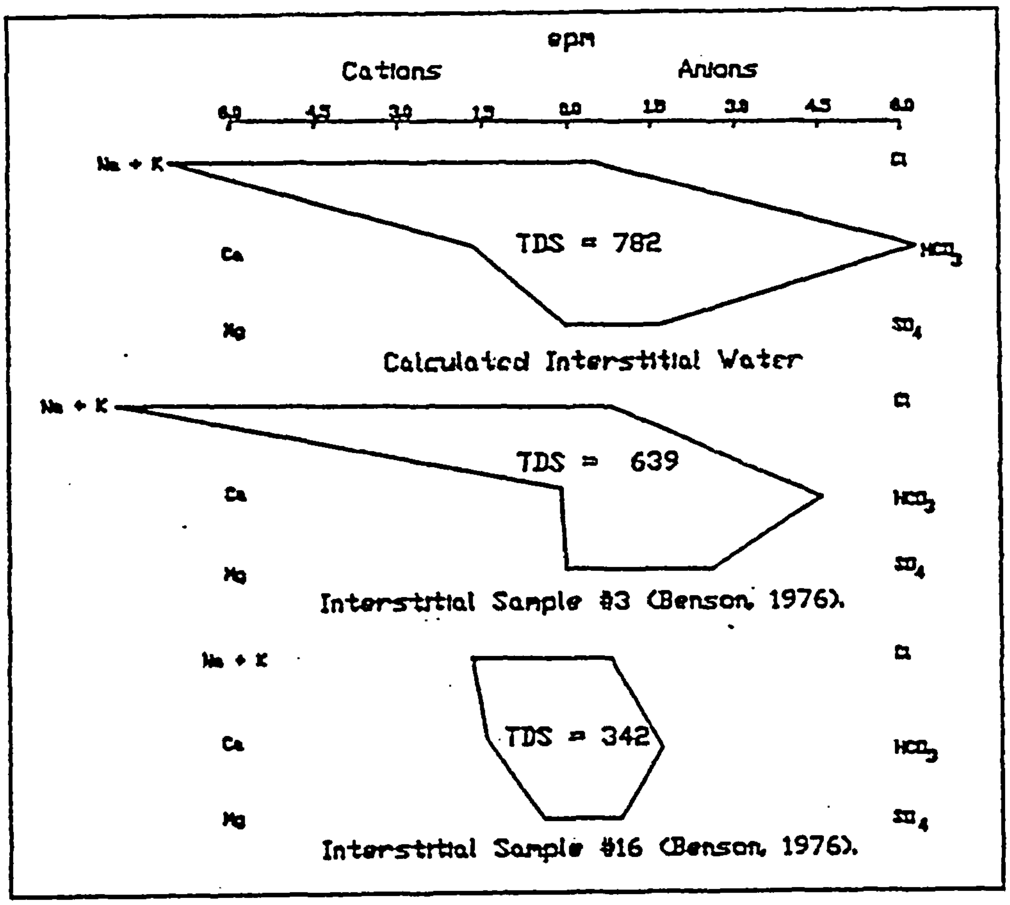

Figure 29. Stiff Diagrams of a Calculated Interstitial Water from A Bomb Pulse, and Two Interstitial Samples

sample #16 is not representative of interstitial water.

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 this 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 to 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 strain on the interstitial pores of a formation, stressing them and forcing out interstitial fluid into a nearby fracture system. This process is reflected as an increase in discharge as well as an increase in concentration of the dissolved ions and an

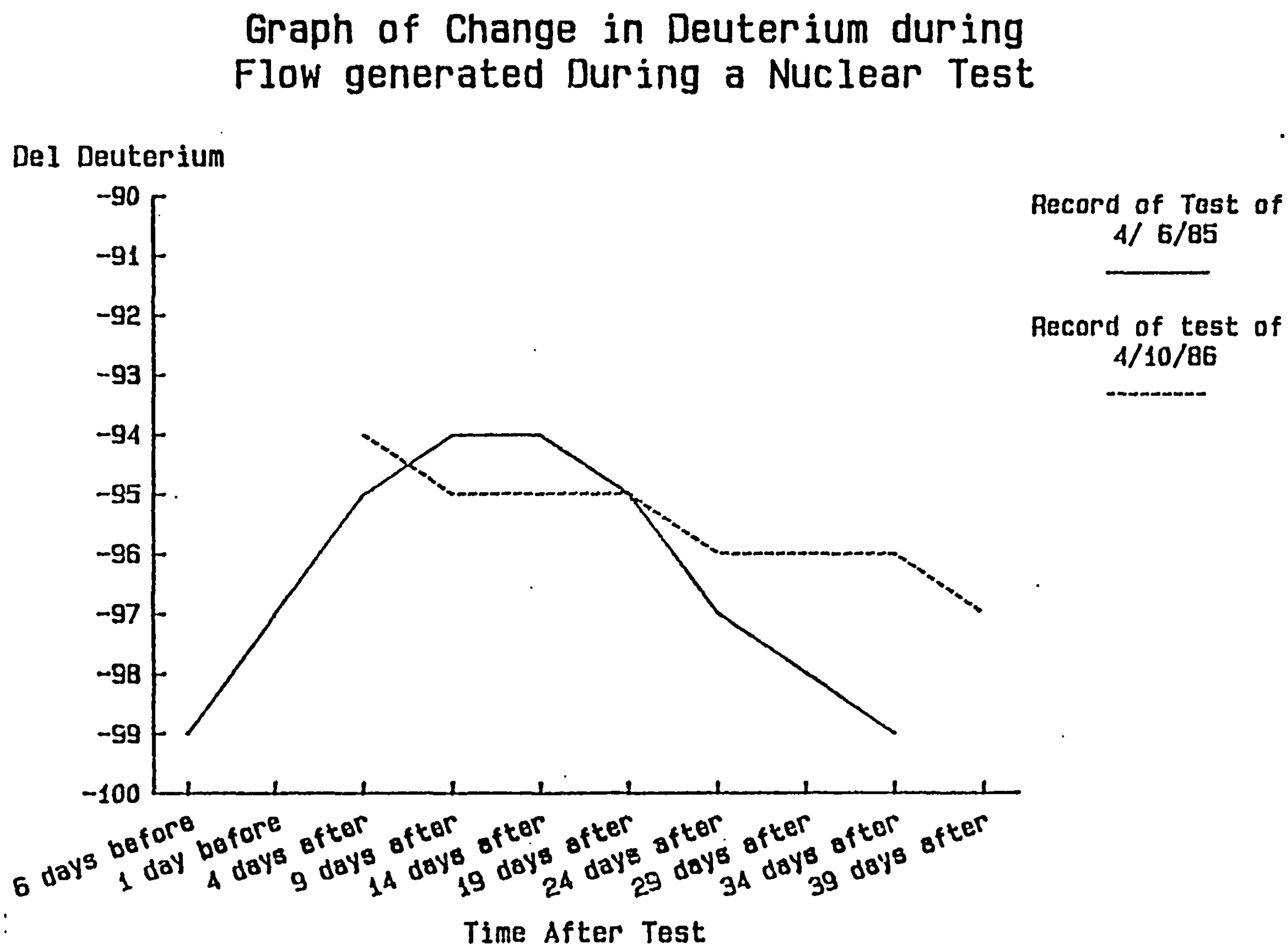

Figure 30. A Plot of Deuterium Versus Time Following A Nuclear Test

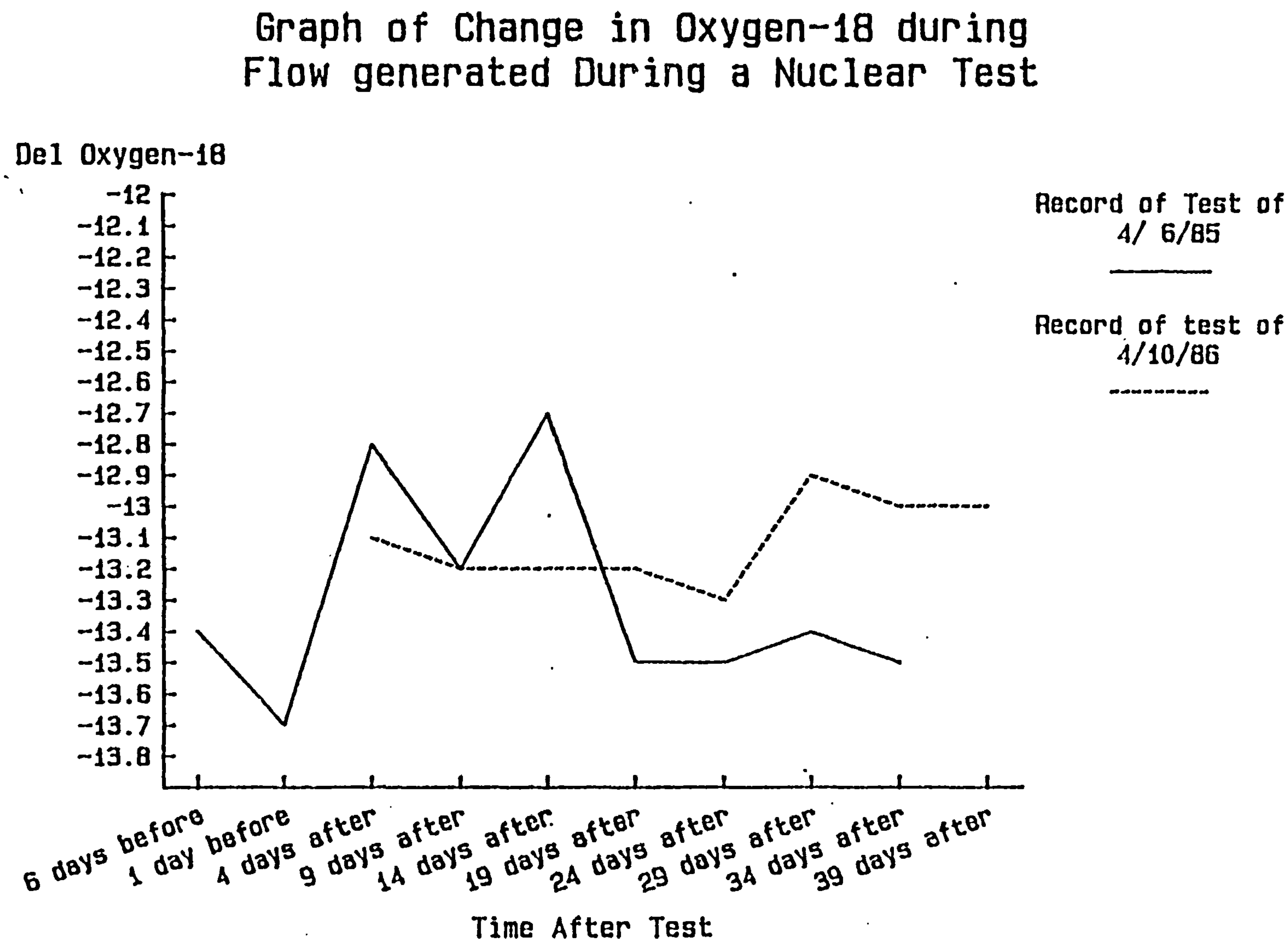

Figure 31. A Plot of Oxygen-18 Versus Time Following A Nuclear Test

enrichment of the ground-water isotopic composition at the tunnel seep.

