Estimated Ground-Water Recharge from Streamflow in Fortymile Wash near Yucca Mountain, Nevada

by Charles S. Savard

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 97-4273

Prepared in cooperation with the
NEVADA OPERATIONS OFFICE,
U.S. DEPARTMENT OF ENERGY, under
Interagency Agreement DE-AI08-92NV10874

Denver, Colorado
1998

DRAFT DISCLAIMER

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Mark Schaefer, Acting Director

For additional information write to:

Chief, Earth Science Investigation
Yucca Mountain Project Branch
U.S. Geological Survey
Program Branch of Information Services
Box 25286
Denver Federal Center
Denver, CO 80225-0046

Copies of this report can be purchased from:

U.S. Geological Survey
Information Services
Box 25286
Federal Center
Denver, CO 80225

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS

Multiply	*By*	*To obtain*
cubic meter (m^3)	35.31	cubic foot
cubic meter	0.000811	acre-foot
cubic meters per second (m^3/s)	35.31	cubic feet per second
kilometer (km)	0.6214	mile
meter (m)	3.281	foot
square kilometer (km^2)	0.3861	square mile

ESTIMATED GROUND-WATER RECHARGE FROM STREAMFLOW IN FORTYMILE WASH NEAR YUCCA MOUNTAIN, NEVADA

By Charles S. Savard

ABSTRACT

Fortymile Wash, an ephemeral stream, in the Yucca Mountain area of Nevada, has periods of no streamflow for several years, but ground-water recharge has occurred after infrequent streamflows. Water levels rose after winter/spring streamflows in Fortymile Wash in 1983, 1992, 1993, and 1995 in three Fortymile Canyon boreholes, UE-29 a #1, UE-29 a #2, and UE-29 UZN #91. Ground-water recharge probably also occurred after winter/spring streamflow in 1969 and summer/fall streamflow in 1984. The winter/spring streamflows were preceded by negative swings in the Southern Oscillation Index.

Ground-water recharge rates were estimated from measured and estimated streamflow volumes, measured and estimated streamflow infiltration loss volumes, and estimated ground-water recharge volumes for four reaches (Fortymile Canyon, upper Jackass Flats, lower Jackass Flats, and Amargosa Desert) in the Fortymile Wash drainage basin. Streamflow volumes were estimated for ungaged portions of Fortymile Wash based on nearby gaged streamflow, peak discharges, streamflow volumes, and water-level rises in wells. Streamflow infiltration loss volumes for each reach were estimated using a streamflow volume loss factor of 7,300 cubic meters per kilometer, estimated from streamflow volume and distance traveled data. Although ground-water recharge processes from streamflow infiltration are nonlinear, a linear relation was assumed between streamflow infiltration loss volume and ground-water recharge volume. The linear relation started at 9,000 cubic meters of streamflow infiltration loss volume for the Fortymile Canyon reach, 40,000 cubic meters for the Amargosa Desert reach, and 70,000 cubic meters for the upper and lower Jackass Flats reaches, then for every cubic meter of streamflow infiltration loss, a cubic meter of ground-water recharge was estimated to occur. Winter/spring and summer/fall ground-water recharge rates were computed for 1969-95, 1983-95, and 1992-95 for each of the four reaches based on the estimated volume of ground-water recharge divided by the length of time for the period. A seasonal long-term ground-water recharge rate for each reach was estimated based on the three different time period estimates. A combined long-term ground-water recharge rate was estimated: 27,000 cubic meters per year for Fortymile Canyon, 1,100 cubic meters per year for upper Jackass Flats, 16,400 cubic meters per year for lower Jackass Flats, and 64,300 cubic meters per year for the Amargosa Desert reach by adding the winter/spring and the summer/fall rates.

INTRODUCTION

The Yucca Mountain area is being evaluated by the U.S. Department of Energy for its suitability to store high-level nuclear waste in a mined, underground repository (U.S. Department of Energy, 1988). Hydrologic data are being collected by the U.S. logical Survey throughout a 150 square kilomete

(km^2) study area about 150 kilometers (km) northwest of Las Vegas in southern Nevada (fig. 1) for site characterization.

Fortymile Wash is an ephemeral stream channel near Yucca Mountain with tributaries draining the east side of Yucca Mountain and then forming a distributary system in the Amargosa Desert. Streamflow may not occur for several years or may occur several times during a year in Fortymile Wash. Fortymile Wash is a tributary to the Amargosa River which drains into Death Valley. As part of the site characterization work, hydrologic data needed to determine the amount of ground-water recharge from streamflow in Fortymile Wash to the ground-water flow system were collected for the Fortymile Wash study. Ground-water recharge in this report refers to the volume of water reaching the water table after infiltrating the streambed and passing through the unsaturated zone. Claassen (1985), White and Chuma (1987), and Benson and Klieforth (1989) proposed ground-water recharge from Fortymile Wash streamflow, but did not estimate the amount or a rate. Czarnecki and Waddell (1984) proposed a preliminary rate based on their ground-water computer simulation study of the area. The relation between streamflow and rises in the ground-water level in boreholes in Fortymile Canyon, attributed to ground-water recharge, has been shown for 1992, 1993 and 1995 (Savard, 1994 and 1995b). An estimate of the ground-water recharge rate is needed to determine how water moves through the ground-water system.

This work was done by the U.S. Geological Survey in cooperation with the Yucca Mountain Site Characterization Project Office of the U.S. Department of Energy under Interagency Agreement DE-AI08-92NV10874.

PURPOSE AND SCOPE

The two purposes of this report are to qualitatively document ground-water recharge from streamflow in Fortymile Wash during the period 1969-95 from previously unpublished ground-water levels in boreholes in Fortymile Canyon during 1982-91 and 1995, and to quantitatively estimate the long-term ground-water recharge rate from streamflow in Fortymile Wash for four reaches of Fortymile Wash (Fortymile Canyon, upper Jackass Flats, lower Jackass Flats, and Amargosa Desert). The long-term ground-water recharge rate was estimated from estimates of the volume of water available for infiltration, the volume of infiltration losses from streamflow, the ground-water recharge volume from infiltration losses, and an analysis of the different periods of data availability. The volume of water available for infiltration and ground-water recharge in the four reaches was estimated from known streamflow in ephemeral Fortymile Wash, which was measured at several gaging station locations. The volume of infiltration losses from streamflow for the four reaches was estimated from a streamflow volume loss factor applied to the estimated streamflows. The ground-water recharge volume was estimated from a linear relation between infiltration loss volume and ground-water recharge volume for each of the four reaches. Ground-water recharge rates were estimated for three different periods of data availability (1969-95, 1983-95, and 1992-95) and a long-term ground-water recharge rate estimated for each of the four reaches.

The estimated long-term ground-water recharge rates for the four reaches are compared to previous estimates of ground-water recharge. The changes in a Pacific Ocean climate index (the Southern Oscillation Index), which preceded streamflow and ground-water recharge in the Fortymile Wash area, is discussed.

PREVIOUS WORK

Previous studies have determined ground-water recharge is occurring from streamflow in Fortymile Wash. Water-quality studies have studied precipitation, surface water, and ground-water isotopic and common ion concentrations and concluded recharge water is entering the ground-water system north of Yucca Mountain from streamflow. Computer simulation of the ground-water system has determined recharge from Fortymile Wash is a significant component of the water budget. Ground-water levels rise after streamflow events in Fortymile Canyon. Channel geomorphic studies indicate water is being lost from streamflow in the Yucca Mountain area.

Several previous water chemistry studies have determined streamflow in Fortymile Wash is a source of ground-water recharge. Claassen (1985) investigated common ion and isotope ages and concluded ground water in the west-central Amargosa Desert was recharged primarily from overland flow of snowmelt near the present-day Fortymile Wash stream channel.

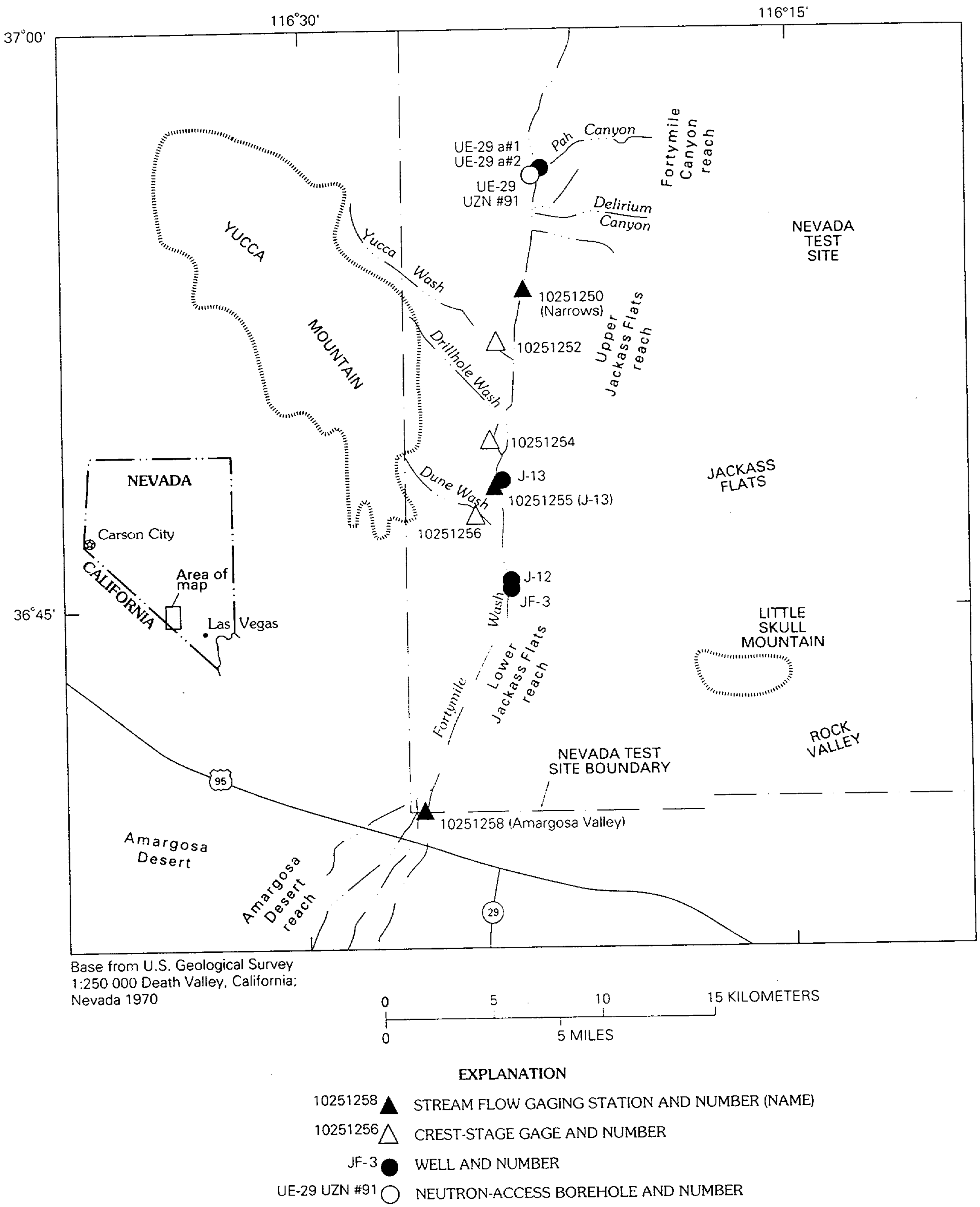

Figure 1. Location of selected streamflow gaging stations, crest-stage gages, neutron-access boreholes, and wells in the Fortymile Wash drainage basin near Yucca Mountain, Nevada.

White and Chuma (1987) investigated carbon and isotopic mass balances of the Oasis Valley - Fortymile Canyon ground-water basin and concluded ground water in Fortymile Canyon may be from local origin. Benson and Klieforth (1989) investigated stable isotopes in precipitation and ground water in the Yucca Mountain area and concluded ground-water recharge occurred by infiltration of cold-season precipitation, probably along the bottom of Fortymile Canyon.

Wadell (1982) and Czarnecki and Wadell (1984) studied the ground-water system in the Yucca Mountain area using a computer simulation of the ground-water system. A component of ground-water recharge from streamflow in Fortymile Wash was needed for the model to simulate natural conditions.

Several other studies concentrated on streamflow and the ephemeral stream channel characteristics of Fortymile Wash. Osterkamp and others (1994) estimated ground-water recharge from streamflow in Fortymile Wash with a geomorphic/distributed-parameter simulation approach. Huber (1988) proposed the Fortymile Wash drainage pattern has not had major changes within the last 11 million years. He also proposed the channel incision of Fortymile Wash into the alluvial fan deposits south of Fortymile Canyon has been there since the middle Pleistocene. Grasso (1996) investigated the hydrology of lakes and streams in the Death Valley drainage basin. Pabst and others (1993) and Kane and others (1994) documented streamflow in Fortymile Wash. Beck and Glancy (1995) discussed the 1995 flood in Fortymile Wash.

During 1992-95, seven periods of streamflow occurred in the lower Fortymile Wash drainage basin (Savard, 1994 and 1995b). After the streamflow, ground-water levels rose in boreholes UE-29 a #1, UE-29 a #2, and UE-29 UZN #91. Ambos and others (1995) and Savard (1995a and 1996) reported on the precipitation that caused the streamflow. Savard (1995a and 1996) also reported on movement of water from the stream channel through the unsaturated zone and the water quality of streamflow.

The regional ground-water system underneath Fortymile Wash has been described by Young (1972), Winograd and Thordarson (1975), and Waddell and others (1984). Ground-water levels for wells and boreholes in the Fortymile Wash area can be found in several reports (Robison, 1984, Robison and others, 1988, Gemmel, 1990, O'Brien, 1991, Luckey and others, 1993, Boucher, 1994, La Camera and Westenburg, 1994, Hale and Westenburg, 1995, O'Brien and others, 1995, and Westenburg and La Camera, 1996). Waddell (1984) described hydrologic and drill-hole data for boreholes UE-29 a #1 and UE-29 a #2 in Fortymile Canyon.

STREAMFLOW IN THE FORTYMILE WASH DRAINAGE BASIN

The streamflow gaging network in the Yucca Mountain area consists of continuous-record gaging stations and peak flow crest-stage gages (Pabst and others, 1993, Kane and others, 1994, Emett and others, 1994, Clary and others, 1995, Bauer and others, 1996). Streamflow in the Fortymile Wash main channel near Yucca Mountain is measured at three continuous-record gaging stations (table 1). Fortymile Wash at Narrows, Nevada Test Site, Nevada (10251250) is the most upstream gage. Fortymile Wash near Well J-13, Nevada Test Site, Nevada (10251255) is the middle gage, 10.1 km downstream of the Narrows gage. Fortymile Wash near Amargosa Valley, Nevada (10251258) is the most downstream gage, 16.8 km downstream of the J-13 gage. These stations became operational in 1983-84. Three crest-stage gages recorded peak streamflow in tributaries to Fortymile Wash in the Yucca Mountain area, Yucca Wash near Mouth, Nevada Test Site, Nevada (10251252), Drillhole Wash at Mouth, Nevada Test Site, Nevada (10251254), and Dune Wash near Busted Butte, Nevada Test Site, Nevada (10251256) (table 1).

The Fortymile Wash drainage basin can be divided into four sections, the upper headwater area, Fortymile Canyon, the incised channel in Jackass Flats, and the lower distributary area in the Amargosa Desert. The upper headwater area is north of Fortymile Canyon and ground-water recharge was not studied in this area. From the headwater area, Fortymile Wash runs approximately due south through Fortymile Canyon, through Jackass Flats, and into the Amargosa Desert.

