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GROUND-WATER RECHARGE IN FORTYMILE WASH NEAR YUCCA MOUNTAIN, NEVADA, 1992-93

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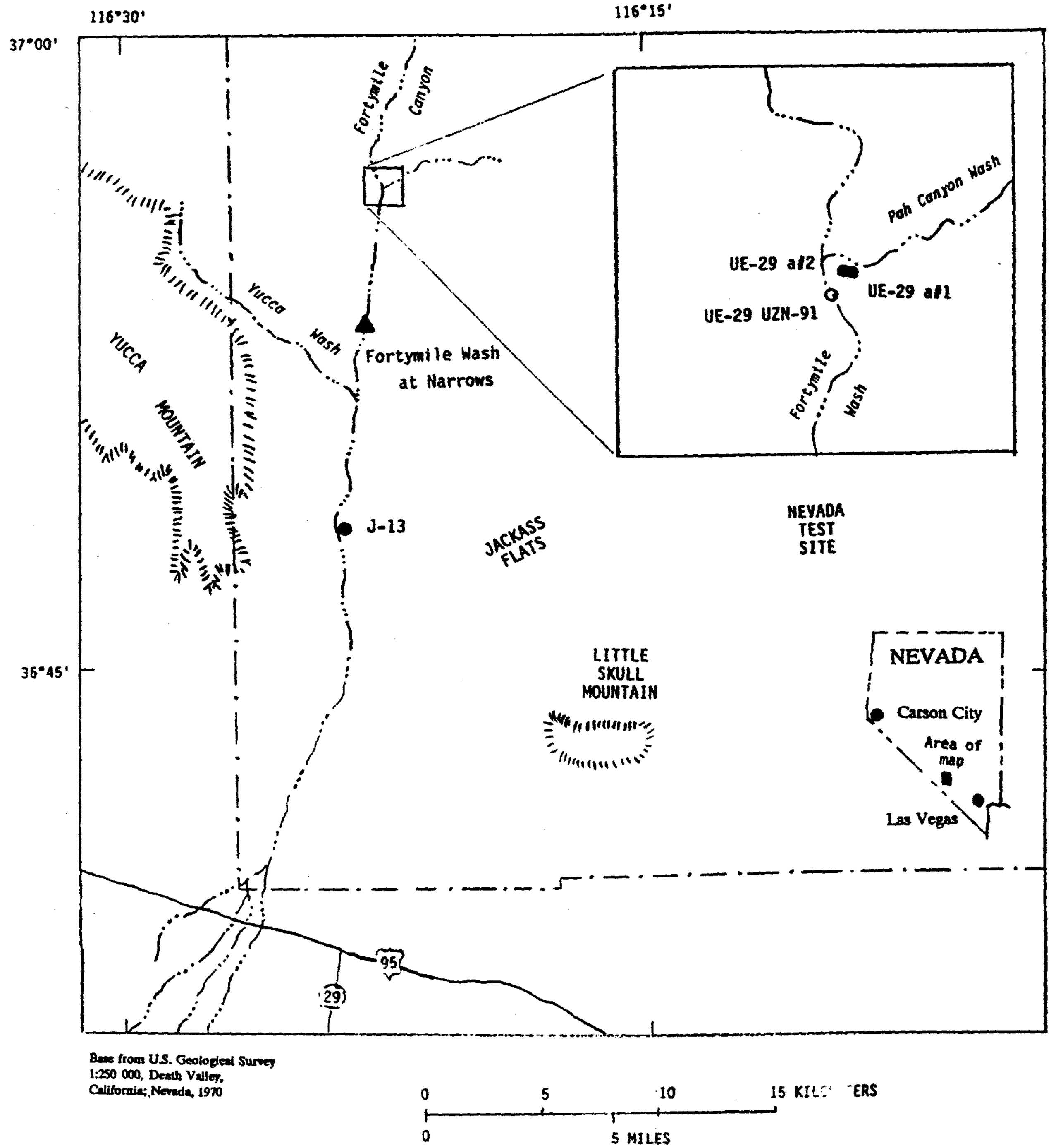
ABSTRACT