Conclusions and Recommendations

The hydrology of Rainier Mesa is dominated by fracture flow through the majority of the formations. Of these, the Indian Trails Formation has the lowest hydraulic conductivities and acts as an aquitard; however, certain fractures within this formation are hydraulically connected to stratigraphically higher water-bearing fractures. It is these fractures which control the movement of water from the Indian Trails Formation to the regional water table.

The ground water present in the Indian Trails Formation has been considered to be relict water from a pluvial period. Since seasonal increases in discharge exist and the isotopic signatures of these seeps are within the range of present day precipitation, then the source of the water found at the tunnel seeps is recent precipitation.

The precipitation record of Rainier Mesa revealed two seasons of the year which could recharge the mesa, winter and summer. Since winter is characterized by the greatest amount of precipitation and summer is characterized by the greatest potential for evapotranspiration, it was thought that winter precipitation recharged Rainier Mesa. This was confirmed by an examination of the last four years of the isotopic ratios of the precipitation as it relates to the isotopic ratios of the tunnel seeps. Winter precipitation was found to best match the isotopic signature of the tunnel seeps.

Discharge and humidity records were combined in order to estimate the total flux of water from U12n tunnel. It was determined that 34,900 ± 5,500 m^3 of water passed through U12n tunnel each year. The recharge basin was estimated to be 1.47 ± .29 km^2. Assuming that the characteristics of the Rainier Mesa Formations which control infiltration are homogeneous throughout the mesa, a simple calculation relating basin area to recharge can be performed. This calculation estimated a total of 271,000 ± 141,000 m^3 of water recharging the mesa each year. This estimate was divided into the total cubic meters of precipitation which falls on U12n Tunnel recharge basin each year. The results indicate an average of 8.5 ± 21% of all precipitation recharges Rainier Mesa. The 7% estimated by Thordarson (1965), is within this range.

An examination of the chemistry of the water emanating from various tunnel seeps indicated similiar waters. The isotopic ratios revealed that U12n.05 drift water is generally enriched in both oxygen-18 and deuterium. This indicates that very little mixing occurs between the fracture systems, yet similiar chemical reactions yield similiar water chemistries. Several explanations are offered to explain the isotopic enrichment of 05 water over 03 water. The first is the greater altitude of the recharge area of the U12n.03 drift could account for the difference. The second is a greater degree of contamination of the 05 drift by nuclear testing, the third possibility is the 05 fracture system is more likely to be recharged by summer precipitation due to its location at the bottom of the biggest wash on Rainier Mesa.

The period of hydraulic response was determined by averaging the discharge records following suspected recharge events. The results found a net increase in discharge at approximately four months after the recharge event.

Several methodologies were attempted in trying to determine the travel time of ground water from the mesa surface to the tunnel level. Two tracer studies, a tritium study, and several statistical methods based on isotopes proved to be unsuccessful. An isotopically depleted season of winter precipitation occurred in the winter of 1985 to 1986. Simple mixing calculations predict that this pulse of light recharge will be noticable as an isotopic depletion at the tunnel seeps. Thus, a continued monitoring program will be implemented.

The effect of nuclear testing on localized ground-water flow and chemistry was examined. The results were based on ground-water discharge, chemistry, and isotopic ratios. Nuclear tests within the mesa generate a seismic P wave which increases interstitial flow into the active transport system. This increased flow contains a possible relict interstitial water high in sulfate content and an enriched stable isotopic signature.

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 1985-86 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 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 this 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.

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APPENDIX I

Methodology and Equipment used during Laboratory Ground-Water Analysis

CHEMICAL SPECIES ANALYZED, METHOD OF ANALYSIS,

AND EQUIPMENT USED.

Species	Methodology for preparation	Equipment used during analysis	Reference
pH	150.1	Beckmann 4500 Titrator	1
Spec Cond.	120.1	Beckman RC-19 Conductivity Bridge	1
Alkalinity	305.1	Brinkmann Metrohm 636 Automated Titrator	1
Chloride	325.1	Coulter Industrial Kemolab	1
Sulfate	375.4	Hach 2100 Turbidimeter	1
Nitrate and Nitrite	100-70 353.2	2 Channel Technicon autoanalyzer	1 2
Sodium	273.1	Instrumentation Lab. AA/AE Spectrophotometer	1
Potassium	258.1	Same as above	1
Magnesium	242.1	Same as above	1
Calcium	215.1	Same as above	1
Lithium		Same as above	3

Bromide	300.0	Spectra Physics 4270 Integrator	1

1 Ballinger, 1979

2 Unknown, 1973

3 Fishman, 1985

APPENDIX II

Ground-Water Seep Discharge

U12n.03 Discharge (1/min)

1985

	September			October			November		
	Morn.	Noon	Eve.	Morn.	Noon	Eve.	Morn.	Noon	Eve
1				3.25	3.25	3.31	2.81	2.81	2.81
2				3.25	3.31	2.25	2.81	2.81	2.81
3				2.25	3.31	3.36	2.81	2.81	2.81
4				3.36	3.31	3.31	2.81	2.81	2.81
5				3.31	3.31	3.31	2.81	2.81	2.81
6				3.31	3.31	3.31	2.81	2.81	2.81
7				3.31	3.31	3.31	2.81	2.86	2.86
8				3.31	3.31	3.31	2.86	2.86	2.92
9				3.31	3.31	3.31	2.92	2.92	2.92
10				3.31	3.31	3.31	2.92	2.92	2.92
11				3.31	3.31	3.31	2.97	2.97	3.03
12				3.31	3.31	3.31	2.97	2.97	2.92
13				3.31	3.31	3.31	2.92	2.92	2.92
14				3.31	3.31	3.31	2.92	2.92	2.92
15				3.31	3.31	3.31	2.92	2.92	2.97
16				3.31	3.31	3.31	2.97	2.97	3.03
17				3.31	3.31	3.31	3.03	3.08	3.08
18				3.31	3.31	3.31	3.03	3.03	2.97
19				3.31	3.31	3.31	2.97	2.97	2.97
20				3.31	3.31	3.31	2.97	3.03	3.08
21				3.31	3.31	3.31	3.08	3.08	3.08
22				3.31	2.61	2.61	3.08	3.08	3.08
23				2.61	2.61	2.66	3.08	3.08	3.08
24				2.66	2.66	2.66	3.08	3.08	3.08
25				2.66	2.71	2.71	3.14	3.14	3.14
26				2.71	2.71	2.71	3.14	3.14	3.14
27		3.54	3.19	2.71	2.76	2.76	3.08	3.03	3.03
28	3.25	3.25	3.25	2.76	2.76	2.76	3.08	3.08	3.08
29	3.19	3.19	3.14	2.76	2.76	2.76	3.14	3.14	3.14
30	3.19	3.25	3.25	2.76	2.81	2.81	3.14	3.14	3.08
31				2.81	2.81	2.81			

U12n.03 Discharge (l/min)

1985 - 1986

	December			January			Febuary		
	Morn.	Noon	Eve.	Morn.	Noon	Eve.	Morn.	Noon	Eve
1	3.08	3.08	3.08	2.71	2.66	2.66	2.66	2.61	2.71
2	3.08	3.08	3.08	2.66	2.61	2.61	2.71	2.71	2.66
3	3.08	3.08	3.08	2.61	2.61	2.61	2.61	2.61	2.61
4	3.08	3.08	3.08	2.61	2.61	2.61	2.61	2.61	2.61
5	3.14	3.25	3.36	2.61	2.61	2.61	2.61	2.61	2.61
6	3.19	3.25	3.19	2.61	2.61	2.61	2.61	2.61	2.61
7	3.19	3.19	3.14	2.61	2.56	2.56	2.61	2.61	2.61
8	3.19	3.19	3.19	2.56	2.56	2.61	2.66	2.66	2.66
9	3.14	3.14	3.14	2.61	2.66	2.66	2.61	2.61	2.61
10	3.14	3.14	3.14	2.61	2.61	2.61	2.61	2.61	2.61
11	3.14	3.14	3.14	2.61	2.61	2.61	2.61	2.56	2.56
12	3.08	3.08	3.08	2.61	2.66	2.66	2.56	----	2.86
13	3.08	3.08	3.08	2.66	2.61	2.66	2.66	2.61	2.56
14	3.03	3.03	3.03	2.71	2.76	2.81	2.56	2.61	2.66
15	3.08	3.08	3.03	2.81	2.76	2.71	2.81	2.76	2.71
16	2.97	2.97	2.97	2.66	2.97	2.81	2.61	2.56	2.56
17	2.92	2.92	2.97	2.71	2.66	2.61	2.56	2.56	2.56
18	2.97	2.97	2.97	2.56	2.56	2.61	2.56	2.56	2.56
19	2.97	2.97	2.97	2.61	2.61	2.61	2.56	2.56	2.56
20	2.92	2.92	2.92	2.66	2.92	2.92	2.56	2.56	2.56
21	2.92	2.92	2.92	2.81	2.76	2.71	2.51	2.51	2.56
22	2.92	2.92	2.92	2.66	2.61	2.76	2.56	2.56	2.56
23	2.92	2.92	2.86	2.61	2.61	2.61	2.56	2.56	2.61
24	2.86	2.86	2.86	2.61	2.61	2.61	2.61	2.56	2.56
25	2.86	2.86	2.86	2.61	2.56	2.61	2.61	2.61	2.61
26	2.86	2.86	2.86	2.61	2.61	2.61	2.56	2.56	2.56
27	2.86	2.81	2.81	2.66	2.66	2.66	2.56	2.56	2.56
28	2.76	2.81	2.81	2.66	2.71	2.71	2.61	2.61	2.61
29	2.76	2.76	2.76	2.66	2.66	2.71			
30	2.76	2.76	2.86	2.71	2.71	2.71			
31	2.81	2.76	2.71	2.66	2.66	2.66			

U12n.03 Discharge (1/min)

1986

	March			April			May		
	Morn.	Noon	Eve.	Morn.	Noon	Eve.	Morn.	Noon	Eve
1	2.76	2.71	2.66	3.19	3.19	3.19	2.71	2.71	2.71
2	2.61	2.61	2.61	3.19	3.19	3.19	2.71	2.71	2.71
3	2.56	2.51	2.51	3.25	3.25	3.19	2.71	2.71	2.76
4	2.51	2.51	2.51	3.14	3.08	3.08	2.76	2.71	2.71
5	2.51	2.51	2.51	3.08	3.19	3.19	2.71	2.71	2.71
6	2.51	2.51	2.51	3.19	3.14	3.08	2.92	2.86	2.86
7	2.51	2.56	2.56	3.08	3.08	3.03	2.81	2.81	2.76
8	2.56	2.61	2.61	3.03	3.08	3.08	2.76	2.71	2.66
9	----	----	----	3.08	3.19	3.25	2.66	2.61	2.97
10	----	----	----	3.25	3.67	5.80	2.97	3.08	3.08
11	----	3.42	3.25	4.18	3.31	3.03	3.03	2.97	3.03
12	3.25	3.19	3.19	2.86	2.81	2.81	3.03	3.03	3.03
13	3.14	3.14	3.19	2.76	2.71	2.71	3.03	3.03	3.08
14	3.19	3.14	3.14	2.71	2.71	2.71	3.08	3.08	3.08
15	3.31	3.31	3.31	2.71	2.71	2.76	3.08	3.08	3.08
16	3.25	3.19	3.19	2.76	2.76	2.76	2.61	2.61	2.51
17	3.19	3.19	3.14	2.76	2.71	2.71	2.51	2.51	2.51
18	3.14	3.14	3.08	2.71	2.71	2.71	2.56	2.56	2.56
19	3.08	3.08	3.08	2.71	2.71	2.71	2.56	2.56	2.61
20	3.08	3.14	3.14	2.71	2.71	2.76	2.61	2.61	2.66
21	3.14	3.14	3.19	2.76	2.76	2.81	2.66	2.66	2.66
22	3.19	3.25	3.25	2.81	2.97	2.92	2.71	2.71	2.66
23	3.19	3.25	3.31	2.86	2.81	2.81	2.61	2.61	2.61
24	3.25	3.25	3.19	2.81	2.76	2.76	2.61	2.56	2.56
25	3.14	3.08	3.08	2.76	2.76	2.81	2.56	2.56	2.61
26	3.08	3.14	3.19	2.81	2.76	2.76	2.61	2.61	2.61
27	3.19	3.19	3.14	2.71	2.71	2.71	2.61	2.61	2.71
28	3.14	3.14	3.19	2.71	2.76	2.76	2.66	2.66	2.61
29	3.19	3.19	3.14	2.76	2.76	2.71	2.61	2.56	2.56
30	3.14	3.14	3.14	2.71	2.71	2.71	2.61	2.61	2.61
31	3.14	3.19	3.19				2.56	2.56	2.61