Ground-water recharge was only studied from the Pah Canyon area, approximately in the middle of Fortymile Canyon, downstream to the Amargosa Desert. Fortymile Wash was broken into four reaches defined by geography and gage location. The first reach is in Fortymile Canyon extending from the Pah Canyon area to the Narrows gage. The second reach is in upper Jackass Flats extending from the Narrows gage to the J-13 gage, where Fortymile Wash changes

Table 1. Selected streamflow gaging stations and crest-stage gages in the Fortymile Wash drainage basin near Yucca Mountain, Nevada.

[G, continuous-record streamflow gaging station; C, crest-stage gage]

Station number	Station name	Latitude Longitude	Gage type	Drainage Area (square kilometers)	Period of Record
10251250	Fortymile Wash at Narrows, Nevada Test Site, Nevada	36°53'13" 116°22'50"	G	668	September 1983 - September 1995
10251252	Yucca Wash near mouth, Nevada Test Site, Nevada	36°51'58" 116°23'38"	C	44.0	1982-95
10251254	Drillhole Wash at mouth, Nevada Test Site, Nevada	36°49'13" 116°23'52"	C	42.2	1983-95
10251255	Fortymile Wash near Well J-13, Nevada Test Site, Nevada	36°48'27" 116°24'01"	G	787	November 1983 - September 1995
10251256	Dune Wash near Busted Butte, Nevada Test Site, Nevada	36°47'35" 116°24'29"	C	17.5	1982-95
10251258	Fortymile Wash near Amargosa Valley, Nevada	36°40'18" 116°26'03"	G	818	November 1983 - September 1995

from a channel in a canyon to an incised channel in alluvial material. The third reach is in lower Jackass Flats extending from the J-13 gage to the Amargosa Valley gage, where Fortymile Wash changes from the incised channel to a distributary system. The fourth reach is in the Amargosa Desert extending from the Amargosa Valley gage to the Amargosa Desert, where Fortymile Wash is a distributary network.

Fortymile Wash is an ephemeral stream and does not have any streamflow for long periods of time (fig. 2 and 3). No streamflow was recorded at the J-13 gage from mid 1985 to early 1995. Streamflow may occur in one part of the drainage basin and then infiltrate into the streambed sediments before reaching a gage. Streamflow only occurs for short periods of time, several hours to several days. Mean daily discharges are much smaller in magnitude than instantaneous peak discharges. When streamflow does occur, there is the possibility of ground-water recharge from the infiltration losses.

FORTYMILE WASH STREAMFLOW, 1969-95

The January 25 and February 24-26, 1969, streamflows were only investigated south of Yucca Mountain at the U.S. Highway 95 crossing in 1969. Peak discharges were estimated to be 42 cubic meters per second (m^3/s) on January 25 (Glancy, P. A., U.S. Geological Survey, written commun., 1995) and 94 m^3/s during February 24-26 (U.S. Geological Survey, 1970). Squires and Young (1984) report a peak discharge of about 560 m^3/s near the J-13 gage based on high-water marks surveyed during the early 1980's. They assigned a date to coincide with the February 24-26, 1969, streamflow several kilometers downstrear at the U.S. Highway 95 crossing. An eyewitness to t streamflow confirmed the Fortymile Wash channel was filled with water across the bottom of the incised section near well J-12 at one time during the February 24-26 period. All four reaches of Fortymile Wash are assumed to have had streamflow during January 25 and February 24-26 based on the knowledge of documented streamflows during 1983, 1984, and 1995.

Just prior to gage installation on Fortymile Wash, streamflow occurred in the Fortymile Wash drainage basin on March 3, 1983. Estimated peak discharges at the three gaging stations on Fortymile Wash were 43 m^3/s at the Narrows gage, 16 m^3/s at the J-13 gage, and 11 m^3/s at Amargosa Valley gage. A peak discharge of 2.8 m^3/s was estimated at the Yucca Wash crest-stage gage. No evidence of streamflow was found at the Drillhole Wash or Dune Wash crest-stage gages. All four reaches of Fortymile Wash probably had streamflow throughout their entire length on March 3.

During July 21-23, 1984, streamflow occurred in all of the four reaches of Fortymile Wash. During

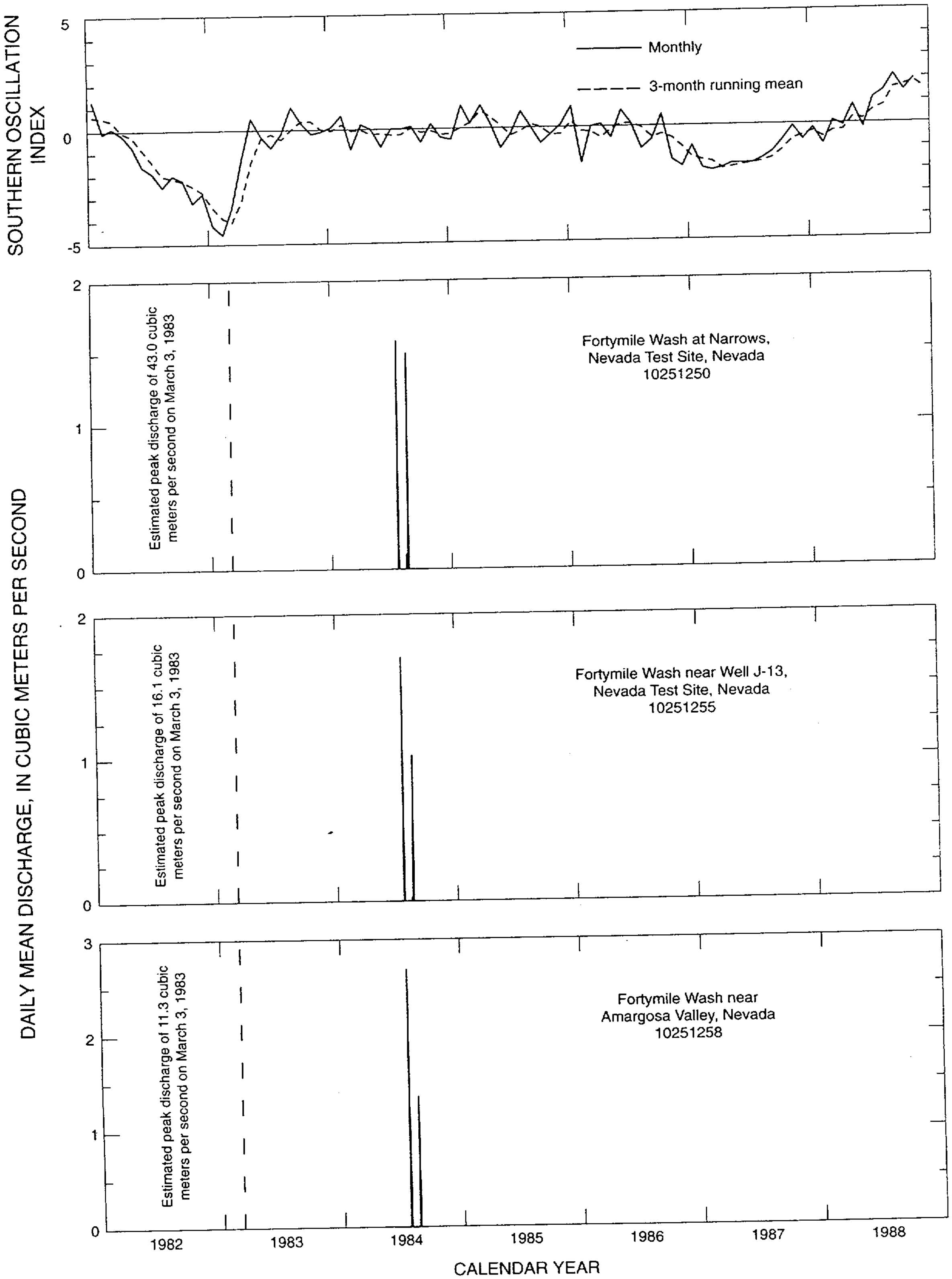

Figure 2. Fortymile Wash streamflow and the Southern Oscillation Index during 1982-88.

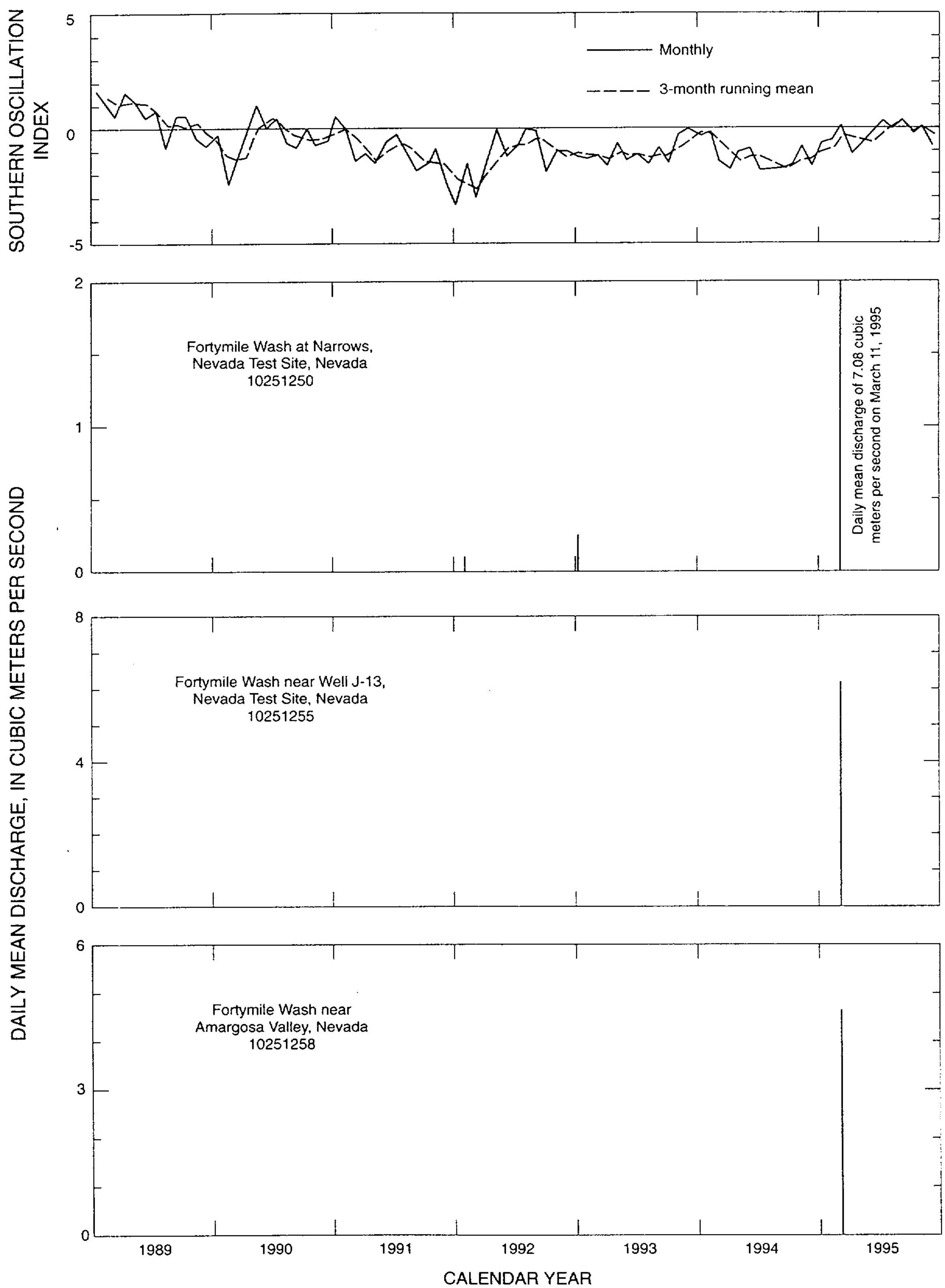

Figure 3. Fortymile Wash streamflow and the Southern Oscillation Index during 1989-95.

the period one large peak discharge and several small peak discharges were recorded at the three Fortymile Wash gages. The maximum peak discharges estimated were 21 m^3/s at the Narrows gage, 53 m^3/s at the J-13 gage, and 40 m^3/s at the Amargosa Valley gage. At the crest-stage gages, the peak discharges were 27 m^3/s at Yucca Wash and 22 m^3/s at Drillhole Wash. No streamflow was recorded at the Dune Wash crest-stage gage.

During August 14-16, 1984, streamflow occurred at all three Fortymile Wash gages. However, it is not known if streamflow had enough volume to be continuous from gage to gage, or if the streamflow was local.

During August 18-20, 1984, streamflow occurred in all of the four reaches of Fortymile Wash. One large peak discharge and several small to medium peak discharges were recorded at the three Fortymile Wash gages. The maximum peak discharge was 19 m^3/s at the Narrows gage, 24 m^3/s at the J-13 gage, and 9.5 m^3/s at the Amargosa Valley gage. At the crest-stage gages, the peaks were 0.88 m^3/s at Yucca Wash, 1.2 m^3/s at Drillhole Wash gage, and 0.4 m^3/s at Dune Wash.

During July 19-20, 1985, streamflow occurred at all three Fortymile Wash gages. The peak discharges were 0.33 m^3/s at the Narrows gage, 0.17 m^3/s at the J-13 gage, and 0.09 m^3/s at the Amargosa Valley gage. At the crest-stage gages, the peak discharges were 0.88 m^3/s at Yucca Wash, 0.48 m^3/s at Drillhole Wash, and 2.7 m^3/s at Dune Wash. Since streamflows at the Narrows gage on later dates had larger peak discharges and did not reach the next downstream gage at J-13, it is believed the streamflows were only local and did not have enough volume to be continuous from gage to gage.

On February 23, 1987, November 6, 1987, and September 23, 1990, streamflow occurred at the Amargosa Valley gage. All peak discharges were less than 0.025 m^3/s. On May 7, 1987, streamflow with a peak discharge of 0.003 m^3/s occurred at the Yucca Wash crest-stage gage. On August 12-13, 1991, streamflow occurred in Fortymile Canyon near the boreholes with peak discharge estimated to be between 0.6 and 0.85 m^3/s. On September 7, 1991, streamflow with a peak discharge of 0.12 m^3/s occurred at the Dune Wash crest-stage gage. All of these streamflows were small in volume and local.

During February 12-15, 1992, streamflow occurred in the Fortymile Canyon and upper Jackass Flats reaches. The volume of Pah Canyon streamflow was sufficient to reach Fortymile Wash and then almost reached the Delirium Canyon area. Several tributaries to Fortymile Wash in the Delirium Canyon area had sufficient streamflow to reach the main Fortymile Wash channel. The combined streamflow from these tributaries had sufficient volume to reach the Narrows gage on February 12, which had a peak discharge of 0.68 m^3/s. The streamflow went about 2.5 km downstream of the Narrows gage while infiltrating into the streambed sediments. Streamflow also occurred in Yucca Wash, with peak discharges of 0.42 m^3/s and 0.10 m^3/s, and in Dune Wash, with a peak discharge of 0.045 m^3/s. The largest Yucca Wash streamflow went approximately 560 m from the crest-stage gage to the mouth and then 30-40 m downstream in Fortymile Wash while infiltrating.

During March 30-31, 1992, streamflows occurred in the Fortymile Canyon reach. Streamflow from Pah Canyon and Delirium Canyon reached Fortymile Wash, but infiltrated before reaching the Narrows gage. Streamflow also occurred in Yucca Wash, with a peak discharge less than 0.03 m^3/s, and Dune Wash, with a peak discharge of 0.03 m^3/s.

During January 17-19, 1993, streamflow occurred in the Fortymile Canyon and upper Jackass Flats reaches. Streamflow from Pah Canyon and Delirium Canyon tributaries combined with streamflow from the upper Fortymile Wash drainage and went through the Narrows gage, with a peak of 1.5 m^3/s. The streamflow continued downstream and combined with streamflow from Yucca Wash. Yucca Wash had two peak discharges, 0.57 m^3/s and 2.3 m^3/s, during this three-day period. The streamflow continued until it was about 7.6 km below the Narrows gage.