Ground-water recharge occurred after five separate streamflow event periods in the Pah Canyon area of Fortymile Wash approximately 10 kilometers from Yucca Mountain, Nevada during 1992-93. Ground-water levels rose in two wells, UE-29 a#1 and UE-29 a#2, and one neutron-access borehole, UE-29 UZN-91, after each streamflow event period. A maximum rise of 2.9 meters occurred at UE-29 a#1 thirteen days after the largest streamflow event where depth to water changed from 27.3 to 24.4 meters. Water levels fluctuated 3.89 meters in UE-29 a#1, 2.92 meters in UE-29 a#2, and 2.10 meters in UE-29 UZN-91 during the period January, 1992 to September, 1993. During two of the streamflow event periods, one in 1992 and one in 1993, there was flow around the neutron-access borehole located in the Fortymile Wash channel. Three other streamflow event periods were documented in Pah Canyon Wash but the streamflow infiltrated prior to reaching the neutron-access borehole location. Volumetric-water-content profiles were measured periodically in the neutron-access borehole. After the 1992 streamflow event period, water content increased in the upper six meters of the unsaturated zone. After the 1993 streamflow event period, water content increased in the entire unsaturated section, approximately 16 meters thick at the neutron-access borehole. Water levels in the neutron-access borehole rose even when there was no apparent water movement through the unsaturated zone as inferred by changes in the volumetric-water contents. This rise is attributed to ground-water recharge from nearby infiltration of Pah Canyon Wash streamflow. A ground-water mound probably formed beneath Pah Canyon Wash and spread laterally as evidenced by larger rises in water levels in UE-29 a#1 and UE-29 a#2, which are closer to Pah Canyon Wash than UE-29 UZN-91.

I. INTRODUCTION

Quantification of the ground-water recharge from streamflow in the Fortymile Wash watershed will contribute to regional ground-water studies. Regional ground-water studies are an important component in the studies evaluating the ground-water flow system as a barrier to the potential migration of radionuclides from the potential underground high-level nuclear waste repository. Knowledge gained in understanding the ground-water recharge mechanisms and pathways in the Pah Canyon area, which is 10 km to the northeast of Yucca Mountain, may transfer to Yucca Mountain site specific studies. The current data collection network in Fortymile Canyon does not permit quantification of ground-water recharge, however a qualitative understanding of ground-water recharge was developed from these data.

Ground-water levels rose in two wells, UE-29 a#1 (a#1) and UE-29 a#2 (a#2), and in one neutron-access borehole, UE-29 UZN-91 (N-91), in the Pah Canyon area of Fortymile Wash after five streamflow event periods during the period 1992-93. This is the first hydrologic time series evidence of ground-water recharge in the Fortymile Wash watershed, which has been hypothesized by previous water quality[1,2,3] and regional ground-water studies[4,5]. The peak streamflows during the five streamflow event periods were of different magnitudes and durations and the following rises in ground-water level were of different magnitudes. Only two of the streamflow event periods had streamflow that flowed over the neutron-access borehole N-91 location and affected the unsaturated zone vertical-water-content profile.



EXPLANATION

● WELL
○ NEUTRON-ACCESS BOREHOLE
▲ GAGING STATION
— · — NEVADA TEST SITE BOUNDARY

Figure 1.--Location of wells, neutron-access borehole, and gaging station.

II. DATA

A. Streamflow

Five different streamflow event periods were documented by field reconnaissance during 1992-93 near the confluence of Pah Canyon Wash and Fortymile Wash in Fortymile Canyon. The confluence of Pah Canyon Wash and Fortymile Wash is westnorthwest of a#1 and a#2 (fig. 1). N-91 is located in the channel of Fortymile Wash downstream of the confluence. Streamflow occurred during periods of precipitation, traveled down the wash channels, and infiltrated into the streambed sediments. Based on visual inspection of streambed deposits and inspection of small sediment dams built across wash channels, it was possible to partially reconstruct streamflow histories. The small sediment dams were built by constructing 0.05 to 0.1 m high sediment berms across the active channel. Streamflows eroded away the streambed-sediment berms leaving a visual record that streamflow had occurred. Small sediment dams were built and rebuilt after the streamflow events in the Fortymile Wash channel 5 m upstream of N-91 and in Pah Canyon Wash approximately 100 m above its mouth.

The dates of the five streamflow event periods are listed in Table 1. During the first and third streamflow event periods there was flow around the surface casing of N-91 in the Fortymile Wash channel. The second, fourth, and fifth streamflow event periods had smaller streamflows that infiltrated into the Pah Canyon Wash sediments before reaching Fortymile Wash since no evidence of streamflow was found in Fortymile Wash. The duration of each streamflow event probably was on the order of several hours. The precise time of an event could not be reconstructed from the available field evidence nor from the gage record from the nearby downstream gage, Fortymile Wash at Narrows. Streamflow during the first streamflow event period from the Pah Canyon area infiltrated into the streambed sediments and did not reach the gaging station. A separate streamflow event in Fortymile Wash that occurred downstream of the Pah Canyon area did reach the gage on February 12, 1992. Both of these streamflow events were probably associated with the same precipitation event, but streamflow from the first Pah Canyon area streamflow event period could have happened anytime during the period of February 12 to 15, 1992. During the third streamflow event period there may have been more than one event during the period January 17 to 19, 1993. Records from the gaging station showed several events during this period. Field evidence (wetted channel, fresh streambed deposits and high water marks, and destruction of the sediment dam) in the Pah Canyon area indicated at least one event, which could have destroyed evidence of earlier smaller events, or masked the identification of later smaller events. During the third streamflow event period, peak discharge was the largest of the five event periods.