U12n.03 Discharge (1/min)

1986

	June			July			August		
	Morn.	Noon	Eve.	Morn.	Noon	Eve.	Morn.	Noon	Eve.
1	2.61	2.61	2.61	----	2.36	2.41	2.36	2.51	2.51
2	2.61	2.56	2.56	2.36	2.36	2.61	2.51	2.46	2.51
3	2.56	2.61	2.56	2.61	2.51	2.41	2.51	2.51	2.51
4	2.56	2.61	2.61	2.41	2.36	2.36	2.51	2.32	2.27
5	2.61	2.76	2.71	2.36	2.36	2.36	2.22	2.27	2.22
6	2.66	2.61	2.61	2.36	2.36	2.36	2.18	2.13	2.13
7	2.66	2.71	2.71	2.36	2.36	2.36	2.13	2.09	2.13
8	2.66	2.61	2.61	2.36	2.36	2.41	2.13	2.13	2.18
9	2.61	2.61	2.61	2.41	2.41	2.41	2.18	2.18	2.18
10	2.61	2.61	2.66	2.41	2.41	2.41	2.13	2.13	2.13
11	2.66	2.61	2.61	2.41	2.41	2.41	2.27	2.22	2.27
12	2.61	2.61	2.61	2.41	2.36	2.36	2.18	2.13	2.13
13	2.61	2.61	2.56	2.41	2.41	2.41	2.13	2.13	2.13
14	2.56	2.56	2.56	2.41	2.41	2.36	2.13	2.13	2.13
15	2.61	2.76	2.81	2.36	2.36	2.36	2.13	2.18	2.13
16	2.76	2.71	2.66	2.36	2.36	2.36	2.13	----	2.41
17	2.61	2.61	2.81	2.36	2.36	2.51	2.31	2.27	2.27
18	2.86	2.86	2.86	2.46	2.41	2.36	2.22	2.18	2.18
19	----	----	----	2.36	2.36	2.32	2.13	2.18	2.32
20	----	----	----	2.32	2.32	2.36	2.32	2.27	2.27
21	----	----	----	2.36	2.36	2.36	2.18	2.18	2.18
22	----	----	----	2.36	2.36	2.36	2.18	2.18	2.18
23	----	----	----	2.36	2.32	2.32	2.18	2.18	2.18
24	----	----	----	2.32	2.36	2.36	2.18	2.18	2.18
25	----	----	----	2.36	2.36	2.36	2.13	2.13	2.18
26	----	----	----	2.36	2.36	2.36	2.18	2.22	2.18
27	----	----	----	2.36	2.36	2.36	2.13	2.13	2.13
28	----	----	----	2.36	2.36	2.51	2.13	2.18	2.18
29	----	----	----	2.56	2.46	2.41	2.18	2.18	2.22
30	----	----	----	2.36	2.36	2.36	2.18	2.18	2.18
31				2.36	2.36	2.36	2.18	2.18	2.18

U12n.03 Discharge (1/min)

1986

	September			October			November		
	Morn.	Noon	Eve.	Morn.	Noon	Eve.	Morn.	Noon	Eve.
1	2.18	2.18	2.18						
2	2.18	2.18	2.36						
3	2.31	2.22	----						
4	----	----	----						
5	----	2.27							
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
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22									
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24									
25									
26									
27									
28									
29									
30									
31									

U12n.05 Discharge (l/min)

1985 - 1986

	December			January			Febuary		
	Morn.	Noon	Eve.	Morn.	Noon	Eve.	Morn.	Noon	Eve.
1				5.25	5.25	5.25	5.10	5.10	5.10
2				5.25	5.25	4.88	5.10	5.17	5.17
3				4.73	4.66	4.52	5.17	5.17	5.32
4		4.66	4.66	4.45	4.45	4.45	5.32	5.32	5.32
5	5.10	5.10	5.02	4.45	4.45	4.45	5.32	5.32	5.32
6	5.02	5.02	5.02	4.45	4.45	4.45	5.32	5.32	5.32
7	5.02	5.02	5.02	4.88	4.80	5.02	5.40	5.40	5.48
8	5.10	5.17	5.25	5.17	4.88	4.73	5.48	5.56	5.64
9	5.25	5.25	5.17	4.59	4.80	5.10	5.72	5.80	5.80
10	5.17	5.17	5.17	5.17	5.17	5.25	5.80	5.40	5.56
11	5.17	5.10	5.10	5.25	5.32	5.32	5.56	5.48	5.48
12	5.02	5.10	5.10	5.32	5.32	5.25	5.56	5.56	5.56
13	5.10	5.10	5.17	5.25	5.25	5.32	5.56	5.56	5.56
14	5.17	5.17	5.17	5.32	5.40	5.17	5.56	5.56	5.56
15	5.17	5.17	5.10	4.88	4.80	4.73	5.56	5.56	5.56
16	5.10	5.10	5.10	4.95	5.17	5.25	5.56	5.56	5.56
17	5.17	5.17	5.10	5.32	5.40	5.40	5.56	5.56	5.56
18	5.10	5.10	5.10	5.40	5.40	5.40	5.56	5.56	5.56
19	5.02	5.02	5.02	5.40	5.40	5.40	5.56	5.56	5.56
20	5.10	5.10	5.10	5.40	5.40	5.40	5.56	5.56	5.56
21	5.10	5.10	5.17	5.40	5.40	5.32	5.56	5.56	5.56
22	5.17	5.17	5.17	5.32	5.32	5.25	5.56	5.56	5.56
23	5.17	5.17	5.17	5.25	5.25	5.25	5.56	5.56	5.56
24	5.17	5.25	5.25	5.17	5.17	5.17	5.56	5.17	5.25
25	5.25	5.25	5.25	4.80	4.31	4.24	5.32	5.40	5.40
26	5.25	5.25	5.25	4.24	4.24	4.24	5.40	5.40	5.25
27	5.25	5.25	5.25	4.24	4.24	4.24	5.32	5.40	5.40
28	5.25	5.32	5.32	4.59	4.80	4.88	5.40	5.40	5.40
29	5.32	5.32	5.32	4.95	5.02	5.02			
30	5.32	5.32	5.32	5.10	5.10	5.10			
31	5.25	5.25	5.25	5.10	5.10	5.10			

U12n.05 Discharge (l/min)

	1986								
	March			April			May		
	Morn.	Noon	Eve.	Morn.	Noon	Eve.	Morn.	Noon	Eve.
1	5.40	5.40	5.48	6.56	6.38	6.38	7.09	7.09	7.09
2	5.48	5.48	5.48	6.38	6.38	6.30	7.09	7.09	7.09
3	5.48	5.48	5.48	6.13	6.64	6.82	7.37	7.09	7.09
4	5.48	5.48	5.48	6.91	6.91	7.00	7.09	7.09	7.09
5	5.17	5.25	5.32	7.00	6.91	6.91	7.18	7.00	7.00
6	5.40	5.70	5.48	6.91	16.91	6.91	7.00	7.00	----
7	5.48	5.56	5.56	6.91	16.82	6.82	----	----	----
8	5.64	5.64	5.72	6.82	6.82	6.82	----	----	----
9	5.72	5.80	5.80	6.82	6.82	6.82	----	7.37	7.37
10	5.88	5.88	5.96	7.18	0.27	10.85	7.37	7.37	7.37
11	5.96	6.04	6.04	10.73	0.16	10.27	7.37	7.37	7.37
12	6.47	6.91	7.09	9.93	9.82	9.71	7.27	7.27	7.27
13	7.18	7.27	7.37	9.60	9.49	9.38	7.27	7.37	7.37
14	7.56	7.46	7.46	9.38	9.28	8.75	7.37	7.18	7.09
15	7.09	6.82	6.47	8.75	8.95	8.96	7.09	7.18	7.18
16	6.38	6.38	6.38	8.96	8.85	8.85	7.37	7.37	7.46
17	6.38	6.38	6.38	8.85	8.85	8.85	7.46	7.46	7.46
18	6.38	6.38	6.38	8.85	8.75	8.75	7.46	7.46	7.56
19	6.38	6.47	6.47	8.75	8.75	8.75	7.56	7.56	7.56
20	6.30	6.04	6.04	8.75	8.64	8.64	7.56	7.56	7.56
21	6.04	6.13	6.13	8.64	8.64	8.64	7.56	7.56	7.56
22	6.21	6.30	6.30	8.54	8.54	8.64	7.56	7.37	7.27
23	6.30	6.38	6.38	8.75	8.75	8.75	7.27	7.37	7.37
24	6.38	6.38	6.38	8.75	8.54	8.54	7.37	7.37	7.37
25	6.91	7.00	7.00	8.54	8.44	7.94	7.37	7.37	7.37
26	7.00	7.09	7.09	7.84	7.75	7.65	7.37	7.37	7.37
27	7.18	7.18	7.18	7.56	7.46	7.46	7.37	7.37	7.37
28	7.18	7.18	7.18	7.37	7.37	7.27	7.37	7.27	7.27
29	7.18	7.18	7.18	7.27	7.18	7.18	7.27	7.27	7.27
30	7.18	7.27	7.27	7.18	7.18	7.18	7.27	7.27	7.18
31	7.27	7.18	7.09				7.18	7.18	7.18

U12n.05 Discharge (1/min)

1986

	June			July			August		
	Morn.	Noon	Eve.	Morn.	Noon	Eve.	Morn.	Noon	Eve.
1	7.18	7.18	7.18	9.38	9.38	9.38	10.05	10.05	10.05
2	7.18	7.18	7.18	9.49	9.49	9.49	10.05	10.05	10.05
3	7.18	7.18	7.18	9.49	9.49	9.49	10.05	10.05	10.05
4	7.18	7.18	7.27	9.49	9.49	9.49	10.05	10.05	10.05
5	7.27	7.37	7.37	9.49	9.49	9.60	10.05	10.05	10.05
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	9.93	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.05 Discharge (1/min)

	1986								
	September			October			November		
	Morn.	Noon	Eve.	Morn.	Noon	Eve.	Morn.	Noon	Eve.
1	9.38	9.38	9.38						
2	9.38	9.17	9.17						
3	9.17	9.17	9.17						
4	9.17	9.17	9.17						
5	9.17	9.17							
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									
26									
27									
28									
29									
30									
31									

U12n.Portal Discharge (in l/min)

1985 - 1986

	December			January			Febuary		
	Morn.	Noon	Eve.	Morn.	Noon	Eve.	Morn.	Noon	Eve
1					59.21*			61.69	
2					119.87			66.84	
3					59.21*			65.10	
4		55.99*			59.21*			78.87	
5		55.99*			59.21*			67.73	
6		49.88			65.10			56.78*	
7		57.59			59.21			55.99	
8		54.21*			10.85			52.88*	
9		73.17			63.38			52.88*	
10		68.62			73.17			52.88*	
11		91.05			73.17			56.78	
12		55.99*			59.21*			59.21	
13		55.20*			59.21*			61.69	
14		55.20*			75.04			63.38	
15		83.82			68.62			60.85	
16		76.94			80.83			72.24	
17		58.39*			75.04			65.10	
18		54.42			62.53			55.20	
19		58.39			61.69			43.50	
20		77.90			58.39*			16.28	
21		58.39*			58.39*			18.23	
22		58.39*			63.38			52.12	
23		59.21*			61.69			61.69	
24		82.82			63.38			59.21	
25		69.51			64.24			58.39	
26		60.03*			62.53			58.39	
27		59.21*			62.83			53.65	
28		59.21*			58.39*			42.15	
29		59.21*			58.39*				
30		59.21*			63.38				
31		59.21*			64.24				

* Denotes just baseflow emanating from U12n tunnel portal.