During February 9 and 23, 1993, streamflow occurred in the Fortymile Canyon reach. Streamflow from Pah Canyon and Delirium Canyon infiltrated before reaching the Narrows gage.

During January 25-27, 1995, streamflow occurred in the Fortymile Canyon reach, upper Jackass Flats reach, and on Yucca Mountain. Streamflow from the Pah Canyon and Delirium Canyon areas combined and went through the Narrows gage, with a peak discharge of 0.2 m^3/s. The streamflow volume was small and completely infiltrated 150 m downstream of the gage. Yucca Wash had streamflow, with a peak discharge of 5.2 m^3/s, that reached Fortymile Wash but did not have sufficient volume to reach the

J-13 gage. Streamflow in Drillhole and Dune Washes on Yucca Mountain infiltrated before reaching the crest-stage gages at the mouths of these tributaries. The amount of streamflow on Yucca Mountain was probably increased by man-made disturbances, such as roads and drill pads, where soil compaction decreased infiltration capacity. During the January 25-27 streamflow, water was observed coming down roads and from the Exploratory Studies Facility pad.

During March 11-13, 1995, streamflow occurred in all four Fortymile Wash reaches and on Yucca Mountain. Peak discharges were 85 m^3/s at the Narrows gage, 85 m^3/s at the J-13 gage, and 34 m^3/s at the Amargosa Valley gage. The peak discharge during this period was the largest recorded at the Narrows and the J-13 gages. Pah Canyon and Delirium Canyon tributaries had streamflow as well as several unnamed tributaries in Fortymile Canyon. U.S. Highway 95 south of the Nevada Test Site (NTS) was closed because of water flowing over the road into the Amargosa Desert.

RELATION BETWEEN FORTYMILE WASH STREAMFLOW AND THE SOUTHERN OSCILLATION INDEX

The relation between wet and dry periods in the southwest U.S. and the Pacific Ocean area climate has been investigated (Cayan and Peterson, 1989, Redmond and Koch, 1991, Cayan and Webb, 1992, Kahya and Dracup, 1993, Dracup and Kahya, 1994). Oceanic conditions in the Pacific oscillate between two conditions, commonly known as El Niño and La Niña. Atmospheric conditions also oscillate in the Pacific area. The oceanic and atmospheric oscillations appear to be coupled together and are known as the El Niño/Southern Oscillation (ENSO) event (Enfield, 1989). ENSO appears to be a leading indicator of weather patterns throughout the Pacific rim. The Southern Oscillation Index (SOI) is used as a general indicator for ENSO conditions.

The SOI is computed using the long-term differences in sea level pressures between Tahiti, French Polynesia, and Darwin, Australia. The SOI is published by the Climate Analysis Center, U.S. Department of Commerce to indicate differences in the climatic conditions of the central and western Pacific. The SOI is negative when there is sustained high pressure in Darwin and low pressure in Tahiti, and El Niño conditions occur. Moisture is funneled into the southwest U.S. and the normally arid area receives precipitation.

Winter/spring streamflow in Fortymile Wash appears to be related to the SOI, because when winter/spring streamflow occurred, the SOI was negative (fig. 2 and 3). El Niño conditions occurred (the SOI was negative) (Ropelewski and Halpert, 1986, Quinn and others, 1987, and Cayan and Webb, 1992) prior to winter/spring streamflow in 1969, 1983, 1992, 1993, and 1995. In the winter/spring of 1987 no streamflow occurred in the Fortymile Wash drainage basin except for a February 23 streamflow at the Amargosa Valley gage, mean daily discharge of 0.001 m^3/s, after a negative swing in the SOI. Negative swings in the SOI do not always mean there will be streamflow in Fortymile Wash but indicate the possibility of winter/spring storms tracking across the Fortymile Wash drainage basin with enough precipitation for streamflow to occur.

GROUND-WATER RECHARGE

Ground-water recharge from Fortymile Wash streamflow has been identified as an important component to the ground-water system in the Yucca Mountain area (Czarnecki and Wadell, 1984). Czarnecki and Wadell estimated a recharge rate of 8,080,000 m^3/year from Fortymile Wash streamflow in their computer simulation of ground-water flow in the vicinity of Yucca Mountain. Osterkamp and others (1994) estimated a recharge rate of 590,000 m^3/year from Fortymile Wash streamflow in their geomorphic/distributed parameter simulation. This report uses estimated streamflow volumes from 1969-95, estimates the infiltration losses from streamflow, estimates the ground-water recharge volume from the infiltration losses, and then adjusts computed long-term ground-water recharge rates based on available data for the four reaches of Fortymile Wash.

Water levels in three boreholes, UE-29 a #1, UE-29 a #2, and UE-29 UZN #91 (fig. 1), in the Fortymile Canyon area have responded to infiltration and recharge from streamflow (Savard, 1994, 1995a, 1995b, and 1996). Water levels in well J-13, in upper Jackass Flats, and in wells J-12 and JF-3, in lower Jackass Flats, have not responded after streamflow (La Camera and Westenburg, 1994, Hale and Westenburg, 1995, and Westenburg and La Camera, 1996). In tymile Canyon the depth to water is shallow, approximately 15 to 100 meters (m), compared to Jackass Flats where the depth to water is greater, approximately 100 to 350 m.

Borehole UE-29 a #1 was drilled to 65.5 m in 1982 to investigate ground-water recharge processes in Fortymile Canyon. After drilling equipment became stuck in the borehole, UE-29 a #2 was drilled approximately 9 m away to a depth of 421 m. Borehole UE-29 a #1 is open to alluvium and rock formations from 10.7 to 65.5 m. Borehole UE-29 a #2 is open to the rock formations from 86.9 to 213 and from 247 to 421 m. Open-ended tubing was installed to a depth of 357 m to allow access to the lower portion of UE-29 a #2 in case of hole collapse. The lithology penetrated by the boreholes is assumed to be the same because they are only 9 m apart. Wadell (1984) presents a detailed lithologic log of UE-29 a #2. Generally, the lithology is 0 to 12 m, alluvium; 12 to 57.3 m, rhyolite; 57.3 to 65 m, tuff; 65 to 189 m, rhyolite; and 189 to 421 m, rhyolite. The water level in UE-29 a #1 is 2 to 3 m higher than in UE-29 a #2 because the boreholes are open to different geologic strata. Both boreholes are on an alluvial bench along Fortymile Wash in Fortymile Canyon near the confluence with Pah Canyon. On February 15, 1995, casings on both boreholes were extended and the measuring points were raised, 0.762 m for UE-29 a #1 and 0.740 m for UE-29 a #2.

Borehole UE-29 UZN #91 is a neutron-access borehole drilled to 28.6 m in 1986 to investigate water movement through the unsaturated zone under Fortymile Wash. The borehole is open to rock formations from 27.1 to 28.6 m. Blout and others (1994) present a detailed lithologic log for the borehole. Generally, the lithology penetrated by the borehole is 0 to 19.5 m alluvium and colluvium and 19.5 to 28.6 m, tuff. The borehole was in the main channel of Fortymile Wash, approximately 150 m downstream of the confluence of Fortymile Wash and Pah Canyon tributary, but during the March 11, 1995 streamflow, the main channel moved east approximately 10 m. UE-29 UZN #91 is now on a gravel bar adjacent to the main channel. Because of the bar deposition, the borehole casing was extended with a 0.610 m pipe extension on April 5, 1995. Volumetric water-content profiles for the unsaturated zone of the borehole are given in Flint and Flint (1995) for 1990-93, Savard (1995a) for 1992, and Savard (1996) for 1993-94.

RISES IN GROUND-WATER LEVELS AFTER STREAMFLOW

Water levels in three boreholes in Fortymile Canyon, UE-29 a #1, UE-29 a #2, and UE-29 UZN #91, rose after some streamflow periods (fig. 4-6). Water levels were measured infrequently during 1983-92. From 1992-95 water-level measurements were made more frequently, as often as daily, to document water-level rises after streamflow.

After the March 3, 1983, streamflow, water levels rose at least one meter in UE-29 a #1 and UE-29 a #2. The first water-level measurements after the streamflow were made in October 1983. Assuming the water-level rises were similar to the documented rises in 1992, 1993, and 1995, water levels in both boreholes probably peaked approximately two to three weeks after the streamflow and then began a steady decline.

Water levels were not measured in UE-29 a #1 and UE-29 a #2 after the summer streamflow in 1984 and rises in water levels are not apparent from measurements made after the summer streamflow in 1985. Because of the infrequent measurements, water-level rises may have declined and not been observed. Rises in water levels for all three boreholes were not observed after the August 1991 streamflow.

Water levels rose a meter or less in all three boreholes after the February and March 1992 streamflows. Water levels peaked approximately 2 to 3 weeks after the streamflow. Water-level rises on June 29, 1992, in UE-29 a #2 and UE-29 UZN #91 are attributed to an earthquake at Little Skull Mountain, approximately 25 km to the southeast. The water level declined in UE-29 a #1.

Water levels rose in all three boreholes after the January and February 1993 streamflows. UE-29 a #1 had the largest rise of the three boreholes, approximately 4 m, after the three streamflows. UE-29 a #2 rose almost 3 m. UE-29 UZN #91 rose approximately 2 m. Water levels peaked approximately 2 to 3 weeks after each streamflow. The 1993 rises were greater than the 1992 rises.

Water levels rose in all three boreholes after the January and March 1995 streamflows. Total water level rise was 5.9 m for UE-29 a #1, 5.5 m for UE-29 UZN #91, and 4.6 m for UE-29 a #2 after the two streamflows. The largest measured rise after a streamflow for all three boreholes occurred after the March 11-13, 1995 streamflow, 4.5 m for UE-29 a #1 and

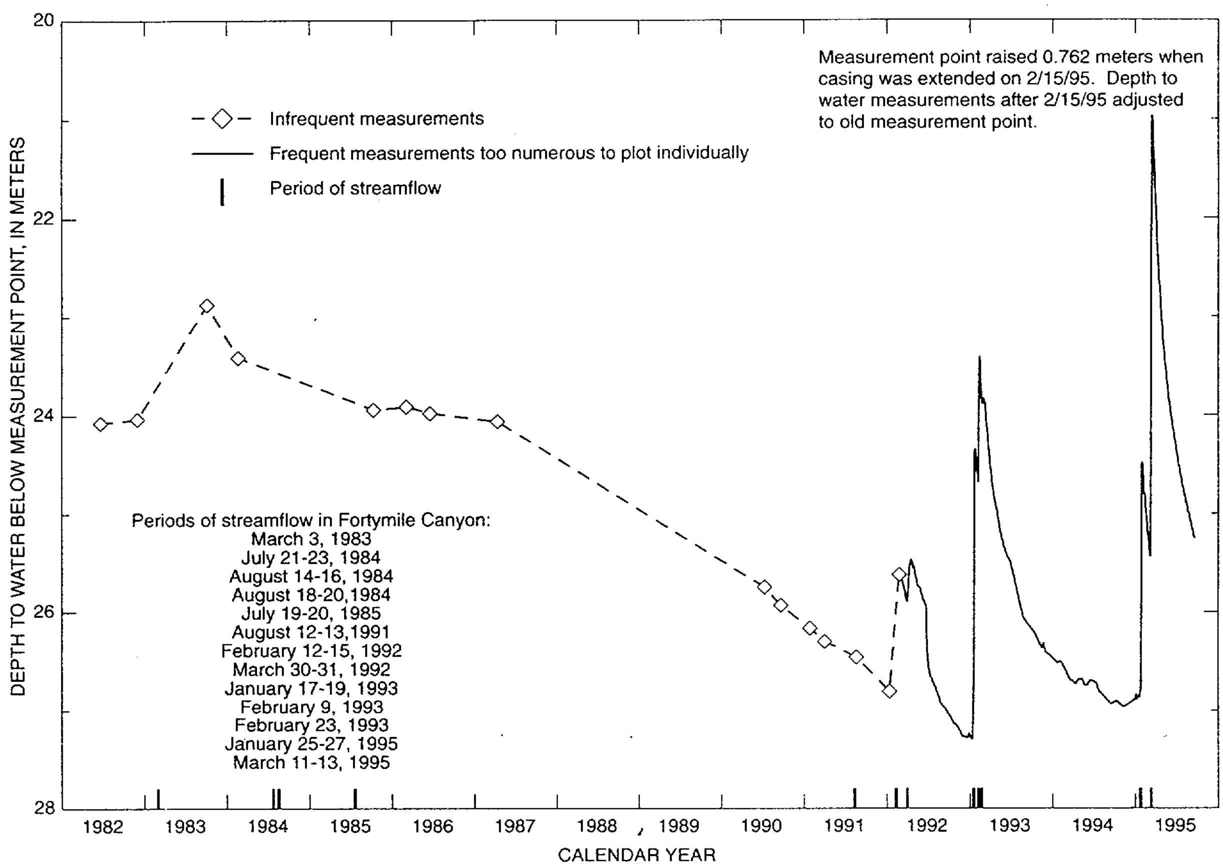

Figure 4. Water level in borehole UE-29 a #1 and periods of streamflow in Fortymile Canyon near Yucca Mountain, Nevada, 1982-95.

3.4 m for UE-29 a #2 and UE-29 UZN #91. All three boreholes had the highest water level ever measured after the rise from the March 11-13, 1995 streamflow. Water levels peaked in less than 1 week to almost 3 weeks after the streamflows.

Water-level rises in the three boreholes were different after a streamflow. These differences among the boreholes are probably due to the development of a ground-water mound under the stream channel which had the streamflow (Savard, 1994). The ground-water mound shape, height, and the areal extent is not understood because of the inadequate geometry of the boreholes and the stream channel. The March 1992 and February 1993 streamflows only occurred in Pah Canyon tributary and not in Fortymile Wash. UE-29 a #1 and UE-29 a #2, which are closer to the tributary than UE-29 UZN #91, had larger rises in the water level. These differences in water-level rises indicate a ground-water mound centered under the tributary channel which was spreading out laterally.