Table 1.--Dates and locations of streamflow event periods.
[X - evidence of streamflow found at location]

Stream-flow event period number	Date	Evidence of streamflow at	
		Fortymile Wash	Pah Canyon
1	Feb. 12-15, 1992	X	X
2	Mar. 31, 1992		X
3	Jan. 17-19, 1993	X	X
4	Feb. 9, 1993		X
5	Feb. 23, 1993		X

B. Unsaturated-Zone Moisture

Neutron-access borehole N-91 is located in the Fortymile Wash channel and was constructed such that the volumetric water content of the entire unsaturated zone, which consists of alluvial sediments, could be logged with a hand held neutron-meter tool. The small radiation source in the tool permitted observations of water content of at most one meter away from the borehole. Prior to neutron logging in the borehole, depth to water was measured. The subsequent volumetric-water-content profile was terminated above the water level in the borehole to prevent damage to the tool. Neutron meter counts were recorded every 0.1 m from land surface to a depth of 5 m, and every 0.3 m for depths below 5 m. Neutron counts (C) were converted to volumetric water content (VWC) using the empirical equation

$$VWC = (4.864x10^{-9} x C^2) + (1.346x10^{-5} x C) - 0.0139 \quad (1)$$

Change in storage in the unsaturated zone can be inferred from analysis of volumetric-water-content profiles. Moisture movement can then be inferred from this change in storage. Figures 2 and 4 can be used to compare different profiles during 1992-93. Figures 3 and

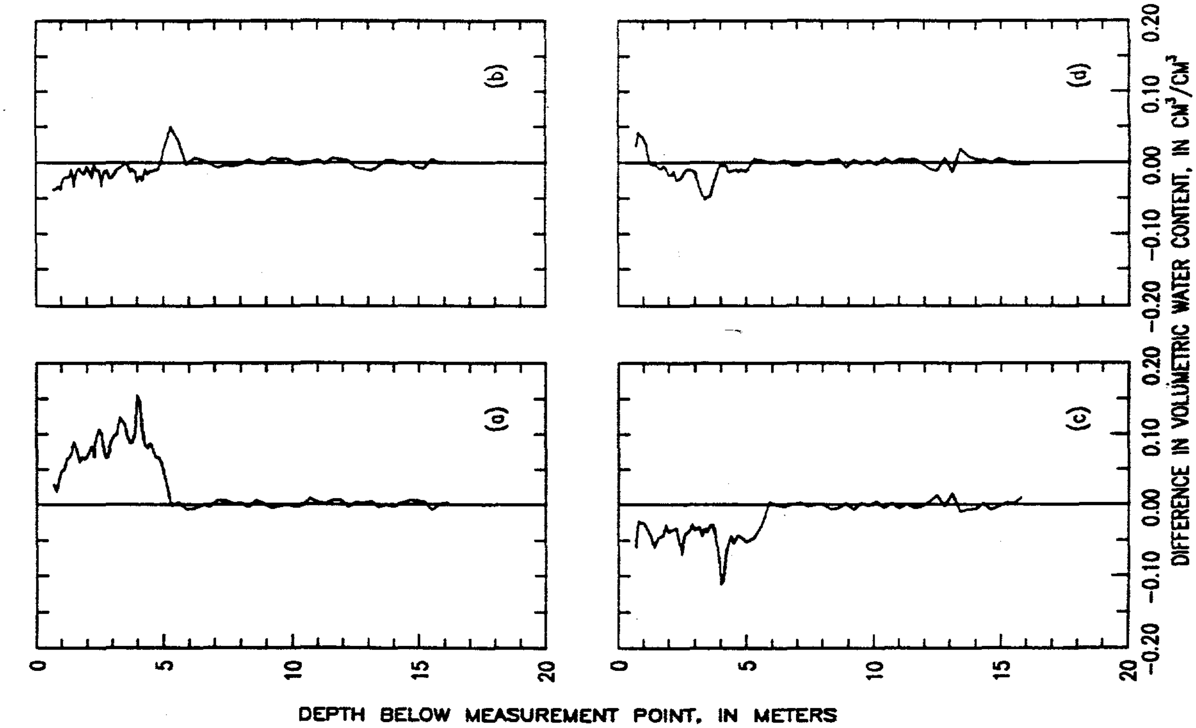


Figure 3.--Difference between volumetric-water-content profiles from (a) 1/28/92 to 2/21/92, (b) 2/21/92 to 5/07/92, (c) 5/07/92 to 8/26/92, and (d) 8/26/92 to 12/11/92 in UE-29 UZN-91.