U12n.Portal Discharge (in l/min)

	1986								
	March			April			May		
	Morn.	Noon	Eve.	Morn.	Noon	Eve.	Morn.	Noon	Eve.
1		45.57			58.39*			-	
2		64.24			57.59*			-	
3		62.53			60.03*			-	
4		61.69			60.03*			-	
5		62.53			60.03*			-	
6		61.69			69.51			-	
7		58.39*			65.10			-	
8		60.85*			-			-	
9		56.78*			-			54.42	
10		65.97			-			53.65	
11		72.24			-			49.88*	
12		65.10			-			50.62*	
13		72.27			-			54.42	
14		70.42			-			43.50	
15		66.84*			-			50.62	
16		72.24			-			53.65	
17		70.42			-			51.36*	
18		75.99			-			51.36*	
19		65.10*			-			56.78	
20		67.73			-			54.42	
21		65.10*			-			52.88	
22		65.10*			-			54.42	
23		67.73			-			53.65*	
24		69.51			-			50.62*	
25		68.62			-			50.62*	
26		67.73			-			50.62*	
27		66.84			-			53.65*	
28		65.10*			-			53.65	
29		65.10*			-			54.42	
30		63.38*			-			50.62*	
31		63.38*						52.88*	

* Denotes just baseflow emanating from U12n Tunnel portal.

U12n.Portal Discharge (in l/min)

	1986								
	June			July			August		
	Morn.	Noon	Eve.	Morn.	Noon	Eve.	Morn.	Noon	Eve.
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 III

U12n Tunnel Humidity and Temperature

Rainier Mesa Relative Humidity

Date Taken	Dry Bulb T (°F)	Wet Bulb T (°F)	Relative Hum.
		03 Drift	
7/ 1/86	64°	57°	66%
7/23/86	66°	61°	76%
8/ 1/86	69°	57°	49%
8/15/86	66°	61°	76%
9/ 5/86	66°	58°	62%
9/18/86	65°	57°	61%
		05 Drift	
7/ 1/86	59°	52°	63%
7/23/86	61°	56°	73%
8/ 1/86	59°	52°	63%
8/15/86	63°	57°	70%
9/ 5/86	62°	56°	74%
9/18/86	59°	54°	73%
		10 drift	
7/ 1/86		No data	
7/23/86	64°	59°	75%
8/ 1/86	62.5°	54°	59%
8/15/86	66°	58°	61%
9/ 5/86	64°	59°	74%
9/18/86	65°	58°	66%
		Outside	
7/ 1/86	86°	59°	13%
7/23/86	84°	67°	42%
8/ 1/86	95°	69°	25%
8/15/86	88°	62°	17%
9/ 5/86	84°	60°	23%
9/18/86	69°	57°	47%

APPENDIX IV

Rainier Mesa Precipitation Record

Rainier Mesa Precipitation Record (in inches)

1981 - 1982

	July	Aug.	Sept	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
1	0.0	0.0	0.0	0.08	0.0	0.0	0.14	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.37
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.07	0.0	0.0	0.0	0.19	0.0	0.0
6	0.0	0.0	0.01	0.0	0.0	0.0	0.01	0.0	0.0
7	0.0	0.0	0.01	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.38	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.32	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.05	0.0	0.0	0.0	0.0	0.0	0.20	0.0
11	0.0	0.0	0.0	0.23	0.0	0.0	0.0	0.01	0.03
12	0.0	0.76	0.0	0.17	0.0	0.0	0.0	0.0	0.0
13	0.0	0.02	0.0	0.10	0.0	0.0	0.0	0.0	0.0
14	0.0	0.61	0.0	0.0	0.0	0.0	0.0	0.0	0.46
15	0.0	0.02	0.0	0.01	0.0	0.0	0.0	0.0	0.24
16	0.0	0.0	0.0	0.01	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0*
18	0.0	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0*
19	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	0.73	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.16	0.0	0.0
22	0.0	0.0	0.0	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	0.0	0.0	0.0
24	0.0	0.0	0.0	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	0.0	0.0	0.0
26	0.0	0.02	0.0	0.0	0.30	0.0	0.0	0.0	0.14
27	0.0	0 0	0.0	0.0	0.05	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.47	0.0	0.11	0.0	0.04
29	0.0	0.0	0.0	0.01	0.56	0.0	0.0		0.13
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
31	0.0	0.0		0.0		0.0	0.0		0.0

Rainier Mesa Precipitation Record (in inches)

1982

	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.
1	0.63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.02	0.23	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.20	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
5	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	0.0	0.0	0.0
7	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	0.01
9	0.0	0.12	0.0	0.0	0.0	0.0	0.0	0.58	0.56
10	0.0	0.53	0.0	0.0	0.0	0.11	0.0	0.22	0.04
11	0.44	0.0	0.0	0.0	0.0	0.01	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.29	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	0.05
14	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
16	0.0	0.0	0.0	0.0	0.0	0.01	0.0	0.0	0.0
17	0.0	0.0	0.02	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.15	0.0	0.29	0.0	0.0	0.0	0.0
19	0.0	0.0	0.07	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.11	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.03	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.01	0.0	0.0	0.27	0.32
23	0.0	0.0	0.0	0.0	0.23	0.0	0.0	0.11	0.0*
24	0.0	0.0	0.0	0.11	0.05	0.73	0.18	0.0	0.0*
25	0.0	0.0	0.0	0.05	0.0	0.66	0.0	0.0	0.0*
26	0.0	0.0	0.0	0.22	0.0	0.25	0.14	0.0	0.0*
27	0.0	0 0	0.0	0.48	0.0	0.14	0.0	0.0	0.0*
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0*
29	0.0	0.0	0.0	0.0	0.0	0.02	0.0	0.0	0.0
30	0.0	0.0	0.11	0.0	0.0	0.25	0.19	1.13	0.0
31		0.0		0.0	0.0		0.03		0.0

* Denotes estimated values

Rainier Mesa Precipitation Record (in inches)

1983

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept
1	0.0	0.0	0.0*	0.0	0.45	0.0	0.0	0.0	0.0
2	0.0	0.05	0.0*	0.0	0.01	0.0	0.0	0.0	0.0
3	0.0	0.15	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
5	0.0	0.0*	0.0*	0.0	0.02	0.0	0.0	0.24	0.0
6	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
8	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
10	0.0	0.0*	0.0	0.0	0.0	0.0	0.0	0.30	0.0
11	0.0	0.0*	0.0	0.51	0.0	0.0	0.0	0.01	0.0
12	0.0	0.0*	0.0*	0.06	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
14	0.0	0.0*	0.0*	0.0*	0.0	0.0	0.0	0.17	0.0
15	0.0	0.0*	0.0*	0.0*	0.0	0.0	0.0	0.06	0.0
16	0.32	0.0*	0.0*	0.0*	0.0	0.0	0.0	1.19	0.0
17	0.07	0.0*	0.0*	0.0*	0.0	0.0	0.0	0.22	0.0
18	0.0	0.0*	0.0*	0.0*	0.0	0.0	0.0	0.0*	0.0
19	0.41	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
21	0.0	0.0*	0.0*	0.0*	0.0	0.0	0.0	0.0*	0.0
22	0.13	0.0*	0.0*	0.0*	0.0	0.0	0.0	0.0*	0.0
23	0.03	0.0*	0.0*	0.0*	0.0	0.0	0.0	0.0*	0.0
24	0.34	0.0*	0.0*	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	0.0	0.0	0.11
26	0.0	0.0*	0.0*	0.0*	0.0	0.0	0.0	0.0	0.60
27	0.53	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	0.02
29	1.11		0.0*	0.0	0.0	0.0	0.0	0.0	0.33
30	0.0		0.0*	0.33	0.0	0.0	0.0	0.0	0.36
31	0.0		0.0*		0.0		0.0	0.0	

* Denotes estimated record.

Rainier Mesa Precipitation Record (in inches)

1983 - 1984

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June
1	0.52	0.0	0.0	0.0	0.0	0.0	0.20	0.0	0.0
2	0.01	0.0	0.01	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.35	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
5	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	0.16	0.0	0.0
7	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
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.02	0.0	0.23	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.03	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
14	0.0	0.0	0.0	0.0	0.07	0.0	0.0	0.0	0.06
15	0.0	0.0	0.0	0.0	0.0	0.03	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.16	0.0	0.0	0.0	0.0
17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.05	0.0	0.0
20	0.0	0.27	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.02	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	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	0.0	0.0	0.0
24	0.0	0.57	0.32	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.05	0.79	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.08	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	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0		0.04	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0
31	0.0		0.0	0.0		0.04		0.0	

Rainier Mesa Precipitation Record (in inches)

1984 - 1985

	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
1	0.0	0.0	0.0	0.10	0.0	0.0	0.0*	0.10	0.0
2	0.44	0.0	0.0	0.12	0.0	0.0	0.0*	0.08	0.07
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0*	0.02	0.0
4	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
6	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
8	0.0	0.0	0.0	0.0	0.01	0.04	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
10	0.0	0.01	0.10	0.0	0.0	0.07	0.0*	0.0*	0.0
11	0.0	0.04	0.0	0.01	0.0	0.09	0.0*	0.0	0.08
12	0.01	0.0	0.0	0.0	0.0	0.06	0.0*	0.0	0.0
13	0.05	0.0	0.0	0.0	0.06	0.0	0.0*	0.0	0.0
14	0.01	0.56	0.0	0.0	0.0	0.0	0.0*	0.0	0.0
15	0.10	0.40	0.0	0.0	0.0	0.28	0.0*	0.0	0.0
16	0.03	0.02	0.18	0.0	0.0	0.62	0.0	0.0	0.02
17	0.0	0.13	0.04	0.0	0.0	0.05	0.0	0.0	0.0
18	0.09	0.07	0.32	0.0	0.0	0.28	0.0	0.0	0.41
19	0.64	0.30	0.0	0.0	0.0	0.0*	0.0	0.0	0.02
20	0.0	0.09	0.0	0.12	0.0	0.0*	0.0	0.0	0.0
21	0.09	0.01	0.0	0.0	0.09	0.0*	0.0	0.0	0.0
22	0.75	0.0	0.0	0.0	0.93	0.0*	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.40	0.0*	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.42	0.0*	0.0	0.0	0.0
25	0.0	0.18	0.0	0.0	0.0	0.0*	0.02	0.0	0.0
26	0.18	0.0	0.0	0.0	0.0	0.0*	0.20	0.0	0.0
27	0.04	0 0	0.0	0.0	0.0	0.0*	0.0	0.0	0.0
28	0.26	0.0	0.0	0.0	0.0	0.0*	0.02	0.0	0.06
29	0.01	0.0	0.0	0.0	0.0	0.0*	0.0		0.0
30	0.07	0.0	0.02	0.0	0.0	0.0*	0.0		0.0
31	0.19	0.0		0.0		0.0*	0.0		0.0