ESTIMATES OF GROUND-WATER RECHARGE VOLUME FROM STREAMFLOW

Ground-water recharge from streamflow is a nonlinear process with many contributing factors such as the variable geology and hydraulic properties of the stream channel sediments both along the stream channel and during the streamflow, the non-steady state of the streamflow, the duration of the streamflow, the changing channel cross section, infiltration differences due to changing hydraulic head during streamflow, and antecedent moisture conditions of the streambed sediments. Direct calculation of ground-water recharge was not possible because of the limited number of boreholes and gages, as well as the limited number of streamflows during the study period, 1969-95. To estimate ground-water recharge volume from streamflow, many assumptions and simplifications were made, such as linear relations to estimate nor

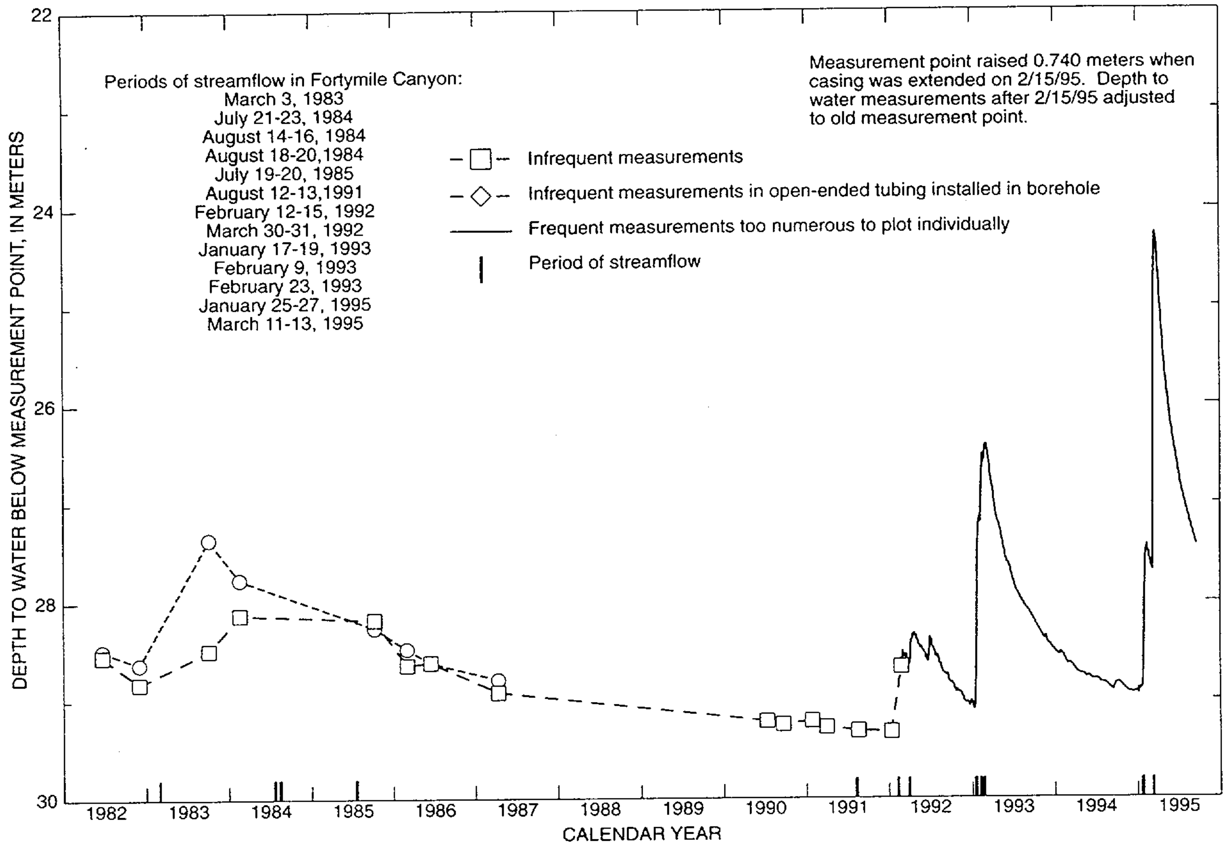

Figure 5. Water level in borehole UE-29 a #2 and periods of streamflow in Fortymile Canyon near Yucca Mountain, Nevada, 1982-95.

ear processes. The ground-water recharge volume estimates relied on known ground-water-level responses from streamflow, streamflow volume changes between gages, and the distance downstream of a gage a streamflow traveled when only infiltration losses were occurring and no ungaged tributary inflow was contributing unmeasured water volume.

Streamflow volumes and infiltration losses

When streamflow travels from one gage to another and there is no tributary or precipitation inflow, the loss in streamflow volume between the gages can be attributed to infiltration and evaporation losses. Evaporation losses are assumed to be negligible compared to infiltration losses because of the short time duration of the streamflow and the cloudy weather which caused the precipitation. The difference in streamflow volume between the upstream and downstream gage can then be considered infiltration losses. However, the streamflow volume must be sufficient to travel between the two gages. Small localized streamflows at the gages can give the impression of a larger continuous streamflow. If the distance localized streamflow traveled downstream of a gage is known, then infiltration losses per distance can be computed. The infiltration losses per distance can then be compared to the losses between gages for larger streamflows.

The measurement error in streamflow has been reduced over time as operational problems with the gages were reduced and the hydraulics of the streamflow at a site were better understood as more data were collected. There will always be some measurement error since the streamflow erodes and deposits streambed and bank material and the channel cross section area changes. A stable channel cross section is needed for the application of the stage-discharge relation to compute gage discharge. Mean daily discharge error at a gage may be more than 15 percent (Pabst and oth-

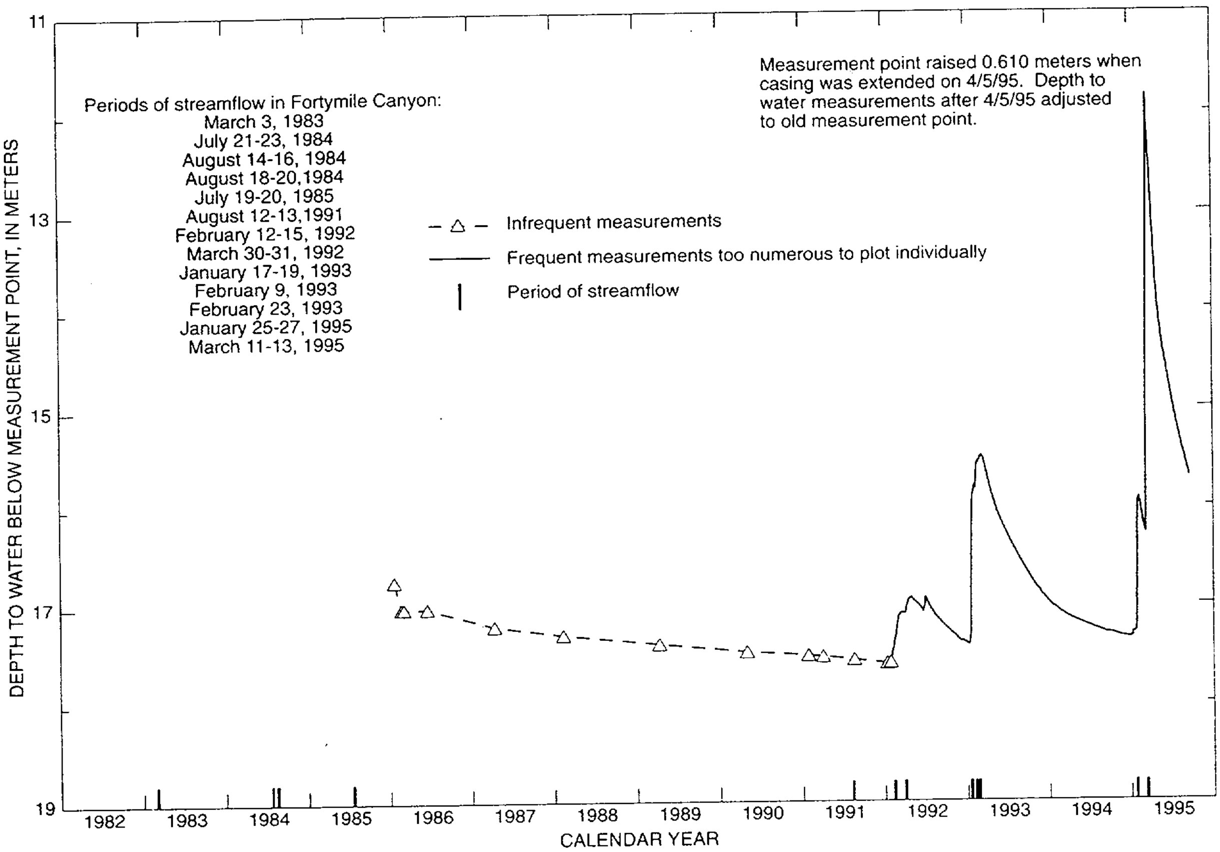

Figure 6. Water level in borehole UE-29 UZN #91 and periods of streamflow in Fortymile Canyon near Yucca Mountain, Nevada, 1982-95.

ers, 1993). Problems of downstream gages having more streamflow volume than upstream gages with no or minor tributary inflow, such as the July 21-23, 1984, streamflow at the Amargosa Valley gage, are now recognized and being corrected. Indirect measurements of peak streamflow have improved with time and probably have become more accurate, resulting in better defined stage-discharge relations.

Infiltration loss for four streamflows in Fortymile Wash can be made without concern about unmeasured tributary inflow from Yucca Wash, Drillhole Wash, Dune Wash, or several smaller unnamed tributaries. The February 12-15, 1992 streamflow at the Narrows had a volume of 8,070 cubic meters (m^3) and traveled 2.5 km downstream. The January 17-19, 1993, streamflow at the Narrows, with a volume of 24,700 m^3, combined with the Yucca Wash streamflow, with an estimated volume of 33,800 m^3, and traveled 7.6 km downstream. Tributary inflow from Yucca Wash during the streamflow was accounted for by estimating the inflow volume (37,900 m^3 estimate made later in section) and then subtracting 4,100 m^3 for infiltration losses in the 0.56 km reach between the crest-stage gage and the confluence with Fortymile Wash. During the January 25-27, 1995 period of streamflow in Fortymile Canyon, the January 25, 1995 streamflow at the Narrows had a volume of 1,470 m^3 and traveled 0.15 km downstream. The March 11-13, 1995 streamflow from the J-13 gage to the Amargosa Valley gage lost a volume of 123,000 m^3 in 16.8 km. Walters (1989) and Sharma and Murthy (1994) developed methods to calculate streamflow infiltration losses from streamflow volume. When these methods were applied to Fortymile Wash streamflow volumes, infiltration losses for the three smaller streamflows were under predicted and infiltration loss for the largest streamflow was over predicted (table 2), so they were not used. The computed streamflow infiltration losses are presented to document other published techniques were considered and did not adequately co

Table 2. Comparison of measured and estimated streamflow infiltration losses for Fortymile Wash near Yucca Mountain, Nevada.

[km, kilometer; m^3, cubic meters; L_k, Infiltration loss in m^3 for the first km; V_m, Inflow volume in m^3; L_a, Infiltration loss in acre-feet for the first mile; V_a, Inflow volume in acre-feet]

	Feb. 12-15, 1992	Jan. 17-19, 1993	Jan. 25-27, 1995	Mar. 11-13, 1995
Inflow volume (m^3)	8,070	58,500	1,470	563,000
Measured infiltration loss	8,070 m^3 in 2.5 km	58,500 m^3 in 7.6 km	1,470 m^3 in 0.15 km	123,000 m^3 in 16.8 km
Estimated infiltration loss using Sharma and Murthy (1994) Eq (8) L_k=1.983$(V_m)^{0.730}$	3,700 m^3 in 3 km	32,000 m^3 in 8 km	410 m^3 in 1 km	379,000 m^3 in 17 km
Estimated infiltration loss using Walters (1990) Eq (9) L_a=0.103$(V_a)^{0.872}$	1,260 m^3 in 3.2 km	7,660 m^3 in 8 km	148 m^3 in 1.6 km	237,000 m^3 in 16.1 km
Estimated infiltration loss using streamflow loss factor of 7,300 m^3 per km	18,200 m^3 in 2.5 km	55,500 m^3 in 7.6 km	1,100 m^3 in 0.15 km	122,600 m^3 in 16.8 km

pute Fortymile Wash streamflow infiltration losses. Other methods require more data that were not available, such as channel width and infiltration rate (Jordan, 1977; Lane, 1983) and also were not used.

A streamflow volume loss factor of 7,300 m^3/km of streamflow was developed from the four measured infiltration losses for Fortymile Wash (fig. 7). The 7,300 m^3/km streamflow volume loss factor was rounded off from a regression analysis of the four data points. The analysis forced the regression through the origin and had a slope of 7,310 m^3/km with a correlation coefficient of 0.99. The 7,300 m^3/km streamflow volume loss factor was applied to the upper three reaches of Fortymile Wash, Fortymile Canyon, and upper and lower Jackass Flats, even though the data were from only two of the reaches.

The accuracy of the streamflow volume loss factor, 7,300 m^3/km, could be improved as more streamflow data are acquired. Only four pairs of distance and streamflow infiltration loss volume data were used to estimate the relation. The data are hard to acquire because measured streamflow volumes between known distances, such as between streamflow gages, cannot have ungaged tributary inflow. An infiltration loss rate of 7,200 m^3 per hour per km in the Negev Desert, Israel (Ben-Zvi, 1996) partially supports the streamflow volume loss factor. Factors such as channel geometry, discharge, duration of streamflow, bed material size, sediment load, and temperature, which are unknown, must be evaluated for similarity to fully support a comparison between the streamflow volume loss factor and the infiltration loss rate. Sediment factors (Crerar and others, 1988) and temperature factors (Constantz and others, 1994) were determined to be important to streamflow infiltration losses in other ground-water recharge from streamflow studies. If data were collected to determine these effects in Fortymile Wash, then the streamflow volume loss factor could be improved. Streamflow infiltration loss is a nonlinear process, but the streamflow volume loss factor was assumed to be a linear process because of limited data available to develop the factor. The streamflow volume loss factor could probably be greatly improved if data were collected to consider some of the nonlinear contributing factors. Application of the streamflow volume loss factor to all four reaches of Fortymile Wash assumes the nonlinear factors do not change between reaches.

Estimates of streamflow volume losses for the four reaches during 1969-95 (table 3) were based on the size of recorded peak discharges, estimates of streamflow volume, the streamflow volume loss factor, and water-level rises in boreholes. These estimates were not made in chronological order, but in order of the most understood to the least understood streamflows.

During the February 12-15, 1992, streamflow, infiltration losses were estimated for Fortymile Canyon, upper Jackass Flats, and lower Jackass Flats reaches. Approximately 12,400 m^3 infiltrated into upper Jackass Flats, a combination of the 8,070 m^3 of streamflow that passed the Narrows gage and an estimated 4,300 m^3 of streamflow from Yucca Wash. The volume from Yucca Wash was estimated based on the magnitude of the peak discharge and the distance the

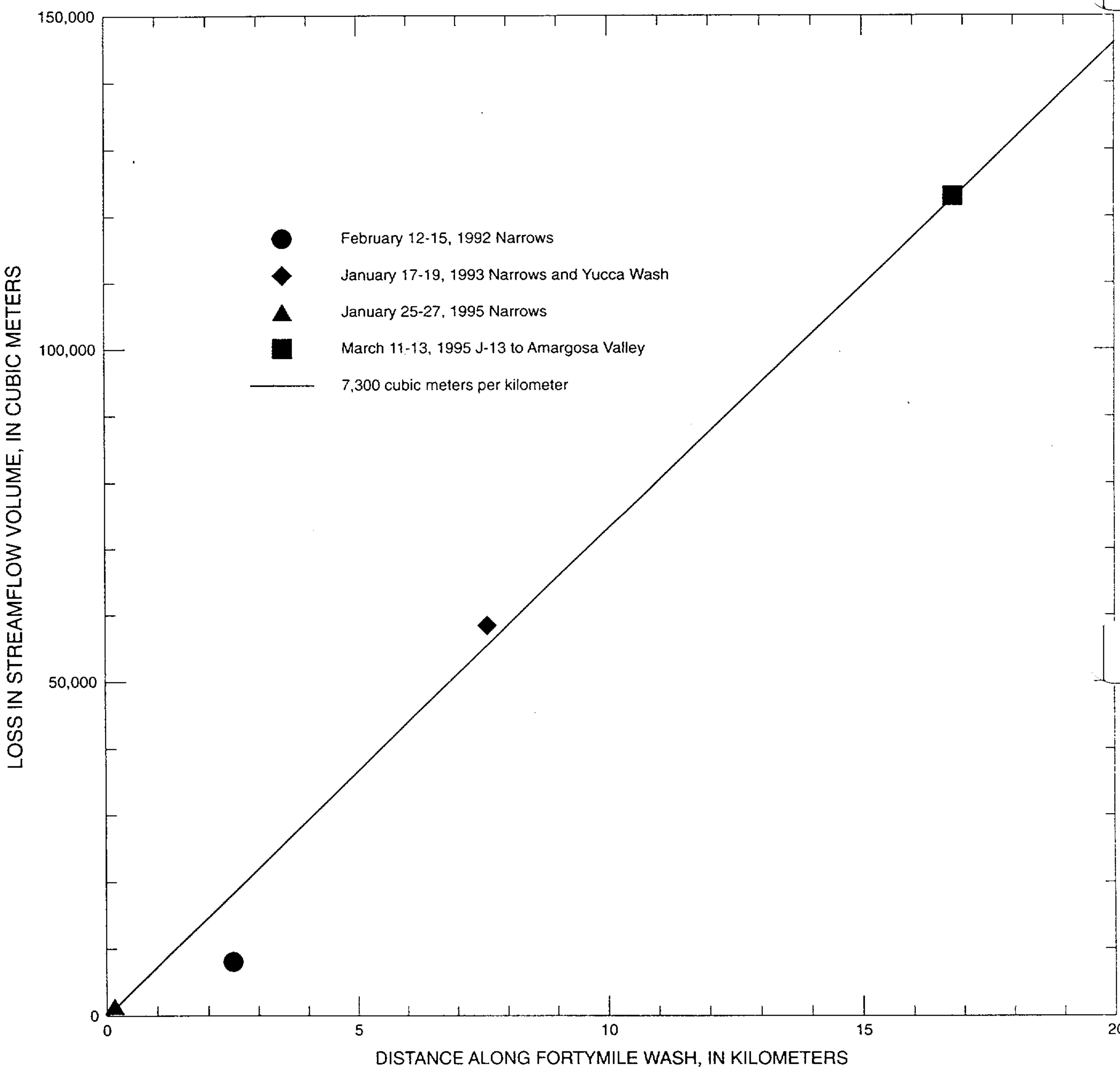

Figure 7. Streamflow volume loss factor for Fortymile Wash near Yucca Mountain, Nevada.