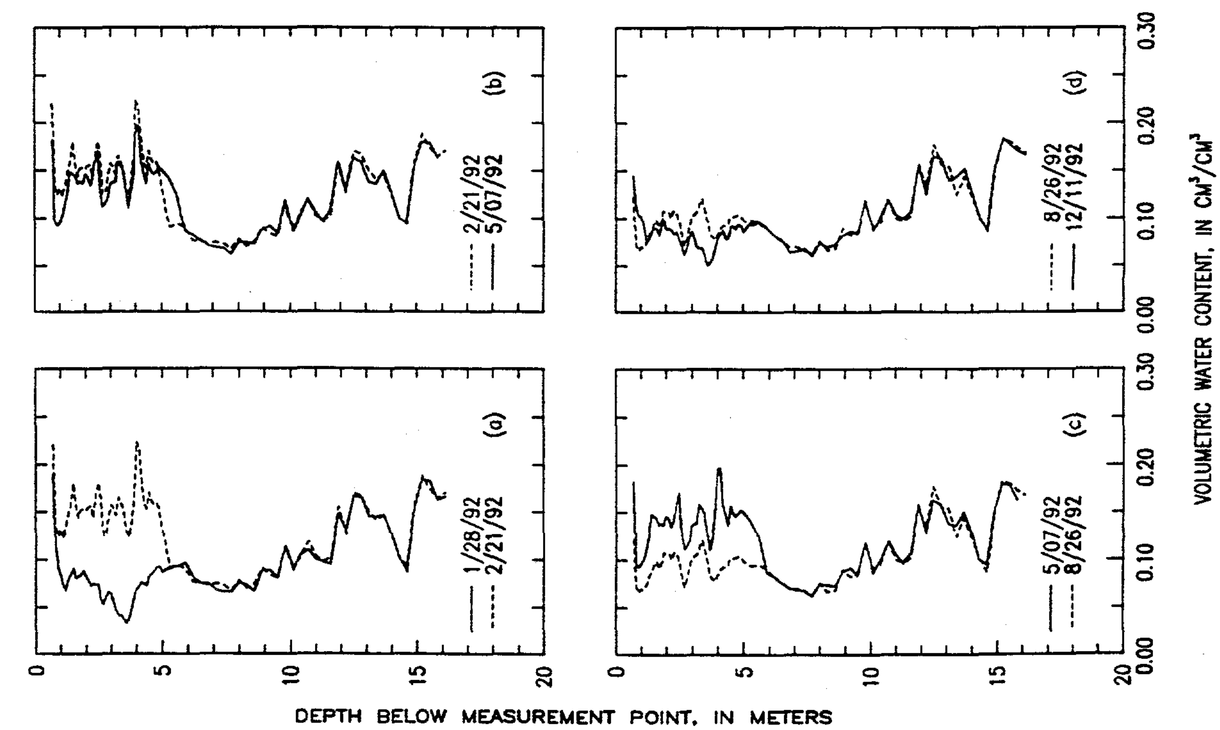


Figure 2.--Volumetric-water-content profiles in UE-29 UZN-91 during 1992.

