COSINE COMPONENTS IN WATER LEVELS AT YUCCA MOUNTAIN

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ABSTRACT

Water-level records from periodically-measured wells at Yucca Mountain, Nevada are analyzed to determine if they contain periodic (cosine) components. Water-level data from selected wells are input to an iterative numerical procedure that determines a "best fitting" cosine function. The available water-level data, with coverage of up to 5 years, appear to be representative of the natural water-level changes.

From our analysis of 9 water-level records, it appears that there may be periodic components (periods of 2-3 years) in the groundwater-level fluctuations at Yucca Mountain, Nevada, although some records are fit better than others by cosine functions. It also appears that the periodic behavior has a spatial distribution. Wells west of Yucca Mountain have different periods and phase shifts from wells on and east of Yucca Mountain. Interestingly, a similar spatial distribution of groundwater chemistry at Yucca Mountain is reported by Matuska (1988). This suggests a physical cause may underlie the different physical and chemical groundwater conditions. Although a variety of natural processes could cause water-level fluctuations, hydrologic processes are the most likely, because the periodicities are only a few years. A possible cause could be periodic recharge related to a periodicity in precipitation. It is interesting that Cochran et al., (1988), show a crude two-year cycle of precipitation for 1961 to 1970 in southern Nevada.

Why periods and phase shifts may differ across Yucca Mountain is unknown. Different phase shifts could indicate different lag times of response to hydrologic stimuli. Difference in periods could mean either that the geologic media is heterogenous and displays heterogeneous response to a single stimulus, or that stimuli differ in certain regions, or that a hydraulic barrier separates the groundwater system into two regions having different water chemistry and recharge areas.

INTRODUCTION

Yucca Mountain is the proposed site for the first high-level radioactive waste repository in the United States. The geologic repository will be located in unsaturated tuff about 300 meters below land surface and 250 meters above the current water table (1). Because of the toxicity and long half-lives of radionuclides to be contained in the repository, and because the subsurface hydrologic system may be a primary pathway for movement of these radionuclides away from the repository, the complete hydrologic system at Yucca Mountain must be characterized. The unsaturated zone has been studied most, primarily because the repository would be located there and less is known about unsaturated zone hydrology, especially in fractured volcanic tuffs. The current representation is of a very slow unsaturated zone flow that occurs in the matrix. Little or no recharge is occurring at Yucca Mountain, but may be occurring beneath the washes or intermittent streams, such as Forty-Mile Wash.

The climatology, meteorology, and surface water hydrology are also being studied to determine the inputs to the subsurface hydrologic system; and investigations of the water table configuration and the saturated zone ground water system are being made to better understand the site hydrogeology and specifically to determine the ground water travel time. The study of the saturated zone can determine: 1) recharge from careful analysis of water table fluctuations; 2) aquifer parameters from the water-level responses to barometric fluctuations; 3) water-level changes with time and any long-term rise or fall of these levels; 4) water-table gradient, flow directions, and travel times. It can also provide: 1) evidence for the three-dimensional flow field responding to thermal- or stress-field changes, as suggested by Szymanski (2); 2) characterization of the flow field's three dimensionality; 3) evidence for hydraulic connectors or barriers; 4) preparation of realistic numerical ground water models and their calibration and verification; 5) evaluation of the validity of ground water history interpretations on ground water chemistry and isotopic studies; and 6) an improved understanding of ground water flow through a fractured anisotropic media.

AVAILABLE WATER-LEVEL DATA

Water-level data at Yucca Mountain are primarily collected by the U.S. Geological Survey and are of several different types. A number of problems have been encountered in collecting these data (3), but our analysis (4) demonstrates that small changes in water levels in one well can also be detected in a nearby well by the measurement methods that have been used. It appears measurement errors are small enough that small natural water-level fluctuations can be detected. This study uses water-level data collected intermittently since the early 1980's.