Table 3. Measured and estimated volumes of streamflow and infiltration losses for the four reaches of Fortymile Wash near Yucca Mountain, Nevada.

Date (mm/dd/yy)	Volume (cubic meters)								
	Estimated Fortymile Canyon infiltration loss	Measured Narrows gage	Estimated upper Jackass Flats tributary inflow	Estimated upper Jackass Flats infiltration loss	Measured J-13 gage	Estimated lower Jackass Flats tributary inflow	Estimated lower Jackass Flats infiltration loss	Measured Amargosa Valley gage	Estimated Amargosa Desert infiltration loss
01/25/69	51,800	-	-	73,700	-	-	123,000	-	280,000
02/24-26/69	51,800	-	-	73,700	-	-	123,000	-	440,000
03/03/83	51,800	-	-	73,700	-	-	123,000	-	128,000
07/21-23/84	51,800	162,000	108,000	73,700	196,000	0	123,000	273,000	273,000
08/14-16/84	51,800	10,500	-	10,500	3,600	-	3,600	1,200	1,200
08/18-20/84	51,800	140,000	51,700	73,700	118,000	133,000	123,000	128,000	128,000
07/19-20/85	4,800	980	8,130	8,280	830	22,140	22,730	240	240
02/23/87	0	0	0	0	0	0	1,000	100	100
05/07/87	0	0	100	100	0	0	0	0	0
11/06/87	0	0	0	0	0	0	500	50	50
09/23/90	0	0	0	0	0	0	1,000	100	100
08/12-13/91	100	0	0	0	0	0	0	0	0
09/07/91	0	0	0	0	0	1,000	1,000	0	0
02/12-15/92	42,300	8,070	4,300	12,400	0	400	400	0	0
03/30-31/92	14,100	0	100	100	0	400	400	0	0
01/17-19/93	51,800	24,700	37,900	62,600	0	0	0	0	0
02/09/93	17,300	0	0	0	0	0	0	0	0
02/23/93	10,400	0	0	0	0	0	0	0	0
01/25-27/95	51,800	1,500	38,000	39,500	0	0	0	0	0
03/11-13/95	51,800	597,000	40,700	73,700	564,000	0	123,000	441,000	440,000

streamflow traveled. The volume was estimated to be approximately 5,000 m^3. Assuming a linear relation between peak discharge and streamflow volume from the same storm, the Narrows volume of 8,070 m^3 was multiplied by the ratio of the peak discharges ([0.42 m^3/s]/[0.68 m^3/s]). The Yucca Wash streamflow went downstream approximately 0.5 km. Thus, from the streamflow volume loss factor the volume was at least 3,650 m^3. Because of the presence of a second peak discharge, 0.10 m^3/s, the streamflow volume was probably larger then 3,650 m^3. The Yucca Wash streamflow volume is probably in the range of 3,650 to 5,000 m^3, and was estimated to be 4,300 m^3. An estimated 42,300 m^3 of streamflow infiltrated above the Narrows gage in Fortymile Canyon from the streamflow in the Delirium and Pah Canyon areas. Using the 7,300 m^3/km streamflow volume loss factor, the 4 km reach from Delirium Canyon to the Narrows gage had an estimated 29,200 m^3 infiltration loss and the 1.8 km reach below Pah Canyon had an estimated 13,100 m^3 infiltration loss. An estimated 400 m^3 of streamflow infiltrated in lower Jackass Flats below the Dune Wash gage based on a comparison with the 0.42 m^3/s peak discharge of Yucca Wash. The Dune Wash peak discharge was 0.045 m^3/s, approximately one-tenth the size of the Yucca Wash peak discharge. Therefore, the volume was probably one-tenth the size.

During the March 30-31, 1992, streamflow, infiltration losses were estimated for Fortymile Canyon, upper Jackass Flats, and lower Jackass Flats reaches. An estimated 14,100 m^3 infiltrated in Fortymile Canyon. This estimate was based on smaller streamflows than the February 12-15, 1992, streamflows in the Pah and Delirium Canyon areas and the related rise in water levels at the boreholes in the Pah Canyon area. The water levels rose approximately one-third of the height of the rise after the February 12-15 streamflow. Assuming a linear relation between water-level rise and infiltration volume, the estimated volume was 14,100 m^3, one-third of 42,300 m^3. An estimated 100 m^3 infiltrated into upper Jackass Flats from Yucca Wash. The volume from Yucca Wash was much smaller than the February 12-15 streamflow based on peak discharge comparison. An estimated 400 m^3 of streamflow infiltrated in lower Jackass Flats below Dune Wash based on a peak discharge of the same size as the February 12-15, 1992, streamflow.

During the January 17-19, 1993, streamflow, infiltration losses were estimated for Fortymile Ca yon and upper Jackass Flats reaches. Approximate 62,600 m^3 infiltrated into upper Jackass Flats, a combination of the 24,700 m^3 of streamflow that passed the Narrows gage and an estimated 37,900 m^3 of streamflow from Yucca Wash. The volume from Yucca Wash was estimated based on the magnitude of the peak discharge, 2.3 m^3/s. Assuming a linear relation between peak discharge and streamflow volume from the same storm, the Narrows volume of 24,700 m^3 was multiplied by the ratio of the peak discharges ([2.3 m^3/s]/[1.5 m^3/s]). An estimated 51,800 m^3 of streamflow infiltrated above the Narrows gage in Fortymile Canyon based on the distance of 7.1 km from Pah Canyon to the Narrows using the streamflow volume loss factor. Also, water-level rises in the Fortymile Canyon boreholes exceeded the February 12-15, 1992 rises, indicating higher infiltration losses.

During the February 9, 1993, streamflow, infiltration losses were estimated for the Fortymile Canyon reach. No streamflow volumes or peak discharges were available from the ungaged portions of the Canyon that had streamflow, so the estimate was made by comparing changes in water levels in the boreholes Water levels rose approximately one-third of the ris after the January 17-19, 1993 streamflow. Assuming a linear relation between infiltration loss and water-level rise, a 17,300 m^3 infiltration loss was estimated, one-third of 51,800 m^3.

During the February 23, 1993, streamflow, infiltration losses were estimated for the Fortymile Canyon reach. No streamflow volumes or peak discharges were available from the ungaged portions of the Canyon that had streamflow, so the estimate was made by comparing changes in water levels in the boreholes. Water levels rose approximately one-fifth of the rise after the January 17-19, 1993 streamflow. Assuming a linear relation between infiltration loss and water-level rise, a 10,400 m^3 infiltration loss was estimated, one-fifth of 51,800 m^3.

During the January 25-27, 1995, streamflow, infiltration losses were estimated for Fortymile Canyon and upper Jackass Flats reaches. Approximately 39,500 m^3 infiltrated into upper Jackass Flats, a combination of approximately 1,500 m^3 of streamflow that passed the Narrows gage and an estimated 38,000 m^3 from Yucca Wash. The volume from Yucca Wash was estimated based on the magnitude of the peak d charge and the maximum distance the streamflow ould have traveled. The streamflow did not reach the -13 gage, 7 km downstream, so it would be less than 51,100 m^3 according to the streamflow volume loss factor. The peak discharge, 5.2 m^3/s, was larger than the January 17-19, 1993 peak of 1.5 m^3/s at the Narrows, so the volume probably exceeded the January 17-19, 1993 of 24,700 m^3 at the Narrows. An infiltration loss estimate of 38,000 m^3 was made for Yucca Wash by taking the average of 51,100 and 24,700 m^3 and rounding to 2 significant figures. An estimated 51,800 m^3 of streamflow infiltrated above the Narrows gage in Fortymile Canyon based on the distance, 7.1 km, the streamflow traveled and the streamflow volume loss factor.

During the March 11-13, 1995, streamflow, infiltration losses were estimated for Fortymile Canyon, upper Jackass Flats, lower Jackass Flats, and the Amargosa Desert reaches. The 10.1-km-long Upper Jackass Flats reach had an estimated infiltration loss of 73,700 m^3 based on the streamflow volume loss factor. The measured volume change between the Narrows and J-13 was only 33,000 m^3. Tributary inflow from Yucca Wash and other unnamed tributaries probably accounted for the additional 40,700 m^3 needed to alance inflow and outflow for the reach. Fortymile Canyon had an estimated infiltration loss of 51,800 m^3 based on the streamflow volume loss factor for the 7.1-km-long reach. Lower Jackass Flats had a measured infiltration loss of 123,000 m^3 between the J-13 and Amargosa Valley gages. There was no apparent tributary inflow to the lower Jackass Flats reach. Fortymile Wash streamflow reached the Amargosa River (Beck and Glancy, 1995) so all of the streamflow volume measured at the Amargosa Valley gage, 441,000 m^3, may not have infiltrated into the Amargosa Desert. Assuming the majority of streamflow infiltrated, an infiltration loss of 440,000 m^3 was estimated.

During the July 21-23, 1984, streamflow, infiltration losses were estimated for Fortymile Canyon, upper Jackass Flats, lower Jackass Flats, and the Amargosa Desert reaches. The streamflow volume loss factor for the 10.1 km reach between the Narrows and J-13 estimated a loss of 73,700 m^3 for Upper Jackass Flats. The volume of streamflow at the Narrows gage was approximately 162,000 m^3 and at the J-13 gage was approximately 196,000 m^3. The tributary inflow vould have to be approximately 108,000 m^3 for iflow to equal outflow (162,000+107,700 = 196,000+73,700) for the reach. Yucca Wash, with a peak discharge of 27 m^3/s, and Drillhole Wash, with a peak discharge of 22 m^3/s, could easily have contributed the necessary volume of streamflow needed for the tributary inflow. Fortymile Canyon had an estimated infiltration loss of 51,800 m^3 based on the streamflow volume loss factor for the 7.1-km-long reach above the Narrows gage. Lower Jackass Flats had an estimated infiltration loss of 123,000 m^3 based on the streamflow loss factor for the 16.8-km-long reach. No tributary inflow was measured at Dune Wash during this period. Inflow to the reach, 196,000 m^3 from the J-13 gage and 0 m^3 from tributaries, is much less than outflow, 123,000 m^3 from infiltration loss and 273,000 m^3 measured at the Amargosa Valley gage. The source of the excess water for this reach is not understood. The streamflow volume measured at the Amargosa Valley gage probably completely infiltrated into the Amargosa Desert reach downstream of the gage.

During the August 14-16, 1984, streamflow, infiltration losses were estimated for Fortymile Canyon, upper Jackass Flats, lower Jackass Flats, and the Amargosa Desert reaches. Upper Jackass Flats infiltration losses were estimated to be approximately 10,500 m^3, the entire amount which passed the Narrows gage. The 3,600 m^3 which passed the J-13 gage was assumed to be of local origin. The volume of the Narrows streamflow was between the February 12-14, 1992 (8,070 m^3) and the January 17-19, 1993 (24,700 m^3) volumes, which both completely infiltrated before reaching the J-13 gage. Fortymile Canyon probably had 51,800 m^3 of streamflow infiltration losses based on the streamflow volume loss factor and other similar streamflows in 1992-95. Lower Jackass Flats infiltration losses were estimated to be approximately 3,600 m^3, the entire amount going through the J-13 gage, which probably came from ungaged tributary inflow. The streamflow volume measured at the Amargosa Valley gage, which was approximately 1,200 m^3, probably completely infiltrated into the Amargosa Desert reach downstream of the gage.

During the August 18-20, 1984, streamflow, infiltration losses were estimated for Fortymile Canyon, upper Jackass Flats, lower Jackass Flats, and the Amargosa Desert reaches. Upper Jackass Flats infiltration losses were estimated to be approximately 73,700 m^3 based on the streamflow volume loss factor. The volume of streamflow was approximately 140,000 m^3 at the Narrows gage and 118,000 m^3 at the J-13 gage. Tributary inflow into upper Jackass Flats would have to be 51,700 m^3 for inflow to equal outflow (140,000+51,700 = 118,000+73,700) for the reach. Yucca Wash, with a peak discharge of 0.88 m^3/s, and Drillhole Wash, with a peak discharge of 1.2 m^3/s, and other ungaged tributaries could easily have contributed the necessary volume of streamflow needed for the tributary inflow. Fortymile Canyon had an estimated 51,800 m^3 of infiltration losses based on the streamflow volume loss factor. Lower Jackass Flats had an estimated 123,000 m^3 of infiltration losses based on the streamflow volume loss factor. The volume of streamflow at the Amargosa Valley gage was approximately 128,000 m^3. Tributary inflow into lower Jackass Flats would have to be approximately 133,000 m^3 for inflow to equal outflow (118,000+133,000 = 128,000+123,000) for the reach. Tributary inflow occurred at Dune Wash but not at such a high volume. It is unknown how to account for this excess water. The streamflow volume at the Amargosa Valley gage, 128,000 m^3, probably completely infiltrated into the Amargosa Desert reach downstream of the gage.

During the July 19-20, 1985, streamflow, infiltration losses were estimated for Fortymile Canyon, upper Jackass Flats, lower Jackass Flats, and the Amargosa Desert reaches. Approximately 980 m^3 of streamflow passed the Narrows gage. This probably completed infiltrated into upper Jackass Flats before reaching the J-13 gage. Approximately 830 m^3 of streamflow passed the J-13 gage. This streamflow probably originated in Drillhole Wash, which had a peak discharge of 0.48 m^3/s. Before the streamflow reached the J-13 gage, infiltration losses were estimated to be 7,300 m^3 based on the streamflow volume loss factor for the 1 km upstream of the J-13 gage. Tributary inflow was approximately 8,130 m^3 (8,130 = 7,300+830) for the upper Jackass Flats reach. The total infiltration loss for upper Jackass Flats was approximately 8,280 m^3 (980+8,130 = 8,280+830). A streamflow infiltration loss for Fortymile Canyon was estimated by comparing the streamflow volume to the August 14-16, 1984 streamflow and infiltration loss. In 1984 the streamflow volume was approximately 10,500 m^3 with 51,800 m^3 of streamflow infiltration losses. Assuming the ratio of measured streamflow volume was the same as the infiltration losses, the infiltration loss for the Fortymile Canyon reach was estimated to be 4,800 m^3 . Approximately 240 m^3 of streamflow passed the Amargosa Valley gage. This streamflow probably originated in Dune Wash, which had a peak discharge of 2.7 m^3/s. Before the streamflow reached the Amargosa Valley gage, infiltration losses were estimated to be 21,900 m^3 based on t streamflow volume loss factor for the 3 km upstream of the Amargosa Valley gage. Tributary inflow was approximately 22,140 m^3 (22,140 = 21,900+240) for the lower Jackass Flats reach. All of the 830 m^3 of streamflow passing the J-13 gage probably infiltrated before reaching the Amargosa Valley gage. The total infiltration loss for lower Jackass Flats was approximately 22,730 m^3 (830+22,140 = 22,730+240). The streamflow volume at the Amargosa Valley gage, 240 m^3, probably completely infiltrated into the Amargosa Desert.