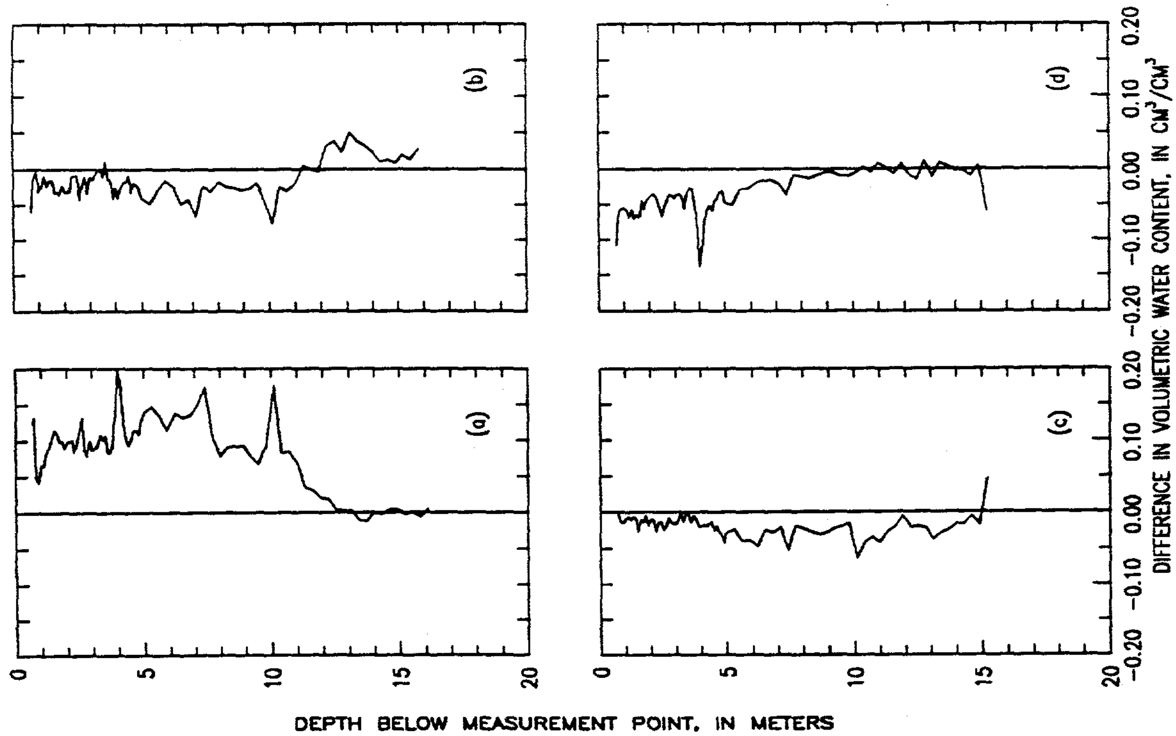


Figure 5.--Difference between volumetric-water-content profiles from (a) 12/11/92 to 1/19/93, (b) 1/19/93 to 1/23/93, (c) 1/23/93 to 4/05/93, and (d) 4/05/93 to 9/09/93 in UE-29 UZN-91.

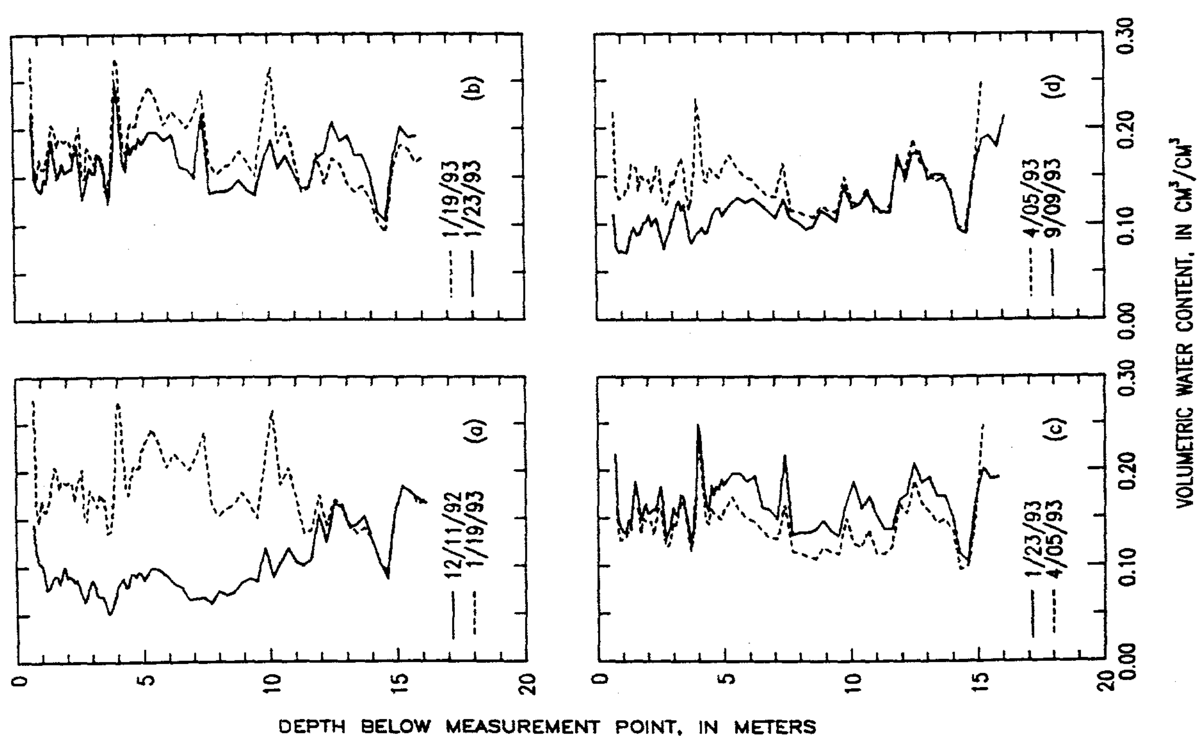


Figure 4.--Volumetric-water-content profiles in UE-29 UZN-91 during 1993.

5 show the computed volumetric-water-content differences between the profiles shown in figures 2 and 4. During the February 12-15, 1992 and the January 17-19, 1993 streamflow event periods there was direct infiltration of water adjacent to the borehole.