* Denotes Estimated record

Rainier Mesa Precipitation Record (in inches)

1985

	Apr.	May.	June	July	Aug.	Sept	Oct.	Nov.	Dec.
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.34
3	0.0	0.0	0.39	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	0.0	0.0
5	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	0.02	0.0	0.0	0.06	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.02	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.19	0.0	0.0	0.0	0.0	0.05	0.0	0.09
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.92	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.89	0.0
13	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
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	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	0.16	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.28	0.0	0.37	0.0	0.0	0.0
19	0.0	0.0	0.0	0.87	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.65	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.02	0.0	0.0	0.05	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.16	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.04	0.0	0.0	0.0	0.0	0.08	0.0
25	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.19	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.01
27	0.0	0 0	0.0	0.0	0.0	0.21	0.0	0.0	0.01
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.01
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.37	0.01
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02	0.01
31		0.0		0.0	0.0		0.0		0.01

Rainier Mesa Precipitation Record (in inches)

1986

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept
1	0.0	0.0	0.0	0.01	0.0	0.0			
2	0.0	0.0	0.04	0.0	0.0	0.0			
3	0.0	0.05	0.0	0.0	0.0	0.0			
4	0.0	0.0	0.0	0.0	0.05	0.0			
5	0.03	0.0	0.0	0.0	0.0	0.0			
6	0.14	0.0	0.0	0.38	0.09	0.0			
7	0.0	0.0	0.0	0.13	0.0	0.0			
8	0.0	0.0	0.20	0.07	0.0	0.0			
9	0.0	0.0	0.0	0.0	0.0	0.0			
10	0.0	0.0	0.44	0.0	0.0	0.0			
11	0.0	0.0	0.04	0.0	0.0	0.0			
12	0.0	0.01	0.0	0.0	0.0	0.0			
13	0.0	0.11	0.30	0.0	0.0	0.0			
14	0.0	0.67	0.01	0.0	0.0	0.0			
15	0.0	0.59	0.31	0.0	0.0	0.0			
16	0.0	0.0	0.37	0.02	0.0	0.0			
17	0.0	0.0	0.05	0.0	0.0	0.0			
18	0.0	0.0	0.0	0.0	0.0	0.0			
19	0.0	0.04	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		0.01	0.0	0.0	0.0			
30	1.07		0.0	0.0	0.0	0.0			
31	0.10		0.03		0.0				

APPENDIX V

U12n Tunnel Dye Receptor and Tritium Concentration

Rainier Mesa Bugs

Sample #	Date Taken	Dates Represented	Results
NTS-B01-03	8/ 8/84	8/ 8/84 and previous	Neg.
NTS-B02-03	8/30/84	8/ 8/84 to 8/30/84	Neg.
NTS-B03-03	10/25/84	8/30/84 to 10/25/84	Neg.
NTS-B04-03	12/ 6/84	10/25/84 to 12/ 6/84	Neg.
NTS-B05-03	1/ 3/85	12/ 6/84 to 1/ 3/85	Neg.
NTS-B06-03	2/22/85	1/ 3/85 to 2/22/85	Neg.
NTS-B07-03	3/26/85	2/22/85 to 3/26/85	Neg.
NTS-B08-03	5/ 1/85	3/26/85 to 5/ 1/85	Neg.
NTS-B09-03	6/ 4/85	5/ 1/85 to 6/ 4/85	Neg.
NTS-B10-03	7/19/85	no bug found	----
NTS-B11-03	10 22/85	7/19/85 to 10/22/85	Neg.
NTS-B12-03	11/22/85	10/22/85 to 11/22/85	Neg.
NTS-B13-03	12/11/85	11/22/85 to 12/11/85	Neg.
NTS-B14-03	1/ 2/86	12/11/85 to 1/ 2/86	Neg.
NTS-B15-03	Tracer Test Terminated.		
NTS-B01-05	8/30/84	8/30/84 and previous	Neg.
NTS-B02-05	10/25/84	8/30/84 to 10/25/84	Neg.
NTS-B03-05	12/ 6/84	10/25/84 to 12/ 6/84	Neg.
NTS-B04-05	1/ 3/85	12/ 6/84 to 1/ 3/85	Neg.
NTS-B05-05	2/22/85	1/ 3/85 to 2/22/85	Neg.
NTS-B06-05	3/26/85	2/22/85 to 3/26/85	Neg.
NTS-B07-05	5/ 1/85	No Bugs found	----
NTS-B08-05	6/ 4/85	5/ 1/85 to 6/ 4/85	Neg.
NTS-B09-05	7/19/85	6/ 4/85 to 7/19/85	Neg.
NTS-B10-05	10 22/85	7/19/85 to 10/22/85	Neg.
NTS-B11-05	11/22/85	10/22/85 to 11/22/85	Neg.
NTS-B12-05	12/11/85	11/22/85 to 12/11/85	Neg.
NTS-B13-05	1/ 2/86	12/11/85 to 1/ 2/86	Neg.
NTS-B14-05	Tracer Test Terminated.		
NTS-B01-10	6/28/84	6/28/84 and previous	Neg.
NTS-B02-10	8/30/84	6/28/84 to 8/30/84	Neg.
NTS-B03-10	10/25/84	No bug found	----
NTS-B04-10	12/ 6/84	10/25/84 to 12/ 6/84	Neg.
NTS-B05-10	1/ 3/85	12/ 6/84 to 1/ 3/85	Neg.
NTS-B06-10	2/22/85	1/ 3/85 to 2/22/85	Neg.
NTS-B07-10	3/26/85	2/22/85 to 3/26/85	Neg.
NTS-B08-10	5/ 1/85	3/26/85 to 5/ 1/85	Neg.
NTS-B09-10	6/ 4/85	No bug found	----
NTS-B10-10	7/19/85	6/ 4/85 to 7/19/85	Neg.
NTS-B11-10	11/ 5/85	7/19/85 to 11/ 5/85	Neg.
NTS-B12-10	12/11/85	11/ 5/85 to 12/11/85	Neg.
NTS-B13-10	1/ 2/86	12/11/85 to 1/ 2/86	Neg.
NTS-B14-10	Tracer Test Terminated.		

Rainier Mesa Bugs

Sample #	Date Taken	Dates Represented	Result
OU12n.031	5/ 9/86	5/ 9/86 and previous	Neg.
OU12n.032	6/ 4/86	5/ 9/86 to 6/ 4/86	Neg.
OU12n.033	6/13/86	6/ 3/86 to 6/13/86	Neg.
OU12n.034	7/ 1/86	6/13/86 to 7/ 1/86	Neg.
OU12n.035	7/23/86	7/ 1/86 to 7/23/86	Neg.
OU12n.036	8/ 1/86	7/23/86 to 8/ 1/86	Neg.
OU12n.037	8/15/86	8/ 1/86 to 8/15/86	Neg.
OU12n.038	9/ 5/86	8/15/86 to 9/ 5/86	Neg.
OU12n.039	9/18/86	9/ 5/86 to 9/18/86	Neg.
OU12n.051	5/ 9/86	5/ 9/86 and previous	Neg.
OU12n.052	6/ 4/86	5/ 9/86 to 6/ 4/86	Neg.
OU12n.053	6/13/86	6/ 3/86 to 6/13/86	Neg.
OU12n.054	7/ 1/86	6/13/86 to 7/ 1/86	Neg.
OU12n.055	7/23/86	7/ 1/86 to 7/23/86	Neg.
OU12n.056	8/ 1/86	7/23/86 to 8/ 1/86	Neg.
OU12n.057	8/15/86	8/ 1/86 to 8/15/86	Neg.
OU12n.058	9/ 5/86	8/15/86 to 9/ 5/86	Neg.
OU12n.059	9/15/86	9/ 5/86 to 9/18/86	Neg.
OU12n.101	5/ 9/86	5/ 9/86 and previous	Neg.
OU12n.102	6/ 4/86	5/ 9/86 to 6/ 4/86	Neg.
OU12n.103	6/13/86	6/ 3/86 to 6/13/86	Neg.
OU12n.104	7/ 1/86	6/13/86 to 7/ 1/86	Neg.
OU12n.105	7/23/86	7/ 1/86 to 7/23/86	Neg.
OU12n.106	8/ 1/86	7/23/86 to 8/ 1/86	Neg.
OU12n.107	8/15/86	8/ 1/86 to 8/15/86	Neg.
OU12n.108	9/ 5/86	8/15/86 to 9/ 5/86	Neg.
OU12n.109	9/18/86	9/ 5/86 to 9/18/86	Neg.
OU12n.P1	5/ 9/86	5/ 9/86 and previous	Neg.
OU12n.P2	6/ 4/86	5/ 9/86 to 6/ 4/86	Neg.
OU12n.P3	6/13/86	6/ 3/86 to 6/13/86	Neg.
OU12n.P4	7/ 1/86	6/13/86 to 7/ 1/86	Neg.
OU12n.P5	7/23/86	7/ 1/86 to 7/23/86	Neg.
OU12n.P6	8/ 1/86	7/23/86 to 8/ 1/86	Neg.
OU12n.P7	8/15/86	8/ 1/86 to 8/15/86	Neg.
OU12n.P8	9/ 5/86	8/15/86 to 9/ 5/86	Neg.
Ou12n.P9	9/18/86	9/ 5/86 to 9/18/86	Neg.
OU12e.P1	5/ 9/86	5/ 9/86 and previous	Neg.
OU12e.P2	6/ 4/86	5/ 9/86 to 6/ 4/86	Neg.
OU12e.P3	6/13/86	6/ 3/86 to 6/13/86	Neg.
OU12e.P4	7/ 1/86	6/13/86 to 7/ 1/86	Neg.
OU12e.P5	7/23/86	7/ 1/86 to 7/23/86	Neg.
OU12e.P6	8/ 1/86	7/23/86 to 8/ 1/86	Neg.
OU12e.P7	8/15/86	8/ 1/86 to 8/15/86	Neg.
OU12e.P8	9/ 5/86	8/15/86 to 9/ 5/86	Neg.

9/18/86-No sample taken, water could not be reached.