During the February 23, 1987, November 6, 1987, and the September 23, 1990 streamflow , infiltration losses were estimated for the lower Jackass Flats and Amargosa Desert reaches. These were small localized streamflows occurring just around the Amargosa Valley gage. Approximately 100 m^3 passed the gage on February 23 and September 23 and 50 m^3 on November 6. Infiltration losses in the Amargosa Desert equaled the volume passing the gage. Infiltration losses in the lower Jackass Flats reach were estimated to be 10 times the amount passing the gage, 1,000 m^3 for February 23 and September 23 and 500 m^3 for November 6. The times 10 multiplier estimated from other streamflows.

During the May 7, 1987, streamflow, an infiltration loss was estimated for the upper Jackass Flats reach. Based on a small peak discharge estimated at the Yucca Wash gage, less than 0.003 m^3/s, the infiltration loss was estimated to be about 100 m^3.

During the August 12-13, 1991, streamflow, an infiltration loss was estimated for the Fortymile Canyon reach. The streamflow volume was probably 100 m^3 with all of the streamflow infiltrating.

During the September 7, 1991 streamflow, an infiltration loss was estimated for the lower Jackass Flats reach. The streamflow volume going through the Dune Wash gage, with a peak discharge of 0.12 m^3/s, was estimated to be 1,000 m^3 , with all of the volume infiltrating.

Streamflow infiltration losses for the upper three reaches during January 25, 1969, February 24-26, 1969, and March 3, 1983 were all estimated based on the streamflow volume loss factor and assuming streamflow occurred throughout the reach length. This assumption is based on the extent of similar streamflows during the summer streamflows in 1 nd the March streamflow in 1995. The infiltration losses were probably 51,800 m^3 for the 7.1 km Fortymile Canyon reach, 73,700 m^3 for the 10.1 km upper Jackass Flats, and 123,000 m^3 for the 16.8 km lower Jackass Flats reach.

Infiltration losses in the Amargosa Desert reach were probably different for the January 25, 1969, the February 24-26, 1969, and the March 3, 1983 streamflows. The February 24-26 streamflow had the largest peak discharge, 94 m^3/s, and probably was the largest in volume. The March 11-13, 1995 streamflow traveled through the Amargosa Desert and reached the Amargosa River channel. The February 24-26 streamflow probably did the same and had the same infiltration loss, the excess volume continued down the Amargosa River. The Amargosa Desert infiltration loss was estimated to be 440,000 m^3, the same as the March 11-13 loss. The January 25 streamflow had a peak discharge, 42 m^3/s, similar in magnitude to the July 21-23, 1984 peak discharge, 40 m^3/s. The infiltration loss was estimated to be 280,000 m^3, slightly larger than the July 21 streamflow infiltration loss. The March 3 peak discharge, 11 m^3/s, was the same magnitude as the August 18, 1984 peak discharge (Glancy, P.A., U.S. Geological Survey, written commun., 1995). The infiltration loss was estimated to be the same, 128,000 m^3, assuming the streamflow volumes were the same.

Ground-water recharge volume

Ground-water recharge volumes were estimated for the four reaches of Fortymile Wash, Fortymile Canyon, upper Jackass Flats, lower Jackass Flats, and the Amargosa Desert (table 4). A linear relation was assumed between the streamflow infiltration losses in a reach and the ground-water recharge volumes (fig. 8). The linear relation for the Fortymile Canyon reach was the model for the other three reaches, because no data were available for those reaches.

Ground-water recharge occurred in the Fortymile Canyon reach after the February 23, 1993 streamflow as evidenced by water-level rises in boreholes UE-29 a #1, UE-29 a #2, and UE-29 UZN #91. This was the smallest estimated streamflow volume loss, 10,400 m^3, to cause measurable ground-water recharge. Thus, infiltration losses slightly smaller than this are assumed to be of sufficient volume to wet the unsaturated zone enough to have ground-water recharge. Infiltration loss started to become ground-water recharge at the assumed volume of 9,000 m^3. Ground-water recharge volumes then were assumed to increase linearly in proportion to infiltration losses. The maximum ground-water recharge volume was 42,800 m^3, when the infiltration loss was 51,800 m^3.

A linear relation between streamflow infiltration volume and ground-water recharge volume was also assumed for the other three reaches. The estimated amount of infiltration volume when ground-water recharge volume started was different based on the different depths to ground water for each reach. The Amargosa Desert reach probably has a larger infiltration loss volume when ground-water recharge starts than the Fortymile Canyon reach. Depths to water in the Amargosa Desert reach, 30 to 100 m, are larger than depths to water in the Fortymile Canyon reach, 15 to 100 m. Also the depth to water for the Amargosa Desert reach is at a maximum in the upstream portion where the most water is available for infiltration and subsequent ground-water recharge; the depth to water in the Fortymile Canyon reach is at a minimum in the upstream portion where the most water is available for infiltration and subsequent ground-water recharge. These differences in depths to water would increase the starting volume of infiltration loss before ground-water recharge because of the larger volume of water needed to wet the unsaturated zone. The Fortymile Wash channel system also becomes a distributary system in the Amargosa Desert and is probably another factor for increasing the infiltration volume needed in the Amargosa Desert reach to start ground-water recharge when compared to the Fortymile Canyon reach. The distributary system widens the channel and infiltration losses are spread out over a larger area. Ground-water recharge is decreased because more water is needed to wet the unsaturated zone before recharge occurs. Another factor probably increasing the infiltration volume needed in the Amargosa Desert reach to start ground-water recharge is the finer bed material found in the downstream portions of the Fortymile Wash channel system (Osterkamp and others, 1994). The finer material would probably impede infiltration in the reach making less water available to wet the unsaturated zone and for ground-water recharge. The Amargosa Desert reach, at least 20 km in length, would still allow the available streamflow to infiltrate, but not at the same rate as the Fortymile Canyon reach. The streamflow infiltration loss volume when ground-water recharge started was estimated to be 40,000 m^3 for the Amargosa Desert reach

Table 4. Estimated ground-water recharge volumes for the four reaches of Fortymile Wash near Yucca Mountain, Nevada.

[a, winter/spring streamflow; b, summer/fall streamflow]

Date (mm/dd/yy)	Estimated ground-water recharge volume (cubic meters)			
	Fortymile Canyon	Upper Jackass Flats	Lower Jackass Flats	Amargosa Desert
01/25/69[a]	42,800	3,700	53,000	240,000
02/24-26/69[a]	42,800	3,700	53,000	400,000
03/03/83[a]	42,800	3,700	53,000	88,000
07/21-23/84[b]	42,800	3,700	53,000	233,000
08/14-16/84[b]	42,800	0	0	0
08/18-20/84[b]	42,800	3,700	53,000	88,000
07/19-20/85[b]	0	0	0	0
02/23/87[a]	0	0	0	0
05/07/87[b]	0	0	0	0
11/06/87[a]	0	0	0	0
09/23/90[b]	0	0	0	0
08/12-13/91[b]	0	0	0	0
09/07/91[b]	0	0	0	0
02/12/92[a]	33,300	0	0	0
03/30-31/92[a]	5,100	0	0	0
01/17-19/93[a]	42,800	0	0	0
02/09/93[a]	8,300	0	0	0
02/23/93[a]	1,400	0	0	0
01/25-27/95[a]	42,800	0	0	0
03/11-13/95[a]	42,800	3,700	53,000	400,000
[b]Summer/Fall 1992-95 Total	0	0	0	0
[a]Winter/Spring 1992-95 Total	176,500	3,700	53,000	400,000
1992-95 Total	176,500	3,700	53,000	400,000
[b]Summer/Fall 1983-95 Total	128,400	7,400	106,000	321,000
[a]Winter/Spring 1983-95 Total	219,300	7,400	106,000	488,000
1983-95 Total	347,700	14,800	212,000	809,000
[b]Summer/Fall 1969-95 Total	128,400	7,400	106,000	321,000
[a]Winter/Spring 1969-95 Total	304,900	14,800	212,000	1,128,000
1969-95 Total	433,300	22,200	318,000	1,449,000

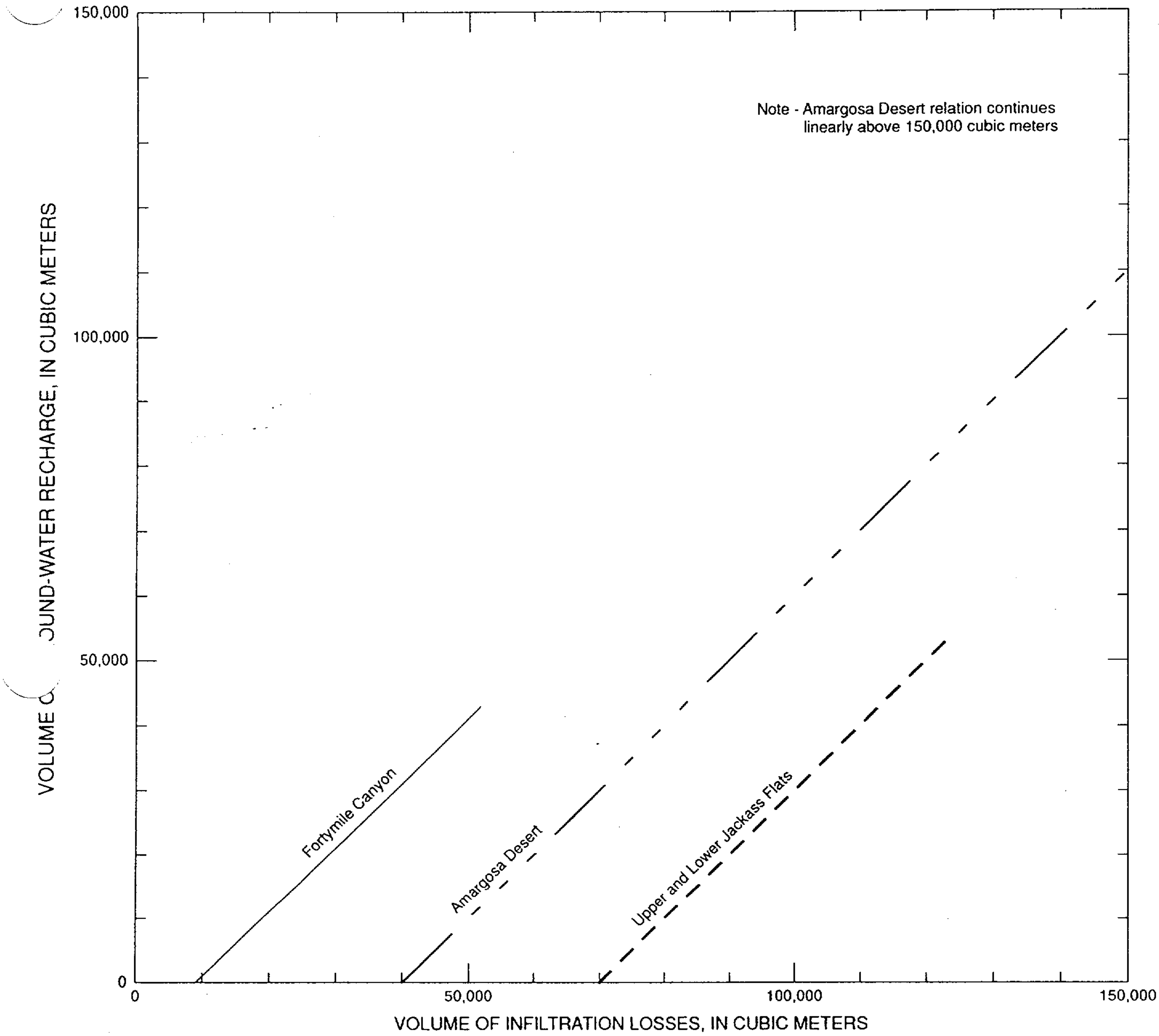

Figure 8. Estimated relations between streamflow infiltration losses and ground-water recharge volumes for the four reaches of Fortymile Wash near Yucca Mountain, Nevada.

based on the greater depth to water, the distributary channel system, and the finer bed material than the Fortymile Canyon reach.

The depths to water in the upper Jackass Flats reach are 100 to 350 m with the upstream portion of the reach being the closest to the water table. Depths to water in this upstream reach probably average around 150 m. The depths to water in the lower Jackass Flats reach are 100 to 300 m with the downstream portion of the reach being closest to the water table. Depths to water in this downstream reach probably average around 150 m. In the upstream portion of the Amargosa Desert reach depths to water probably average 75 m. Because the depths to water in the upper Jackass Flats and the lower Jackass Flats reaches are approximately twice as deep as the Amargosa Desert reach, the streamflow infiltration volumes when ground-water recharge started in the upper and lower Jackass Flats reaches were first estimated to be 80,000 m^3, twice as much as the 40,000 m^3 for the Amargosa Desert reach. The estimates were lowered to 70,000 m^3 because the bed material was not as fine and the streamflow was not spread out in a distributary system, probably making the infiltration and recharge more efficient.

Ground-water recharge volume estimates ranged from 1,400 to 42,800 m^3 for the Fortymile Canyon reach. Recharge occurred after small and large streamflows. Small streamflows that did not reach gages because of infiltration did have sufficient water volume for the infiltration to reach the shallow water table and become ground-water recharge. Large streamflows reached an estimated maximum ground-water recharge volume of 42,800 m^3.

Very little ground-water recharge was estimated for the upper Jackass Flats reach because of the large depth to water. Probably only the large streamflow infiltration volumes in 1969, 1983, 1984, and 1995 were sufficient to reach the deep water table. The recharge was estimated to be 3,700 m^3 after each streamflow. Marie (1985) found water had moved through a 100-m-thick unsaturated zone after infiltration. Thus, there is some support for ground-water recharge to a deep water table from streamflow in an arid environment with a thick alluvial unsaturated zone. No water-level rises in well J-13 along Fortymile Wash in the upper Jackass Flats area have been recognized as recharge after streamflow. This may be a combination of two factors: (1) the well is pumped for water supply and the drawdown and subsequent recovery of water levels may mask water-level rises from streamflow and (2) the well may not be measu frequently enough to record a water-level rise and decline.

More ground-water recharge volume was estimated for the 16.8-km-long lower Jackass Flats reach than the 10.1-km-long upper Jackass Flats reach because more water was available for ground-water recharge in the longer reach. Similar to the upper Jackass Flats reach, probably only the large streamflow infiltration volumes in 1969, 1983, 1984, and 1995 were sufficient to reach the deep water table. The recharge volume was estimated to be 53,000 m^3 after each streamflow. No water level rises in J-12 or JF-3 along Fortymile Wash have been recognized as recharge after streamflow. Again the same two factors as mentioned for J-13 in the upper Jackass Flats reach may be responsible for no measured water-level rises in J-12 or JF-3.