After the February 12-15, 1992 streamflow event period, the volumetric-water-content profile indicated water infiltrated to a depth of 5 m by February 21, 1992 (fig. 2a, 3a). During the period February 21 to May 7, 1992, water redistributed within the profile with water contents decreasing in the upper 5 m and increasing from 5 to 6 m (fig. 2b, 3b). During the period May 7 to August 26, 1992, the water content decreased in the upper 6 m of the borehole probably from evapotranspiration losses (fig. 2c, 3c). During the period August 26 to December 11, 1992, the water content increased in the upper 1 m from precipitation and decreased from 1 to 6 m (fig 2d, 3d). Water from the February 12-15, 1992 streamflow event period which infiltrated into the streambed sediments at the borehole location apparently did not reach the water table at N-91 during 1992. The small differences, less than 0.02 cm^3/cm^3, in the volumetric-water-content below 6 m during 1992 are attributed to operator and instrument error.

After the January 17-19, 1993, streamflow event period the volumetric-water-content profile indicated water infiltrated to a depth of 12 m by January 19, 1993 (fig. 4a, 5a). During the period February 19-23, 1993, water redistributed within the profile with water contents decreasing in the upper 11 m and increasing from 11 to 16 m (fig. 4b, 5b). During the period January 23 to April 5, 1993, the water content decreased in the upper 15 m and increased at 15 m (fig 4c, 5c). Comparisons below 15 m are not possible because the water level in the borehole was rising and logging was terminated below 15 m. During the period April 5 to September 9, 1993, the water content decreased over the entire profile (fig. 4d, 5d). The decrease in the water content from January to September, 1993 is probably a combination of evapotranspiration and vertical drainage of the alluvial material. Water from the January 17-19, 1993 streamflow event period apparently did reach the water table at N-91 as inferred by the increase in water content in the unsaturated zone to the water table.

C. Depths to water

Wells a#1 and a#2 were drilled to depths of 65.5 and 421.5 m, respectively, on an alluvial bench in Fortymile Canyon about 200 m southeast of the confluence of Pah Canyon Wash and Fortymile Wash to investigate the vertical hydraulic and hydrochemical properties[5]. The wells are located approximately ten meters apart. The neutron-access borehole N-91 was located in the main Fortymile Wash channel to monitor changes in the unsaturated zone water content from streamflow events. Because of the shallow water table depth, the neutron-access borehole was drilled into the saturated zone and completed to a depth of 28.65 m.

The water levels are depth-to-water measurements and represent conditions within the interval to which the borehole is open. For a#1, the open interval is 10.7 to 65.5 m and consists of alluvial and volcanic rock. For a#2, the open interval is 86.9 to 421.5 m and consists of volcanic rock. For N-91, the open interval is 27.1 to 28.65 m and consists of volcanic rock.

After each of the streamflow event periods, ground-water levels rose for two to three weeks and then began to decline (fig. 6). Depth to water was 17.6 m in N-91, 26.8 m in a#1, and 29.3 m in a#2 on January 13, 1992, one month prior to the first streamflow event period. After the first streamflow event period, February 12-15, 1992, ground-water levels rose 1.23 m in 19 days in a#1, 0.82 m in 19 days in a#2, and 0.49 m in 33 days in N-91. After the second streamflow event period, March 31, 1992, ground-water levels rose 0.44 m in 17 days in a#1, 0.33 m in 20 days in a#2, and 0.17 m in 30 days in N-91. After this rise, ground-water levels declined in all three holes until the third streamflow event period. After the third streamflow event period, January 17-19, 1993, ground-water levels rose 2.93 m in 13 days in a#1, 1.98 m in 28 days in a#2, and 1.61 m in 25 days in N-91. After the fourth streamflow event period, February 9, 1993, ground-water levels rose 1.28 m in 5 days in a#1, 0.69 m in 9 days in a#2, and 0.27 m in 9 days in N-91. After the fifth streamflow event period, February 23, 1993, ground-water levels rose 0.20 m in 6 days in a#1, 0.20 m in 9 days in a#2, and 0.09 m in 16 days in N-91. Following the rise after the fifth streamflow event period, ground-water levels declined throughout the remainder of 1993. The largest rise was after the largest streamflow event, January 17-19, 1993.

During the period January, 1992 to September, 1993 well a#1 had the largest fluctuation in water levels. Water levels in well a#1 fluctuated 3.89 m with a maximum depth-to-water measurement of 27.30 m and a minimum depth-to-water measurement of 23.41 m. Water levels in well a#2 fluctuated 2.92 m with a maximum depth-to-water measurement of 29.33 m and a minimum depth-to-water measurement of 26.41 m. Water levels in neutron-access borehole N-91 fluctuated