Rainier Mesa Tritium

Sample #	Date taken	Tritium Conc. (in T.U.)
03T.1	7/ 1/86	237
05T.1	7/ 1/86	13000
E. Portal	7/ 1/86	770000
N. portal	7/ 1/86	690000

APPENDIX VI

Ground-Water Chemistry

U12n.03 Gross Chemistry

species	NTS-038-03	NTS-039-03	NTS-040-03	NTS-041-03
	samples			
pH	8.42	8.32	8.34	8.36
sp cond. (umhos/cm)	328	812	769	645
anions (in ppm)				
SiO_2	47	45	44	44
HCO_3	182	231	236	228
CO_3	3.40	0.90	1.30	1.70
Cl	6.60	23.10	16.40	11.50
SO_4	15.10	141.00	160.00	120.00
F	ND	ND	ND	ND
NO_3	1.02	45.20	11.61	3.19
NO_2	ND	ND	ND	ND
cations (in ppm)				
Na	68.60	131.00	125.00	107.00
K	5.75	12.30	11.50	9.51
Ca	5.47	35.30	35.70	31.20
Mg	0.26	1.28	1.31	1.08
NH_4	ND	ND	ND	ND

U12n.03 Gross Chemistry

species	NTS-042-03	NTS-043-03	NTS-044-03	NTS-045-03
	samples			
pH	8.25	8.32	8.43	8.55
sp cond. (umhos/cm)	620	555	340	333
anions (in ppm)				
SiO_2	44	45	47	46
HCO_3	226	215	193	189
CO_3	ND	0.70	3.00	5.50
Cl	8.80	8.10	7.30	6.70
SO_4	120.00	99.20	14.00	13.80
F	ND	ND	ND	ND
NO_3	0.09	1.24	<0.04	1.11
NO_2	ND	ND	ND	ND
cations (in ppm)				
Na	96.00	89.20	72.10	70.20
K	8.77	7.92	5.38	5.35
Ca	34.10	29.10	6.42	5.84
Mg	1.00	0.88	0.28	0.25
NH_4	ND	ND	ND	ND

U12n.03 Gross Chemistry

species	NTS-097-03	NTS-084-03	NTS-095-03
pH	8.23	7.66	7.73
sp cond. (umhos/cm)	325	334	328
anions (in ppm)			
SiO_2	47	47	48
HCO_3	191	196	195
CO_3	ND	ND	ND
Cl	6.60	7.10	6.70
SO_4	13.20	11.90	11.10
F	ND	ND	ND
NO_3	1.50	<0.04	<0.04
NO_2	ND	ND	ND
cations (in ppm)			
Na	68.60	70.50	70.70
K	5.40	6.59	6.44
Ca	5.69	5.80	5.69
Mg	0.25	0.28	0.27
NH_4	ND	ND	ND

U12n.05 Gross Chemistry

	samples			
species	NTS-109-03	NTS-110-03	NTS-111-03	NTS-112-03
pH	8.31	8.22	8.23	8.38
sp cond. (umhos/cm)	348	355	423	434
anions (in ppm)				
SiO_2	51	51	51	51
HCO_3	205	208	242	241
CO_3	0.60	ND	ND	2.40
Cl	8.40	9.90	10.20	9.90
SO_4	11.50	12.90	22.90	25.00
F	ND	ND	ND	ND
NO_3	0.53	1.02	<0.04	<0.04
NO_2	ND	ND	ND	ND
cations (in ppm)				
Na	63.00	65.90	78.10	79.50
K	7.68	7.82	9.51	9.81
Ca	13.90	13.00	17.20	17.94
Mg	0.41	0.41	0.43	0.41
NH_4	ND	ND	ND	ND

U12n.05 Gross Chemistry

species	NTS-113-03	NTS-114-03	NTS-115-03	NTS-116-03
	samples			
pH	8.26	8.26	8.22	8.52
sp cond. (umhos/cm)	416	391	367	367
anions (in ppm)				
SiO_2	51	51	51	ND
HCO_3	236	224	212	195
CO_3	ND	ND	ND	6.30
Cl	9.70	9.40	8.60	10.00
SO_4	23.10	20.10	17.40	18.90
F	ND	ND	ND	ND
NO_3	<0.04	0.62	0.13	ND
NO_2	ND	ND	ND	ND
cations (in ppm)				
Na	76.80	73.50	69.70	70.80
K	9.43	8.95	8.48	8.77
Ca	16.80	15.50	13.70	13.40
Mg	0.35	0.34	0.34	0.50
NH_4	ND	ND	ND	ND

U12n.05 Gross Chemistry

species	samples NTS-117-03	NTS-098-05
pH	8.50	7.72
sp cond. (umhos/cm)	362	316
anions (in ppm)		
SiO_2	51	54
HCO_3	201	187
CO_3	4.80	ND
Cl	8.80	7.80
SO_4	17.20	8.80
F	ND	ND
NO_3	0.84	<0.04
NO_2	ND	ND
cations (in ppm)		
Na	68.30	60.70
K	8.38	8.05
Ca	12.80	10.80
Mg	0.40	0.40
NH_4	ND	ND

APPENDIX VII

Ground-Water and Precipitation

Isotopic Composition

Precipitation Isotope Data

Sample #	Dates Represented	el Deuterium (SMOW)	del Oxygen (SMOW)
NTS-019	12/ 3/81 to 2/ 9/82	-90	-12.8
NTS-020-S	12/ 3/81 to 2/ 9/82	-87	-13.3
NTS-049	2/ 9/82 to 4/30/82	-98	-13.7
NTS-083	4/30/82 to 6/18/82	-90	-13.0
NTS-103	6/18/82 to 8/10/82	-58	- 8.8
NTS-155	8/10/82 to 12/ 3/82	-106	-14.9
NTS-156-S	8/10/82 to 12/ 3/82	-101	-14.6
NTS-175	12/ 3/82 to 2/14/83	-98	-12.8
NTS-185	12/ 3/82 to 2/15/83	-100	-11.8
NTS-197	2/14/83 to 4/15/83	-92	-13.6
NTS-198-S	2/15/83 to 4/15/83	-72	-14.6
NTS-247	4/15/83 to 8/16/83	-39	-5.5
NTS-277	8/16/83 to 10/ 6/83	-116	-16.0
NTS-319	10/ 6/83 to 1/ 5/84	-80	-10.3
NTS-369	1/ 5/84 to 4/ 5/84	-104	-12.6
NTS-387	4/ 5/84 to 6/ 6/84	-89	-13.2
NTS-430	6/ 6/84 to 9/18/84	-72	-10.7
NTS-462	9/18/84 to 11/15/84	-95	-13.4
NTS-520	11/15/84 to 3/12/85	-88	-13.0
NTS-562	3/12/85 to 5/ 8/85	-67	-9.1
NTS-576	5/ 8/85 to 6/13/85	-110	-15.3
NTS-611	6/13/85 to 8/ 7/85	-50	-8.1
NTS-652	8/ 7/85 to 10/ 8/85	-81	-11.8
NTS-659-S	10/ 8/85 to 11/14/85	-127	-18.6
NTS-688	11/14/85 to 12/16/85	-130	-17.9
NTS-705	12/16/85 to 1/15/86	-136	-17.6
NTS-725	1/15/86 to 2/12/86	-128	-18.5
NTS-743	2/12/86 to 3/18/86	-98	-13.7
NTS-744-S	2/12/86 to 3/18/86	-90	-13.1
NTS-784	3/18/86 to 5/28/86	-87	-11.8
NTS-811	5/28/86 to 6/18/86	-86	-10.8

U12n.03 Isotope data

Sample #	Date Represented	del Deuterium (SMOW)	del Oxygen (SMOW)	Li (mg/l)	Br (mg/l)
NTS-001-03	7/ 2/84	-97	-13.3		
NTS-002-03					
NTS-003-03					
NTS-004-03					
NTS-005-03					
NTS-006-03					
NTS-007-03					
NTS-008-03	8/ 6/84	-92	-13.3		
NTS-009-03					
NTS-010-03					
NTS-011-03					
NTS-012-03					
NTS-013-03					
NTS-014-03	9/ 5/84	-99	-13.4		
NTS-015-03					
NTS-016-03					
NTS-017-03					
NTS-018-03	9/25/84	-98	-13.5		
NTS-019-03	12/10/84	-97	-13.2	0.05	0.06
NTS-020-03					
NTS-021-03	1/ 3/85	-92	-12.4		
NTS-022-03					
NTS-023-03	1/20/85	-97	-13.2		
NTS-024-03					
NTS-025-03					
NTS-026-03	2/ 4/85	-96	-13.1		
NTS-027-03					
NTS-028-03					
NTS-029-03					
NTS-030-03	2/24/85	-98	-13.5		
NTS-031-03					
NTS-032-03					
NTS-033-03					
NTS-034-03					
NTS-035-03	3/21/85	-97	-13.5		
NTS-036-03					
NTS-037-03	3/31/85	-99	-13.4		
NTS-038-03	4/ 5/85	-97	-13.7		
NTS-039-03	4/10/85	-95	-12.8		
NTS-040-03	4/15/85	-94	-13.2		
NTS-041-03	4/20/85	-94	-12.7		
NTS-042-03	4/25/85	-95	-13.5		
NTS-043-03	4/30/85	-97	-13.5		
NTS-044-03	5/ 5/85	-98	-13.4		
NTS-045-03	5/10/85	-99	-13.5		

U12n.03 Isotope data

Sample #	Date Represented	del Deuterium (SMOW)	del Oxygen (SMOW)	Li (mg/l)	Br (mg/l)
NTS-046-03	6/ 8/85	-95	-12.8	0.04	0.05
NTS-047-03	6/13/85	-97	-13.4		
NTS-048-03	6/18/85	-98	-13.4		
NTS-049-03					
NTS-050-03					
NTS-051-03	7/ 3/85	-98	-13.5		
NTS-052-03					
NTS-053-03					
NTS-054-03	7/18/85	-98	-13.6		
NTS-055-03					
NTS-056-03					
NTS-057-03					
NTS-058-03	8/ 6/85	-98	-13.5		
NTS-059-03					
NTS-060-03					
NTS-061-03	8/19/85	-98	-13.6		
NTS-062-03	8/24/85	-99	-13.5		
NTS-063-03					
NTS-064-03	9/ 9/85	-97	-13.6		
NTS-065-03					
NTS-066-03	9/19/85	-99	-13.6		
NTS-067-03					
NTS-068-03	10/ 1/85	-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	1/ 6/86	-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	1/31/86	-97	-13.6		
NTS-089-03					
NTS-090-03	2/ 7/86	-98	-13.5		

U12n.03 Isotope data

Sample #	Date Represented	del Deuterium (SMOW)	del Oxygen (SMOW)	Li (mg/l)	Br
NTS-091-03	2/12/86	-100	-13.4		
NTS-092-03					
NTS-093-03	3/20/86	-99	-13.6		
NTS-094-03					
NTS-095-03	3/30/86	-100	-13.6		
NTS-096-03	4/ 3/86	-99	-13.5		
NTS-097-03	5/ 9/86	-101	-13.5		
NTS-098-03					
NTS-099-03					
NTS-100-03	6/17/86	-97	-13.5		
NTS-101-03	7/ 5/86	-97	-13.4		
NTS-102-03	8/ 5/86	-98	-13.5		
NTS-103-03					
NTS-104-04					
NTS-105-03	8/16/86	-97	-13.5		