Ground-water recharge volume estimates ranged from 88,000 to 400,000 m^3 for the Amargosa Desert reach. These were the largest estimated ground-water recharge volumes after a streamflow in the four reaches because of two factors. The first factor was the availability of water for infiltration and subsequent recharge. The second factor was the rel tively shallow depth to water compared to the Jackass Flats reaches. Similar to the Jackass Flats reaches, probably only the large streamflow infiltration volumes in 1969, 1983, 1984, and 1995 were sufficient to reach the water table. No water-level rises in wells and boreholes in the Amargosa Desert have been recognized as recharge after streamflow. But the wells and boreholes may not be located close enough to the channels of the Fortymile Wash distributary system to see the water-level rises or they may not have been measured on a frequent enough basis to record water-level rises and declines. Claassen's (1985) geochemical analysis concluded groundwater in the Amargosa Desert area was recharged from streamflow in or near present-day channels. This supports the ground-water recharge estimate for the Amargosa Desert reach of Fortymile Wash. He also concluded from hydrogen- and oxygen-isotope data the streamflow causing the ground-water recharge was derived from snowmelt. This supports the ground-water recharge estimate in the Amargosa Desert reach of Fortymile Wash because the majority of estimated recharge occurred during the winter/spring period.

The assumed relation between streamflow infiltration loss and ground-water recharge volume could be improved. Rises in ground-water levels in Fortymile Canyon boreholes after streamflow were more detailed in 1993 and 1995, than in 1992 or during 1983-84. After different size future streamflows, a better relation between the streamflow infiltration loss and ground-water recharge could be defined with the more detailed water-level rises. If additional boreholes are drilled, then ground-water mounds under stream channels can be better defined. If the hydraulic properties of the unsaturated and saturated zone in the area of these mounds are better understood then the volume of ground-water recharge could be quantified with some precision and accuracy. An assumption of the streamflow infiltration loss and ground-water recharge volume relation is that recharge starts at some exact streamflow infiltration volume. Depth to water in each of the four reaches is variable. Therefore, errors could be made in the ground-water recharge volumes depending on where in the reach the recharge occurs. The estimated relation between streamflow infiltration volume loss and ground-water recharge volume also assumes the process is linear. This is probably not true for three-dimensional water flow in the unsaturated zone because of a variable water source in a dynamic channel of width and depth, variable geologic and hydrologic properties, and variable antecedent moisture conditions. However, a simple linear process was assumed, because no data were available to determine a more complex process.

ESTIMATE OF LONG-TERM GROUND-WATER RECHARGE RATE

Total ground-water recharge volume estimates over three selected time periods, 1992-95, 1983-95, and 1969-95 (table 4), were used to estimate the long-term ground-water recharge rates for the four reaches (table 5). The ground-water recharge volumes from winter/spring and summer/fall streamflows were considered separately because the streamflows were generated by different types of storms. Winter/spring streamflows occurred during frontal type storms associated with El Niño conditions. Summer/fall streamflows occurred during convective storms. The estimated ground-water recharge volumes during these periods were divided by the length of the period to estimate a ground-water recharge rate. An example winter/spring ground-water recharge rate for the Fortymile Canyon reach during 1992-95 would be the total ground-water recharge volume, 176,500 m^3, divided by the length of the time period, 4 years, which approximately equals 44,100 m^3/year. A seasonal long-term ground-water recharge rate was then estimated for each reach based on the rates of the different periods. A combined long-term ground-water recharge rate for each reach was then estimated by adding the winter/spring and summer/fall rates.

The streamflows and ground-water recharge volumes during 1992-95 were documented more fully than the other two time periods, but were not representative of long-term conditions. The winter/spring ground-water recharge rate for all the reaches is considered high. The winter/spring streamflows in For-

Table 5. Estimated ground-water recharge rates for the four reaches of Fortymile Wash near Yucca Mountain, Nevada.

Period	Length of period (years)	Estimated ground-water recharge rate (cubic meters/year)							
		Fortymile Canyon		Upper Jackass Flats		Lower Jackass Flats		Amargosa Desert	
		Winter/ Spring	Summer/ Fall	Winter/ Spring	Summer/ Fall	Winter/ Spring	Summer/ Fall	Winter/ Spring	Summer/ Fall
1992-95	4	44,100	0	920	0	13,200	0	100,000	0
1983-95	13	16,900	9,900	570	570	8,200	8,200	37,500	24,700
1969-95	27	11,300	4,800	550	270	7,800	3,900	41,800	11,900
Estimated long-term rate	-	17,000	10,000	570	570	8,200	8,200	39,600	24,700
Combined estimated long-term rate	-	27,000		1,100		16,400		64,300	

tymile Canyon associated with the El Niño conditions in 1992, 1993, and 1995 were probably much more frequent than those of long-term conditions. The summer/fall recharge rate of 0 m^3/year for all the reaches is low. No summer/fall streamflows occurred during this period, but summer/fall recharge probably does occur.

The 1983-95 period is the longest period for which streamflow conditions in Jackass Flats and the distributary system into the Amargosa Desert are documented fully. The gaging stations were installed after the March 1983 streamflow and monitored through 1995. Both winter/spring and summer/fall ground-water recharge rates for the upper Jackass Flats, lower Jackass Flats, and Amargosa Desert reaches estimated for this period are assumed to be close to the long-term seasonal recharge rates. The period was long enough to contain several winter/spring streamflows and subsequent recharge during El Niño conditions and several summer/fall streamflows generated by convective storms. Ground-water recharge rates for the Fortymile Canyon reach may be low because small streamflows in the tributaries to Fortymile Wash that did not reach the Narrows gage and subsequent recharge were not documented during 1983-92.

The 1969-95 period was included so the estimated ground-water recharge volume from the two large streamflows in 1969 could be considered in the long-term ground-water recharge rate. No other streamflows were documented in Fortymile Wash between the 1969 and 1983 streamflows. The total summer/fall recharge volume for all reaches during 1969-95 was the same as 1983-95. Because of the longer time period, the summer/fall ground-water recharge rates were smaller for 1969-95 than 1983-95. Because the 1969 streamflows were during the winter/spring season, total winter/spring recharge volumes for all reaches were larger for 1969-95 than for 1983-95. Winter/spring recharge rates were smaller for the Fortymile Canyon, upper Jackass Flats, and lower Jackass Flats reaches for 1969-95 than for 1983-95. The winter/spring recharge rate for the Amargosa Desert reach was larger for 1969-95 than 1983-95. Because of probable undocumented streamflows, the recharge rates for the Fortymile Canyon, upper Jackass Flats, and lower Jackass Flats reaches for both seasons are assumed to be lower than the long-term recharge rates. The summer/fall recharge rate estimated for the Amargosa Desert reach during 1969-95 period was also assumed to be lower than the long-term rate. The winter/spring recharge rate e mated for the Amargosa Desert reach during 196 may be higher than the long-term rate.

The combined long-term ground-water recharge rate for the Fortymile Canyon reach of Fortymile Wash was estimated to be 27,000 m^3 per year, a combination of the winter/spring recharge rate of 17,000 m^3 per year and the summer/spring recharge rate of 10,000 m^3 per year. The winter/spring recharge rate of 17,000 m^3 per year was estimated to be slightly higher than the 1983-95 rate of 16,900 m^3 per year. The small increase was to account for the probable undocumented streamflows in the tributaries to Fortymile Wash in Fortymile Canyon during the early part, 1983-91, of the 1983-95 period. The summer/fall recharge rate of 10,000 m^3 per year was also slightly higher than the 1983-95 estimate of 9,900 m^3 per year to account for undocumented streamflow.

The combined long-term ground-water recharge rate for the upper Jackass Flats reach of Fortymile Wash was estimated to be about 1,100 m^3 per year, a combination of the winter/spring recharge rate of 570 m^3 per year and the summer/fall recharge rate of 570 m^3 per year and then rounded to the nearest h dred value. The long-term winter/spring recharge of 57 m^3 per year was estimated to be equal to the 1983-95 rate. The long-term summer/fall recharge rate of 570 m^3 per year was also estimated to be equal to the 1983-95 rate.

The combined long-term ground-water recharge rate for the lower Jackass Flats reach of Fortymile Wash was estimated to be 16,400 m^3 per year, a combination of the winter/spring recharge rate of 8,200 m^3 per year and the summer/fall recharge rate of 8,200 m^3 per year. The long-term winter/spring and summer/fall rates of 8,200 and 8,200 m^3 per year were estimated to be equal to the 1983-95 rates.

The combined long-term ground-water recharge rate for the Amargosa Desert reach of Fortymile Wash was estimated to 64,300 m^3 per year, a combination of the winter/spring recharge rate of 39,600 m^3 per year and the summer/fall recharge rate of 24,700 m^3 per year. The winter/spring recharge rate of 39,600 m^3 per year was estimated to be the average of the 1969-95 and the 1983-95 rates. The summer/fall rate of 24,700 m^3 per year was estimated to be equal to the 1983-95 rate.

The estimates of seasonal long-term grounc water recharge rates probably could be improved ntinuing to collect streamflow data throughout the ur reaches, especially in the Fortymile Canyon and the Amargosa Desert areas. For this report, the upstream streamflow estimates were made because of documented streamflow downstream. This assumption of streamflow occurring upstream probably is true. However, what tributaries contribute to the downstream flow is not known and the assumption for certain reaches to be having infiltration losses at estimated rates may be in error.

The estimates of long-term ground-water recharge rates could be improved with longer periods of record. Surrogate records such as precipitation, the SOI, tree rings, and lake sediments may be able to extend knowledge of ground-water recharge volumes by correlation. Cayan and Webb (1992) found snow water content and streamflow in the southwest U.S. were increased after negative swings in the SOI. Redmond and Koch (1991) found a correlation between precipitation and negative SOI in the southwest U.S. They also found a negative correlation between annual streamflow and the SOI for the preceding June-November period in the southwest U.S. Kahya and Dracup (1993) found evidence of a relation between reamflow in the southwest U.S. and the SOI. When winter/spring streamflow does occur in Fortymile Wash, the SOI has recently had a negative peak. But no direct correlation was found between the SOI and Fortymile Wash streamflow to extend the estimate of ground-water recharge. Using the SOI to extend record length may not be warranted because Enfield (1989) and Burroughs (1992) suggested the ENSO system may be a dynamic system exhibiting chaotic behavior. Dynamic chaotic systems are unpredictable and a long-term recharge rate from such as a system may prove meaningless. Wilcox and others (1991) and Savard (1990, 1991a, 1991b, and 1992) analyzed western U.S. streamflow for chaotic behavior but did not find any evidence of a simple dynamic system exhibiting chaotic behavior.

Czarnecki and Waddell (1984) used a computer simulation of the ground-water system with a recharge rate of approximately 8,083,000 m^3 per year (0.2563 m^3/s) areally distributed over a section of Fortymile Wash, extending approximately 5 km upstream of the Pah Canyon area to midway between the J-13 and Amargosa Valley gages. A direct comparison of Czarnecki and Waddell's recharge rates to the rates stimated in this report is not entirely appropriate because different sections of Fortymile Wash are specified in each study. The total ground-water recharge rate for this study, 108,800 m^3 per year, is a summation of recharge rates for the four reaches (108,800 = 27,000+1,100+16,400+64,300). The total ground-water recharge rate for Fortymile Wash in this report is much smaller than the recharge rate estimated in the computer simulation. This report does not address ground-water recharge upstream (north) of the Fortymile Wash-Pah Canyon area, or ground-water recharge in the tributaries to Fortymile Wash before they join Fortymile Wash. These two ground-water recharge volumes would increase the recharge rate from this report, but probably not enough to make up the difference between the two estimates.

Osterkamp and others' (1994) recharge estimate based on geomorphic evidence extended from Fortymile Canyon, 2.1 km above the Narrows gage, to the Amargosa Desert, 17.1 km downstream of the U.S. Highway 95 crossing. They separated Fortymile Wash into reaches based on tributary confluences or distances less than a few kilometers, which were smaller than the four reaches in this study. They also made recharge estimates in Yucca and Drillhole Washes. All of their streamflow infiltration loss volume was assumed to be ground-water recharge. From their starting point in Fortymile Canyon to the Narrows, a distance of 2.1 km, they estimated a streamflow infiltration loss rate of 50,000 m^3 per year. This report estimates an annual streamflow infiltration loss rate of 36,000 m^3 per year, a combination of the long-term ground-water recharge rate of 27,000 m^3 per year for the 7.1 km Fortymile Canyon reach and 9,000 m^3 per year from infiltration losses in the unsaturated zone above the water table (fig. 8). For the upper Jackass Flats reach Osterkamp and others (1994) estimated a streamflow infiltration loss rate of 510,000 m^3 per year, where as this report estimates a streamflow infiltration loss rate of 71,100 m^3 per year, a combination of the long-term recharge rate of 1,100 m^3 per year and an estimated 70,000 m^3 per year in the unsaturated zone. For the lower Jackass Flats reach Osterkamp and others (1994) estimated a streamflow infiltration loss rate of 10,000 m^3 per year. This report estimates a streamflow infiltration loss rate of 86,400 m^3 per year, a combination of the 16,400 m^3 per year long-term recharge rate and the 70,000 m^3 per year remaining in the unsaturated zone. For the Amargosa Desert reach Osterkamp and others (1994) estimated a streamflow infiltration loss rate of 20,000 m^3 per year. This report estimates a streamflow infiltration rate of 104,300 m^3 per year, a combination of the 64,300 m^3 per year long-term recharge rate and the 40,000 m^3 per year remaining in the unsaturated zone. Osterkamp and others' (1994) recharge rates were higher in Fortymile Canyon and the upper Jackass Flats reach than this report and lower in the lower Jackass Flats and Amargosa Desert reaches.

SUMMARY

For four reaches of Fortymile Wash near Yucca Mountain, Nevada, (Fortymile Canyon, upper Jackass Flats, lower Jackass Flats, and Amargosa Desert) streamflow data from continuous streamflow gaging stations, crest-stage gages, and miscellaneous sites during 1969-95 and depth-to-water data in boreholes from 1983-95 were used to estimate volumes of streamflow, streamflow infiltration loss, and ground-water recharge. A long-term ground-water recharge rate was estimated based on the winter/spring and summer/fall ground-water recharge rate for the four reaches.

Streamflow occurred throughout the Fortymile Wash channel system from the Pah Canyon area in Fortymile Canyon to the Amargosa Desert in March 1995. Based on data from the gaging stations and miscellaneous sites, streamflow probably occurred throughout the Fortymile channel system in January and February 1969, March 1983, and July and August 1984. In July 1985, streamflow occurred throughout much of the Fortymile Wash channel system, but the entire channel system probably did not have streamflow. In August 1991, February and March 1992, January and February 1993, and January 1995 streamflow occurred in Fortymile Canyon of Fortymile Wash. In February, May, and November 1987, September 1990 and 1991, February and March 1992, and January 1993 and 1995, streamflow occurred in small sections of the Fortymile Wash channel system in Jackass Flats and Amargosa Desert. Winter/spring streamflow in Fortymile Wash occurred after the Southern Oscillation Index was negative.

Ground-water levels in Fortymile Canyon boreholes (UE-29 a #1, UE-29 a #2, and UE-29 UZN #91) rose after the streamflow in 1983, 1992, 1993, and 1995. Streamflow infiltrated into the channel sediments. Ground-water mounds developed under the stream channels, but the areal extent or volumetric water content were not estimated because of unknown geology and the limited amount of areal water-level observations.

Direct computation of streamflow infiltration loss between gaging stations on Fortymile Wash was only accomplished in March 1995 for the lower Jackass Flats reach, J-13 to Amargosa Valley. Ungaged tributary inflow between the gages prevented computation of losses attributed only to streamflow infiltration for the rest of the recorded streamflows in Fortymile Wash. Small localized streamflows during 1984-91 at the gages give the impression that flow was continuous from one gage to another, but reconnaissance of similar small streamflows during 1992-95 confirmed total infiltration occurred before the next downstream gage was reached. The direct streamflow infiltration loss between the J-13 and Amargosa Valley gages and three streamflows that passed the Narrows gage but infiltrated before reaching the J-13 gage were used to estimate a streamflow volume loss factor, 7,300 m^3/km, for all of Fortymile Wash. Streamflow infiltration loss volumes for each of the four Fortymile Wash reaches were estimated for the estimated volumes of streamflow for all the known streamflows during 1969-95.