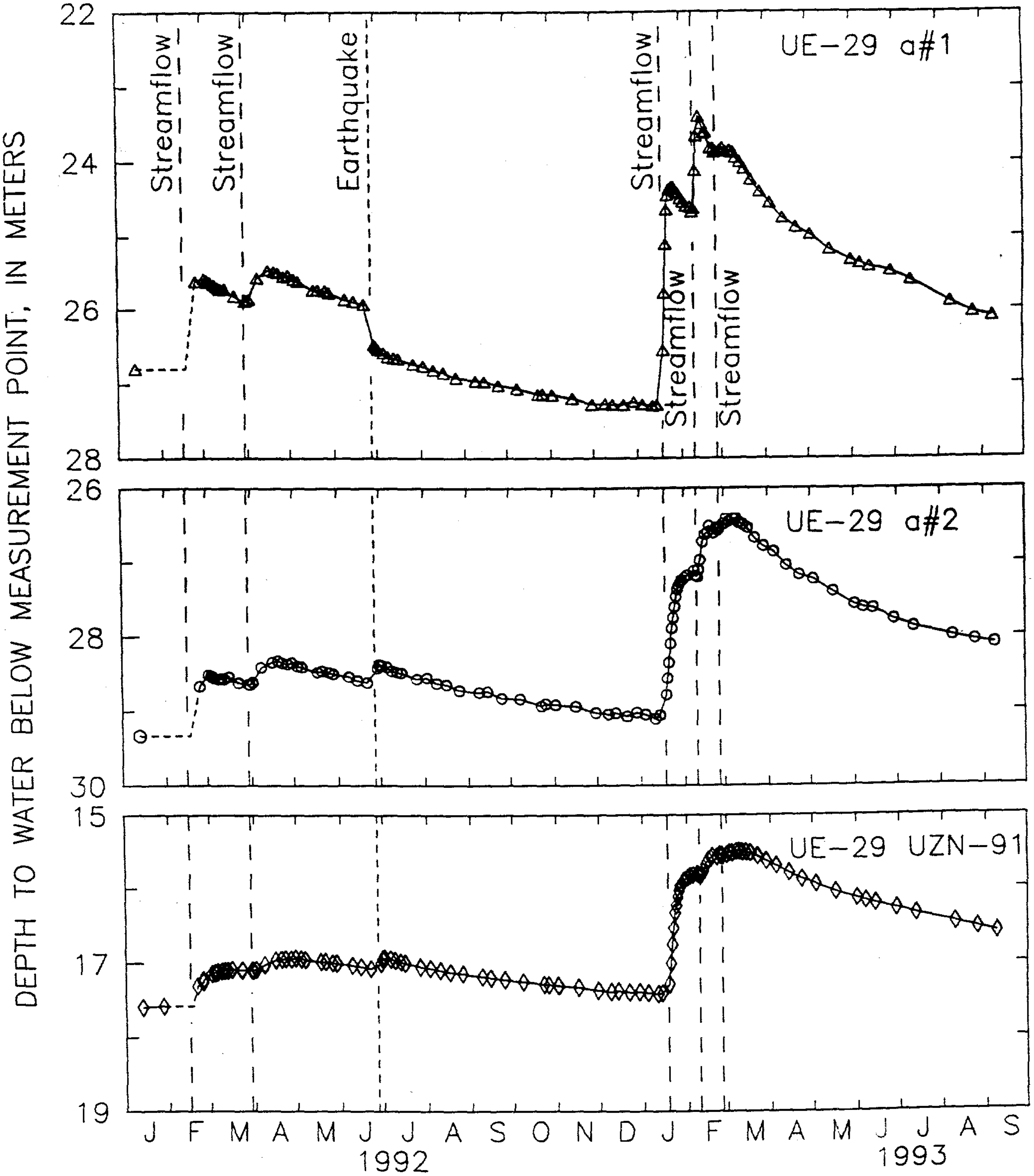


Figure 6.--Depth to water in Fortymile Canyon wells.

2.10 m with a maximum depth-to-water measurement of 17.59 m and a minimum depth-to-water measurement of 15.49 m.

The June 29, 1992 magnitude 5.6 earthquake near Little Skull Mountain affected water levels in the two wells and the neutron-access borehole by causing a shift in the general downward trend. Water levels rose about 0.1 m in a#2 and N-91 and declined about 0.3 m in a#1.

III. DISCUSSION

Rising water levels in three wells indicate ground-water recharge occurred in Fortymile Canyon near the confluence of Pah Canyon Wash and Fortymile Wash. Because the wells were close together no areal estimate of the total ground-water recharge was made. During 1992, water levels rose in neutron-access borehole N-91 even though water did not reach the water table, as inferred from an analysis of change in unsaturated zone storage using volumetric-water-content profiles. During 1993, the water levels began rising before water reached the saturated zone, as inferred from the volumetric-water-content profiles. During 1992 and 93 the water levels rose in the neutron-access borehole after streamflow event periods 2, 4, and 5 when there was no streamflow and therefore no infiltration at the neutron-access borehole location. Two reasons, (1) nearby infiltration and (2) flow through vertical preferential pathways located far enough away from the neutron-access borehole to be undetected were proposed by Savard and others[5] in 1992 to explain water level rises without concurrent water movement through the entire unsaturated zone. A discussion of these and other possible reasons follows.