U12n.05 Isotope data

Sample #	Date Represented	del Deuterium (SMOW)	del Oxygen (SMOW)	Li (mg/1)	Br
NTS-001-05	7/ 2/84	-94	-12.9		
NTS-002-05					
NTS-003-05					
NTS-004-05					
NTS-005-05					
NTS-006-05					
NTS-007-05					
NTS-008-05	8/ 6/84	-92	-12.8		
NTS-009-05					
NTS-010-05					
NTS-011-05					
NTS-012-05					
NTS-013-05					
NTS-014-05	9/ 5/84	-93	-12.9		
NTS-015-05					
NTS-016-05					
NTS-017-05					
NTS-018-05					
NTS-019-05					
NTS-020-05	10/ 5/84	-90	-11.9		
NTS-021-05					
NTS-022-05					
NTS-023-05					
NTS-024-05					
NTS-025-05					
NTS-026-05	11/ 4/84	-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	1/ 7/85	-93	-12.7		
NTS-032-05					
NTS-033-05					
NTS-034-05					
NTS-035-05					
NTS-036-05	2/ 1/85	-94	-13.0		
NTS-037-05					
NTS-038-05					
NTS-039-05	2/16/85	-94	-13.2		
NTS-040-05					
NTS-041-05					
NTS-042-05	3/ 3/85	-93	-12.8		
NTS-043-05					
NTS-044-05					
NTS-045-05					

U12n.05 Isotope data

Sample #	Date Represented	del Deuterium (SMOW)	del Oxygen (SMOW)	Li (mg/1)	Br (mg/1)
NTS-046-05	3/23/85	-95	-13.0		
NTS-047-05	5/ 5/85	-93	-12.9		
NTS-048-05					
NTS-049-05					
NTS-050-05					
NTS-051-05					
NTS-052-05	5/26/85	-95	-12.5		
NTS-053-05	6/ 8/85	-93	-12.5		
NTS-054-05				0.04	0.05
NTS-055-05					
NTS-056-05					
NTS-057-05	6/28/85	-93	-13.0		
NTS-058-05	7/ 3/85	-94	-13.0		
NTS-059-05					
NTS-060-05	7/13/85	-97	-12.9		
NTS-061-05	7/23/85	-95	-12.9		
NTS-062-05					
NTS-063-05					
NTS-064-05	7/ 7/85	-94	-12.1		
NTS-065-05					
NTS-066-05					
NTS-067-05	8/19/85	-93	-13.0		
NTS-068-05					
NTS-069-05	8/28/85	-93	-12.8		
NTS-070-05	9/28/85	-94	-13.0		
NTS-071-05					
NTS-072-05					
NTS-073-05					
NTS-074-05					
NTS-075-05					
NTS-076-05	10/ 1/85	-95	-13.1		
NTS-077-05	10/ 6/85	-96	-12.9		
NTS-078-05	11/ 5/85	-96	-13.1		
NTS-079-05					
NTS-080-05					
NTS-081-05					
NTS-082-05					
NTS-083-05	12/ 6/85	-96	-13.3		
NTS-084-05					
NTS-085-05					
NTS-086-05					
NTS-087-05					
NTS-088-05					
NTS-089-05					
NTS-090-05	1/11/86	-94	-13.0		

U12n.05 Isotope data

Sample #	Date Represented	del Deuterium (SMOW)	del Oxygen (SMOW)	Li (mg/l)	Br (mg/l)
NTS-091-05					
NTS-092-05					
NTS-093-05					
NTS-094-05	1/31/86	-96	-12.9		
NTS-095-05					
NTS-096-05	2/ 7/86	-96	-13.1		
NTS-097-05					
NTS-098-05					
NTS-099-05					
NTS-100-05					
NTS-101-05	3/ 4/86	-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	4/12/86	-94	-13.0		
NTS-111-05	4/17/86	-95	-13.1		
NTS-112-05	4/22/86	-95	-13.2		
NTS-113-05	4/27/86	-95	-13.2	0.05	0.07
NTS-114-05	5/ 2/86	-96	-13.2		
NTS-115-05	5/ 7/86	-96	-13.3		
NTS-116-05	5/ 8/86	-96	-13.4		
NTS-117-05	5/12/86	-97	-12.9	0.04	0.07
NTS-118-05					
NTS-119-05					
NTS-120-05	6/17/86	-92	-13.0		
NTS-121-05	6/22/86	-95	-13.0		
NTS-122-05	6/27/86	-96	-13.1		
NTS-123-05					
NTS-124-05					
NTS-125-05	7/10/86	-94	-13.0		
NTS-126-05					
NTS-127-05	7/20/86	-95	-13.0		
NTS-128-05					
NTS-129-05					
NTS-130-05					
NTS-131-05	8/16/86	-93	-12.6		

Conclusions and Recommendations

The hydrology of Rainier Mesa is dominated by fracture flow through the majority of the formations. Of these, the Indian Trails Formation has the lowest hydraulic conductivities and acts as an aquitard; however, certain fractures within this formation are hydraulically connected to stratigraphically higher water-bearing fractures. It is these fractures which control the movement of water from the Indian Trails Formation to the regional water table.

The ground water present in the Indian Trails Formation has been considered to be relict water from a pluvial period. Since seasonal increases in discharge exist and the isotopic signatures of these seeps are within the range of present day precipitation, then the source of the water found at the tunnel seeps is recent precipitation.

The precipitation record of Rainier Mesa revealed two seasons of the year which could recharge the mesa, winter and summer. Since winter is characterized by the greatest amount of precipitation and summer is characterized by the greatest potential for evapotranspiration, it was thought that winter precipitation recharged Rainier Mesa. This was confirmed by an examination of the last four years of the isotopic ratios of the precipitation as it relates to the isotopic ratios of the tunnel seeps. Winter precipitation was found to best match the isotopic signature of the tunnel seeps.

Discharge and humidity records were combined in order to estimate the total flux of water from U12n tunnel. It was determined that 34,900 $\pm$ 5,500 m^3 of water passed through U12n tunnel each year. The recharge basin was estimated to be 1.47 $\pm$ .29 km^2. Assuming that the characteristics of the Rainier Mesa Formations which control infiltration are homogeneous throughout the mesa, a simple calculation relating basin area to recharge can be performed. This calculation estimated a total of 271,000 $\pm$ 141,000 m^3 of water recharging the mesa each year. This estimate was divided into the total cubic meters of precipitation which falls on U12n Tunnel recharge basin each year. The results indicate an average of 8.5 $\pm$ 21% of all precipitation recharges Rainier Mesa. The 7% estimated by Thordarson (1965), is within this range.

An examination of the chemistry of the water emanating from various tunnel seeps indicated similiar waters. The isotopic ratios revealed that U12n.05 drift water is generally enriched in both oxygen-18 and deuterium. This indicates that very little mixing occurs between the fracture systems, yet similiar chemical reactions yield similiar water chemistries. Several explanations are offered to explain the isotopic enrichment of 05 water over 03 water. The first is the greater altitude of the recharge area of the U12n.03 drift could account for the difference. The second is a greater degree of contamination of the 05 drift by nuclear testing, the third possibility is the 05 fracture system is more likely to be recharged by summer precipitation due to its location at the bottom of the biggest wash on Rainier Mesa.

The period of hydraulic response was determined by averaging the discharge records following suspected recharge events. The results found a net increase in discharge at approximately four months after the recharge event.

Several methodologies were attempted in trying to determine the travel time of ground water from the mesa surface to the tunnel level. Two tracer studies, a tritium study, and several statistical methods based on isotopes proved to be unsuccessful. An isotopically depleted season of winter precipitation occurred in the winter of 1985 to 1986. Simple mixing calculations predict that this pulse of light recharge will be noticable as an isotopic depletion at the tunnel seeps. Thus, a continued monitoring program will be implemented.

The effect of nuclear testing on localized ground-water flow and chemistry was examined. The results were based on ground-water discharge, chemistry, and isotopic ratios. Nuclear tests within the mesa generate a seismic P wave which increases interstitial flow into the active transport system. This increased flow contains a possible relict interstitial water high in sulfate content and an enriched stable isotopic signature.

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 1985-86 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 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 this 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.

HYDROGEOLOGY

Physical Hydrogeology

For this study, the units of hydrologic interest are those formations which exist between the mesa surface, which is the suspected recharge area, and the lower Tunnel Beds where the sample sites exist. This section is approximately 450 m thick, starting at the top with the Rainier Mesa member of the Timber Mountain Tuff and extending down to Tunnel Bed Unit 2. An idealized cross section of this section and the areas of perched saturated ground-water flow are on Figure 4. Thordarson (1965), classified the Tunnel Beds and all of the units stratigraphically overlying it into three types of hydrogeologic units. These are the zeolitic bedded tuffs, friable bedded tuffs, and the welded and partially welded tuffs. The physical properties of these hydrogeologic units are summarized in Table 2.

The zeolitic bedded tuffs within Rainier Mesa are: the lower portions of the Paintbrush Tuff and Stockade Wash Tuff, some portions of the bedded and ash-flow tuffs of Area 20 of the Nevada Test Site, and some portions of the

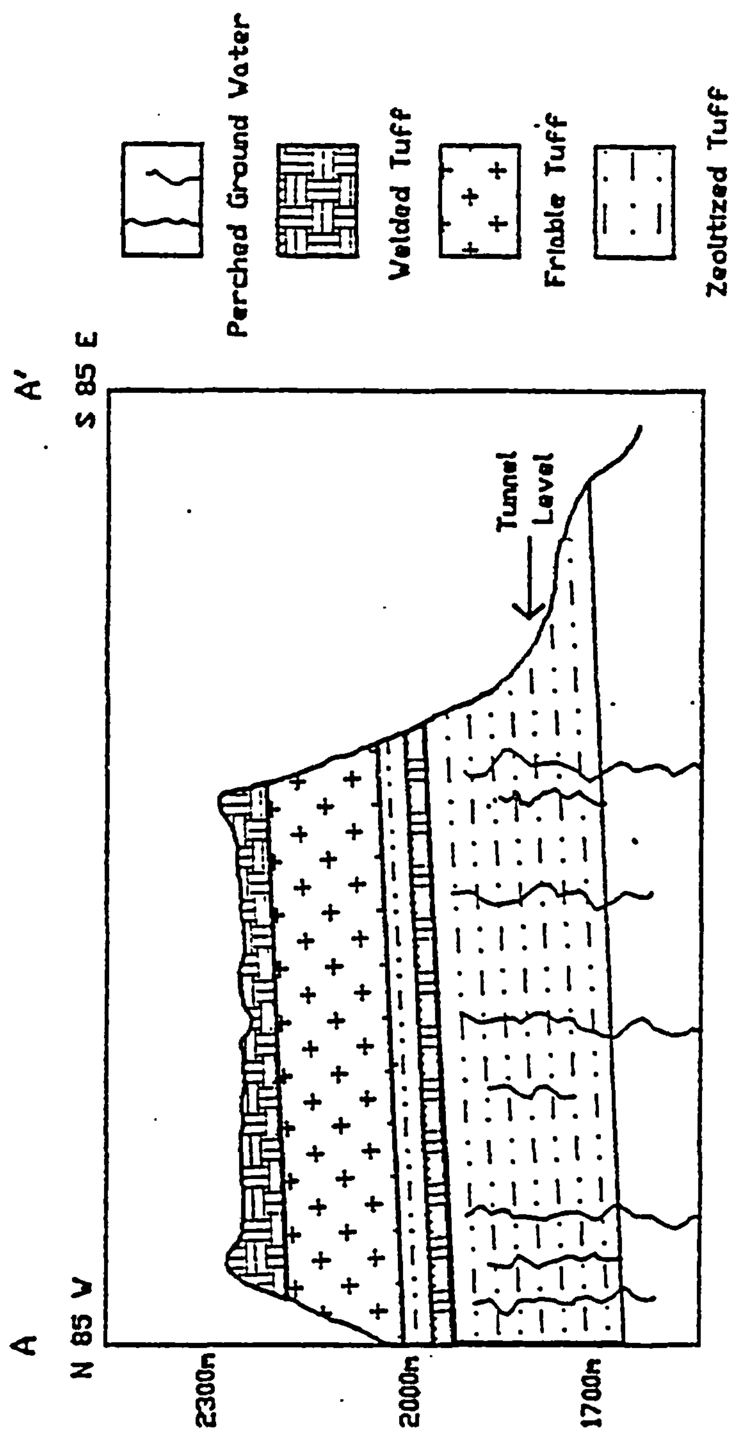

Figure 4. A Cross-section of Rainier Mesa showing the Three types of Hydrogeologic units found there and the Mode and Occurrence of Perched Ground-Water Lenses.