Ground-water recharge volume was estimat for each reach based on the estimated streamflow i tration losses. A linear relation between streamflow infiltration losses and ground-water recharge was assumed for the Fortymile Canyon reach where there was the most supporting data. The other three reaches were assumed to be similar with the starting point of ground-water recharge changing, depending on the depth to water for a reach. Ground-water recharge volumes during 1969-95, 1983-95, and 1992-95 were estimated for each reach. The Amargosa Desert reach had the largest volume of ground-water recharge followed by the Fortymile Canyon reach, then the lower Jackass Flats reach, and the upper Jackass Flats reach had the smallest volume.

Ground-water recharge rates were estimated for each reach based on the ground-water recharge volume and the period of time represented. Separate rates were estimated for winter/spring and summer/fall periods. A combined long-term estimate was made for each reach based on the different time periods. The Amargosa Desert reach had the highest ground-water recharge rate, 64,300 m^3 per year. The Fortymile Canyon reach had a lower rate, 27,000 m^3 per year, even though it had more frequent streamflow. The Am gosa Desert reach was longer. The lower Jackass F ach had the third highest ground-water recharge rate, ,400 m^3 per year. The upper Jackass Flats reach had the lowest ground-water recharge rate, 1,100 m^3 per year. The largest depth to water, 100 to 350 m, of all the reaches was probably the biggest reason for very little recharge in the upper Jackass Flats reach.

REFERENCES CITED

Ambos, D.S., Flint, A.L., and Hevesi, J.A., 1995, Precipitation data for water years 1992 and 1993 from a network of nonrecording gages at Yucca Mountain, Nevada: U.S. Geological Survey Open-File Report 95-146, 100 p.

Bauer, D.J., Foster, B.J., Joyner, J.D., Swanson, R.A., 1996, Water Resources Data, Nevada, Water Year 1995: U.S. Geological Survey Water-Data Report NV-95-1, 734 p.

Beck, D.A. and Glancy, P.A., 1995, Overview of runoff of March 11, 1995, in Fortymile Wash and Amargosa River, southern Nevada: U.S. Geological Survey Fact Sheet FS-210-95, 4 p.

Ben-Zvi, A., 1996, Quantitative prediction of runoff events *in* Issar, A.S. and Resnick, S.D., eds., Runoff, infiltration and subsurface flow of water in arid and semi-arid regions: Water Science and Technology Library, v. 21, Kluwer Academic Publishers, Norwell, Massachusetts, p. 121-130.

Benson, L. and Klieforth, H., 1989, Stable isotopes in precipitation and ground water in the Yucca Mountain region, southern Nevada: Paleoclimate implications *in* Peterson, D.H., ed., Aspects of Climate Variability in the Pacific and the Western Americas: Geophysical Monograph 55, American Geophysical Union, Washington, D.C., p. 41-59.

Blout, D.O., Hammermeister, D.P., Loskot, C.L., and Chornack, M.P., 1994, Geohydrologic data collected from shallow neutron-access boreholes and resultant-preliminary geohydrologic evaluations, Yucca Mountain Area, Nye County, Nevada: U.S. Geological Survey Open-File-Report 92-657, 147 p.

Boucher, M.S., 1994, Water levels in wells J-11 and J-12, 1989-91, Yucca Mountain area, Nevada: U.S. Geological Survey Open-File Report 94-303, 9 p.

Burroughs, W.J., 1992, Weather cycles: real or imaginary?: Cambridge University Press, New York, NY, 201 p.

Cayan, D.R. and Peterson, D.H., 1989, The influence of north Pacific atmospheric circulation on streamflow in the west *in* Peterson, D.H., ed., Aspects of Climate Variability in the Pacific and the Western Americas: Geophysical Monograph 55, American Geophysical Union, Washington, D.C., p. 375-398.

Cayan, D.R. and Webb, R.H., 1992, El Niño/southern oscillation and streamflow in the western United States, *in* Diaz, H.J. and Markgraf, V., eds., El Niño: Historical and Paleoclimatic Aspects of the Southern Oscillation: Cambridge University Press, New York, p. 29-68.

Claassen, H.C., 1985, Sources and mechanisms of recharge for ground water in the West-Central Amargosa Desert, Nevada - a geochemical interpretation: U.S. Geological Survey Professional Paper 712-F, 31 p.

Clary, S.L., McClary, D.R., Whitney, Rita, and Reeves, D.D., 1995, Water Resources Data, Nevada, Water Year 1994: U.S. Geological Survey Water-Data Report NV-94-1, 768 p.

Constantz, Jim, Thomas, C.A., and Zellweger, Gary, 1994, Influence of diurnal variations in stream temperature on streamflow loss and groundwater recharge: Water Resources Research, v. 30, no. 12, p. 3,253-3,264.

Crerar, S., Fry, R.G., Slater, P.M., van Langenhove, G., and Wheeler D., 1988, An unexpected factor affecting recharge from ephemeral river flows in SWA/Namibia *in* Simmers, I., ed., Estimation of Natural Groundwater Recharge: NATO ASI Series, Series C, Mathematical and Physical Sciences Vol. 222, D. Reidel Publishing Company, Boston, p. 11-28.

Czarnecki, J.B. and Waddell, R.K., 1984, Finite-element simulation of ground-water flow in the vicinity of Yucca Mountain, Nevada-California: U.S. Geological Survey Water-Resources Investigations Report 84-4349, 38 p.

Dracup, J.A. and Kahya, Ercan, 1994, The relationship between U.S. streamflow and La Niña events: Water Resources Research, v. 30, no. 7, p. 2,133-2,141.

Enfield, D.B., 1989, El Niño, past and present: Review of geophysics, v. 27, no. 1, p. 159-187.

Emett, D.C., Hutchinson, D.D., Jonson, N.A., and O'Hair, K.L., 1994, Water Resources Data, Nevada, Water Year 1993: U.S. Geological Survey Water-Data Report NV-93-1, 596 p.

Flint, L.E. and Flint, A.L., 1995, Shallow infiltration processes at Yucca Mountain, Nevada - neutron logging data 1984-93: U.S. Geological Survey Water-Resources Investigations Report 95-4035, 46 p.

Gemmel, J.M., 1990, Water levels in periodically measured wells in the Yucca Mountain area, Nevada, 1988: U.S. Geological Survey Open-File Report 90-113, 47 p.

Grasso, D.N., 1996, Hydrology of modern and late Holocene lakes, Death Valley, California: U.S. Geological Survey Water-Resources Investigations Report 95-4237, 54 p.

Hale, G.S. and Westenburg, C.L., 1995, Selected ground-water data for Yucca Mountain region, southern Nevada and eastern California, calendar year 1993: U.S. Geological Survey Open-File Report 95-158, 67 p.

U.S. Geological Survey Open-File Report 95-158, 67 p.

Huber, N.K., 1988, Late Cenozoic evolution of the upper Amargosa River drainage system, southwestern Great Basin, Nevada and California: U.S. Geological Survey Open-File Report 87-617, 26 p.

Jordan, P.R., 1977, Streamflow transmission losses in western Kansas: Journal of the Hydraulics Division, American Society of Civil Engineers, v. 103, no. HY8, p. 905-919.

Kahya, Ercan and Dracup, J.A., 1993, U.S. streamflow patterns in relation to the El Niño/southern oscillation: Water Resources Research, v. 29, no. 8, p. 2,491-2,503.

Kane III, T.G., Bauer, D.J., and Martinez, C.M., 1994, Streamflow and selected precipitation data for Yucca Mountain region, southern Nevada and eastern California, water years 1986-90: U.S. Geological Survey Open-File-Report 94-312, 118 p.

La Camera, R.J. and Westenburg, C.L., 1994, Selected ground-water data for Yucca Mountain region, southern Nevada and eastern California, through December 1992: U.S. Geological Survey Open-File Report 94-54, 161 p.

Lane, L.J., 1983, Transmission losses, *in* National Engineering Handbook, NEH 4: U.S. Department of Agriculture, Soil Conservation Service, p. 19.1-19.21.

Luckey, R.R., Lobmeyer, D.H., and Burkhardt, D.J., 1993, Water levels in continuously monitored wells in the Yucca Mountain area, Nevada, 1985-88: U.S. Geological Survey Open-File Report 91-493, 252 p.

Marie, J.R., 1985, Streamflow losses, consequent flow through a thick unsaturated zone, and recharge to an unconfined aquifer, p. 486-487 *in* Keyes, C.G. Jr. and Ward, T.J., eds., Development and management aspects of irrigation and drainage system proceedings, San Antonio, Texas, July 17-19, 1985: American Society of Civil Engineers, New York, New York.

McKinley, P.W., Long, M.P., and Benson, L.V., 1991, Chemical analyses of water from selected wells and springs in the Yucca Mountain area, Nevada and southwestern California: U.S. Geological Survey Open-File Report 90-355, 47 p.

O'Brien, G.M., 1991, Water levels in periodically measured wells in the Yucca Mountain area, Nevada, 1989: U.S. Geological Survey Open-File Report 91-178, 51 p.

O'Brien, G.M., Tucci, Patrick, Burkhardt, D.J., 1995, Water levels in the Yucca Mountain area, Nevada, 1992: U.S. Geological Survey Open-File Report 94-311, 74 p.

Osterkamp, W.R., Lane, L.J., Savard, C.S., 1994, Recharge estimates using a geomorphic/distributed-parameter simulation approach, Amargosa River basin: Water Resources Bulletin, v. 30, no. 3, p. 493-507.

Pabst, M.E., Beck, D.A., Glancy, P.A., and Johnson, J.A., 1993, Streamflow and selected precipitation data for Yucca Mountain and vicinity, Nye County, Nevada, water years 1983-85: U.S. Geological Survey Open-File Report 93-438, 66 p.

Quinn, W.H., Neal, V.T., and Antunez de Mayolo, S.E., 1987, El Niño occurrences over the past four and a half centuries: Journal of Geophysical Research, v. 92, no. C13, p. 14,449-14,461.

Redmond, K.T. and Koch, R.W., 1991, Surface climate and streamflow variability in the western United States and their relationship to large-scale circulation indices: Water Resources Research, v. 27, no. 9, p. 2,381-2,399.

Robison, J.H., 1984, Ground-water level data and preliminary potentiometric-surface maps, Yucca Mountain and vicinity, Nye County, Nevada: U.S. Geological Survey Water-Resources Investigations Report 84-4197, 8 p.

Robison, J.H., Stephens, D.M., Luckey, R.R., and Baldwin, D.A., 1988, Water levels in periodically measured wells in the Yucca Mountain area, Nevada, 1981-87: U.S. Geological Survey Open-File Report 88-468, 132 p.

Ropelewski, C.F. and Halpert, M.S., 1986, North American precipitation and temperature patterns associated with the El Niño-Southern Oscillation (ENSO): Monthly Weather Review, v. 114, p. 2,352-2,362.

Savard, C.S., 1990, Correlation integral analysis of South Twin River streamflow, central Nevada: preliminary application of chaos theory (abstract): EOS, Transactions of the American Geophysical Union, v. 71, no. 43, Fall meeting supplement, p. 1,341.

----- 1991a, Correlation integrals of South Twin River and Steptoe Creek, Nevada streamflow (abstract): EOS, Transactions of the American Geophysical Union, v. 72, no. 44, Fall meeting supplement, p. 203.

----- 1991b, Still no evidence for chaos in western U.S. streamflow (abstract): EOS, Transactions of the American Geophysical Union, v. 72, no. 17, Spring meeting supplement, p. 60.

----- 1992, Looking for chaos in streamflow with discharge-derivative data (abstract): EOS, Transactions of the American Geophysical Union, v. 73, no. 14, Spring meeting supplement, p. 50.

----- 1994, Ground-water recharge in Fortymile Wash near Yucca Mountain, Nevada, 1992-93 *in* High level radioactive waste management proceedings of the Fifth Annual International Conference, Las Vegas, Nevada, 1994: American Nuclear Society and American Society of Civil Engineers, p. 1,805-1,813.

----- 1995a, Selected hydrologic data from Fortymile Wash in the Yucca Mountain area, Nevada, Water Year

1992: U.S. Geological Survey Open-File-Report 94-317, 38 p.

----- 1995b, Ground-water recharge from small to large streamflow events during El Niño periods under Fortymile Wash near Yucca Mountain, Nevada (abstract): EOS, Transactions of the American Geophysical Union, v. 76, no. 46, Fall meeting supplement, p. F241.

----- 1996, Selected hydrologic data from Fortymile Wash in the Yucca Mountain area, Nevada, water years 1993-94: U.S. Geological Survey Open-File Report 95-709, 30 p.

Sharma, K.D. and Murthy, J.S.R., 1994, Estimating transmission losses in an arid region - a realistic approach: Journal of Arid Environments, v. 27, p. 107-112.

Squires, R.R. and Young, R.L., 1984, Flood potential of Fortymile Wash and its principal southwestern tributaries, Nevada Test Site, southern Nevada: U.S. Geological Survey Water-Resources Investigations Report 83-4001, 33 p.

U.S. Department of Energy, 1988, Site characterization plan, Yucca Mountain site, Nevada research and development area, Nevada: U.S. Department of Energy Report DOE RW/0199, 8 v., various pagination. (HQS.881201.002)

U.S. Geological Survey, 1970, Water resources data for Nevada, 1969--part 1. Surface water records: U.S. Geological Survey Water-Data Report NV-69-1.

Waddell, R. K., 1982, Two-dimensional, steady-state model of ground-water flow, Nevada Test Site and vicinity, Nevada-California: U.S. Geological Survey Water-Resources Investigations Report 82-4085, 72 p.

----- 1984, Hydrologic and drill-hole data for test wells UE-29 a #1 and UE-29 a #2, Fortymile Canyon, Nevada Test Site: U.S. Geological Survey Open-File Report 84-142, 25 p.

Waddell, R.K., Robison, J.H., and Blankennagel, R.K., 1984, Hydrology of Yucca Mountain and vicinity, Nevada-California--investigative results through mid-1983: U.S. Geological Survey Water-Resources Investigations Report 84-4267, 72 p.

Walters, M.O., 1989, Transmission losses in arid region: Journal of Hydraulic Engineering, American Society of Civil Engineers, v. 116, no. 1, p. 129-138.

Westenburg, C.L. and La Camera, R.J., 1996, Selected ground-water data for Yucca Mountain region, southern Nevada and eastern California, through December 1994: U.S. Geological Survey Open-File Report 96-205, 73 p.

White, A.F. and Chuma, N.J., 1987, Carbon and isotopic mass balance models of Oasis Valley - Fortymile Canyon groundwater basin, southern Nevada: Water Resources Research, v. 23, no. 4, p. 571-582.

Wilcox, B.P., Seyfried, M.S., and Matison, T.H., 1991, Searching for chaotic dynamics in snowmelt runoff: Water Resources Research, v. 27, no. 6, p. 1,005-1,010.

Winograd, I.J. and Thordarson, William, 1975, Hydrogeologic and hydrochemical framework, south-central Great Basin, Nevada-California, with special reference to the Nevada Test Site: U.S. Geological Survey Professional Paper 712-C, 126 p.

Young, R.A., 1972, Water supply for the nuclear rocket development station at the U.S. Atomic Energy Commission's Nevada Test Site: U.S. Geological Survey Water-Supply Paper 1938, 19 p.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1998 - 673-083 / 20022 REGION NO. 8