Nearby infiltration in Pah Canyon Wash, approximately 100 m to the north, is the most likely explanation for the water level rises in the neutron-access borehole after examining the 1993 data. The rises are probably the result of a ground-water mound expanding laterally from beneath Pah Canyon Wash and extending to the nearby wells and neutron-access borehole. The formation of a ground-water mound beneath Pah Canyon Wash is supported by observations of a source for the water from streamflow events in Pah Canyon Wash and not in Fortymile Wash. Also supporting this are the larger water-level rises in a#1 and a#2 which are closer to Pah Canyon Wash than N-91.

Flow through preferential vertical pathways taking the moisture movement far enough away from the neutron-access borehole to be undetected may be another explanation for the water-level rises without concurrent movement through the entire unsaturated zone. If a preferred pathway existed then the recharge water should have followed the same pathway in 1993 as in 92. A comparison between the 1992 and 93 volumetric-water-content profiles shows that water content only increased to a depth of 6 m in 1992 but increased to 15 m in 1993. Why did the 1993 water follow a different pathway than the 1992 water? A possible reason may be that the preferred pathway became saturated in 1993 and the moisture found additional pathways. Another reason may be that the pathways were changed by the 1992 earthquake near Little Skull Mountain. Alternatively, no preferred pathway is needed at all. Instead moisture moved down into the alluvial material just 6 m in 1992 and over 15 m in 1993 when more water infiltrated into the alluvial sediments at the borehole location because of a larger streamflow event. Further data collection would be needed to assess fully the preferred pathway explanation.

The explanation of an impermeable mass beneath the neutron-access borehole N-91 location may be another explanation for the water levels to rise without concurrent moisture movement through the entire unsaturated zone. If an impermeable mass was present then water would be impeded after both infiltration events and the 1992 and 93 volumetric-water-content profiles would be similar. This is not the case, the 1993 profiles indicate a change in storage from 6 to 15 m while the 1992 profiles do not. Thus an impermeable mass seems unlikely to explain why water levels rise without changes in storage indicated by vertical-water content profiles.

Another explanation for the water level rises without concurrent moisture movement through the entire unsaturated zone was that logging was too infrequent to characterize rapid infiltration events. Examining the profiles after the infiltration events, the alluvial material took several months to return to preinfiltration moisture conditions. This suggests that a change in the volumetric-water-content profile from infiltration during streamflow events persists for several months and any changes in storage would then show up in subsequent logs. Thus evidence for a rapid infiltration event would still be detected at a later date by the logging. Therefore rapid infiltration events undetected by the logging frequency does not seem to be a valid explanation.

Another explanation for the water level rises without concurrent moisture movement through the entire unsaturated zone would be that a part of the alluvial material had a water content/hydraulic conductivity function with conductivities that were sensitive to water content and only needed small increases in water content to get high conductivities, thus permitting water to move through the alluvial material rapidly and not be monitored by the logging. Although no actual water content/hydraulic conductivity functions have been developed for the alluvial material, different depths of the alluvial material could have very different functions because of the heterogenous layering. Thus during 1992 from 6 m to the water table only small increases in the water content were needed for water to move from the upper 6 m to the water table. However during 1993 there is large increase in water content from 6 to 15 m. Could a water content/hydraulic conductivity function exist for the 6 to 15 m interval that would allow for recharge water to be passed through in 1992 and 1993 but with these different water contents? Without the actual function there is no way of knowing. Thus the sensitive water content/hydraulic conductivity function is a possible explanation for the water level rises by letting moisture move through portions of the unsaturated zone with small, possibly undetectable, increases in water content.

IV. SUMMARY

Ground-water recharge occurred in the Pah Canyon area of Fortymile Canyon as evidenced by rising water levels in a#1, a#2, and N-91. Five distinct events of ground-water recharge correlate to five streamflow events in Pah Canyon Wash and Fortymile Wash. The source of the ground-water recharge was streamflow infiltrating through the streambed sediments and the underlaying alluvial material. Two of the streamflow events flowed around a neutron-access borehole located in the Fortymile Wash channel. Analysis of the volumetric-moisture-content profiles from the neutron-access borehole indicated a change in storage in the alluvial material. The change in storage can be attributed to water moving down 6 m in 1992 and over 15 m in 1993. Measured water level rises in the neutron-access borehole when no water from a streamflow event infiltrated at the borehole are attributed to nearby recharge in a stream channel and a laterally expanding ground-water mound.

NOMENCLATURE

m	meters
VWC	Volumetric water content in cm^3/cm^3
C	Neutron tool count

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