TABLE 2. FORMATIONS OF RAINIER MESA AND A SUMMARY OF THEIR HYDRAULIC PROPERTIES USING AVAILABLE DATA.

Formation and Member	Interstitial Permeability	Interstitial Porosity	Effective Permeability
Timber Mountain Tuff, Rainier Mesa Member	$4.72X10^{-9}m/s$	14%	Fracture
Paintbrush Tuff	$1.75X10^{-6}m/s$	40%	Interstitial
Belted Range Tuff, Grouse Canyon Member	$2.80X10^{-9}m/s$	19%	Fracture
Tunnel Bed Unit 4, Indian Trail Formation	$9.44X10^{-9}m/s$	38%	Fracture
Unit 3	$1.40X10^{-9}m/s$	35%	Fracture
Unit 2	----no data---	32%	Fracture
Unit 1	----no data---	25%	Fracture

Data from Thordarson, 1965.

lava and tuffs of Dead Horse Flat, as well as most sections of the Tunnel Bed units. The ash-flows and ash-falls which comprise the zeolitic bedded tuffs originally contained pumice and glass shards, which were subsequently altered *in situ* to the zeolites clinoptilolite, mordenite, and some analcime (Benson, 1980).

Core samples taken by Thordarson (1965) from the Tunnel Beds yielded an average interstitial porosity ranging from 25 to 38 percent. Byers (1961), determined the pore spaces found within the Tunnel Beds are close to 100 percent saturation. The uppermost zeolitized bedded tuff, which is in the lower section of the Paintbrush Tuff, contains an interstitial porosity of 27 to 29 percent (Diment *et al.*, 1959a). Saturation in this unit was also found to be close to 100 percent.

The range of interstitial permeability for the Tunnel Beds are from $0.19 X 10^{-9}$ to $9.44 X 10^{-9}$ m/s. The mean interstitial permeability for the lower Paintbrush Tuff was found to be $9.44 X 10^{-9}$ m/s. The porosity values between these two units closely agree, yet the permeability values may vary up to an order of magnitude These values are thought to be a representative range for most zeolitized tuffs within Rainier Mesa.

Within the tunnels mined into the zeolitic bedded tuffs, a general absence of water on the walls is noted. This evidence, coupled with the presence of very low interstitial permeability, indicates that pore water is strongly held by capillary forces within these units. It is appropriate to assume that the interstitial waters travel extremely slow through these units. The above evidence does not preclude the possibility of the movement of interstitial waters into the tunnels by the process of evaporation. This hypothesis is supported by samples taken from the tunnel walls by Byers (1961), and Diment (1959a). The interstitial pores of these samples were saturated only 62 to 70 percent. If ground water is moving into the tunnels by evaporation from the pore spaces, then it is contributing to the total discharge derived from each tunnel. The extent of this contribution will be analyzed in a latter section.

Free flowing ground water is found primarily within the Tunnel Bed fracture system. The majority of these water-bearing fractures are normal faults characterized by several centimeters of displacement. A fracture analysis was undertaken by Thordarson (1965) within U12e tunnel. It was determined that 50 to 60 percent of all normal faults yielded fracture water, while only 2 percent of induration joints, cooling joints, and other types of fractures were water bearing. This phenomenon is most likely due to the greater extent and continuity of the normal faults.

Interspersed among the water-bearing fractures are dry fractures. It is assumed that the fracture system is poorly connected hydraulically. This hypothesis is supported by thermal variations of relatively close fracture seeps, and the extreme variation in initial discharge for these same seeps (Thordarson, 1965). Some fracture systems drain and are dry within a few weeks after mining. Others, which are relatively close by, have acted as continous seeps since the initial excavation, albeit at much lower discharge rates than initially recorded (Thordarson, 1965).

The top of the zone of saturation has been determined by numerous test holes drilled into Rainier Mesa. The elevation of the water table varies up to 100 meters owing to the poor hydraulic continuity of the water-bearing fractures. However, the mean elevation is approximately 1820 m, which is in Tunnel Bed Units 3 and 4 (Thordarson, 1965). The present water table elevation most likely reflects lowered levels due to extensive gravity drainage of the fractures by mining activities.

The friable bedded tuffs are composed of the lower part of the Grouse Canyon Member and the bulk of the Paintbrush Tuff. These units were deposited as an ash-fall which remained relatively unaltered and uncemented. The interstitial porosity and permeability of these units are relatively high in comparison to the other tuffs of Rainier Mesa. Samples from the Paintbrush Tuff indicate a porosity of 40 percent and a mean interstitial permeability of $1.7X10^{-6}$ m/s (Emerick and Houser, 1962). In the same study, it was determined that the interstitial spaces were saturated at an average of 64 percent. An examination of the fractures within the friable bedded tuffs by Thordarson (1965), revealed that most faults are rarely preserved in these units, yet those that exist are usually sealed by fault gouge to a considerable degree. The dominant form of transport is thought to be partially saturated interstitial flow, which is a result of the formation's relatively high permeability and porosity, and low fracture frequency.

The welded and partially welded tuffs are composed of the Tub Spring Member, and most of the Grouse Canyon Member of the Belted Range Tuff, the Stockade Wash and Tiva Canyon members of the Paintbrush Tuff, and the Rainier Mesa Member of the Timber Mountain Tuff. These Tuffs were formed as ash-flows which were welded together during deposition. Cooling joints and structural deformation fractures are abundant and well preserved in these formations.

The interstitial porosity of the Rainier Mesa and Grouse Canyon members average 14 and 19 percent respectively. The interstitial permeability of these units average 4.72×10^{-9} m/s (Thordarson, 1965). Owing to the high fracture frequency within the welded and partially welded tuffs and the low porosity and permeability of the matrix, fracture flow is thought to be the dominant form of transport within these units (Thordarson, 1965).

According to Thordarson (1965), ground water within Rainier Mesa occurs as a series of perched lenses within fractures of the zeolitic bedded tuffs of the Indian Trails Formation. The regional zone of saturation is at least 1000 m below the surface of the mesa and 500 meters below the tunnel level. The movement of ground water is downward from the recharge area at the top of the mesa, through the fractures of the Rainier Mesa Member, and then through the underlying friable Paintbrush Tuff. Vertical movement through these units is probably rapid, due to their relatively larger effective permeability. However, upon reaching the less permeable zeolitic bedded tuff, the ground water creates a series of perched lenses which slowly drain through the fracture system of the formation, or into the tunnel system. The friable bedded tuff of the overlying Paintbrush Tuff acts as a large perched aquifer supplying ground water to the fracture systems throughout the dry portions of the year. Once ground water has percolated past the tunnel level, movement continues downward until the regional water table is reached.

Chemical Hydrogeology

As ground water passes through Rainier Mesa, incongruent dissolution processes create a sodium bicarbonate water found within the fractures (White et al.,

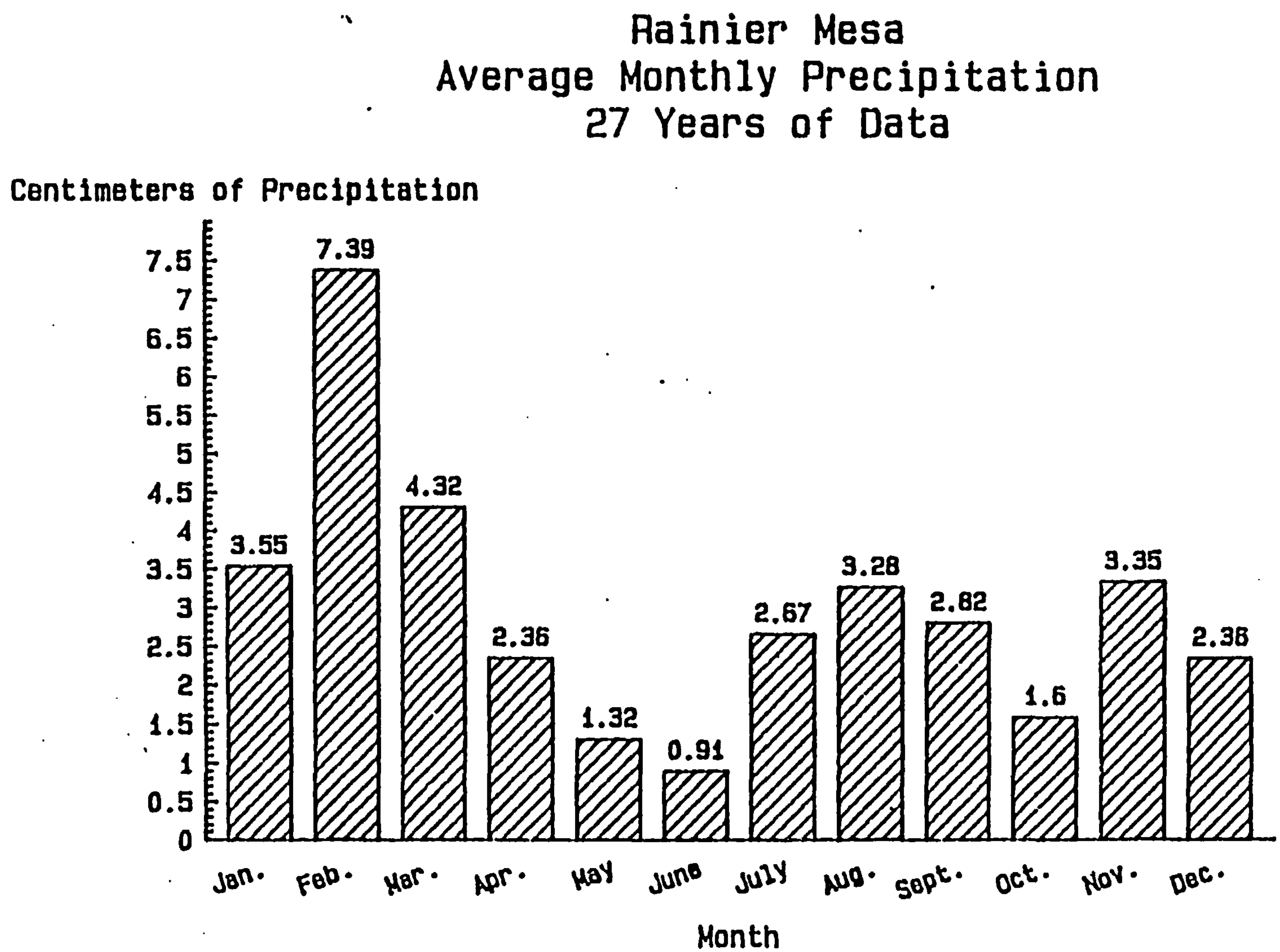

Figure 3. Rainier Mesa Average Monthly Precipitation

HYDROGEOLOGIC INVESTIGATIONS OF FLOW IN FRACTURED TUFFS, RAINIER MESA, NEVADA TEST SITE

by

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A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

in

Geoscience

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