JUSTIFICATION

Hydrologic data may possess periodic components and thus time series analyses have been applied by McCuen and

Snyder (5). For example, precipitation commonly varies on an annual basis and thus recharge and ground water levels also typically fluctuate with a yearly period. Careful analysis of the fluctuations of ground water levels may provide evidence that recharge is occurring, and allow determination of its distribution and magnitude (6,7). If these characteristics of recharge could be determined for the Yucca Mountain area, this may allow better understanding of the water flow through the unsaturated zone necessary to cause the recharge. In addition, these data would then provide a better basis for determining the travel time of radionuclides from the repository to the water table.

Traditional spectral analysis could not be performed because our data is not uniformly spaced in time. It is possible to determine if data possess periodic components by applying a numerical method to fit a cosine function to irregularly spaced data.

NUMERICAL METHODS

A variation of the general least squares approximation method was implemented on a computer for the purpose of determining whether the data contained periodic cosine components. This method is described fully in Rice (8).

METHODOLOGY FOR STUDY

We analyze nine sets of water-level data in eight selected wells (one well has data for two depth intervals) that are distributed across the area. Additional analyses of water-level records at other wells would be very useful, but could not be performed at the present time because of funding limitations.

Each analysis consists of the following main steps: 1) Data are entered as listed in Robison et al. (3). 2) The measurement dates are converted into days after January 1, 1983 to create a standard time scale for comparison purposes. 3) A linear trend is calculated and removed from the data by the computer program FIT.M. 4) Estimates of period and phase shift are provided by the user and FIT.M is used to calculate optimal parameters for a cosine curve that fits the data. 5) Review of the residuals after the cosine function is removed aids the user in determining how well the cosine function fits the data.

In the results section, we present plots for selected analyses. Each analysis creates a series of three plots. The first plot is of the original data and the linear trend. The second plot displays the data with the linear trend removed and the fitted cosine function. The third plot is of the residuals after both the linear trend and the cosine function are removed.

RESULTS

Examples of water-level records are provided that demonstrate varying degrees of periodicity. We crudely classify the cosine function fits as good, fair, or poor.

An example of a good cosine function fit is at well WT-11 (Fig. 1). It appears that the removal of the linear trend improves somewhat the periodic aspect of the record. The cosine function has a period of 888 days and fits quite well throughout the length of record (about 1-1/4 cycles), although near day 900, the cosine function falls slightly below the data and near day 1100 it is slightly above the data. The residuals after the cosine function removal appear mostly random; no periodicity is evident.

In the course of our evaluation of the existence and possible cause for the offsets reported in Robison et al (3), analyses were also made of data sets that were created by subtracting the offsets from the original data. Although our evaluation of these offsets demonstrates that they are not caused by measuring equipment changes and instead appear to reflect real rises or declines of water levels, we include an analysis of the offset data for WT-1 (Fig. 2). These data have an entirely different form than the original data. The calculated period (1600 days) is much longer than the period determined for the original data. The residuals after cosine function removal are essentially random. Although the fit is good, it means very little because the data probably do not represent the actual water levels. This demonstrates the importance of obtaining high quality field data. It also emphasizes that all of these results rely on the data sets analyzed, which as we have shown have problems, and thus these results are uncertain.

An example of a fair cosine function fit at WT-1 (Fig. 3). A significant linear trend is removed from the data and again this appears to improve the periodic aspect of the data. Although the cosine function fits quite well until day 700, the function diverges during some periods after this. Between day 800 and 1200 atypically high values occur (which were also measured less frequently during this period) that are not approximated very well by the cosine function. The residuals after removal of the linear trend and cosine function are quite variable although a crude periodicity may remain.

The analysis of water levels in well USW-H5 poses a problem. Our method approximates the best cosine function for the data; it does not provide the best function. The cosine function calculated to fit these data has an unreasonably long period and large amplitude (Fig. 4).

A summary of the results of the analyses to determine periodic components in selected water-level records from Yucca Mountain appear as Table I. The wells are arranged to group records having similar periodic components. In

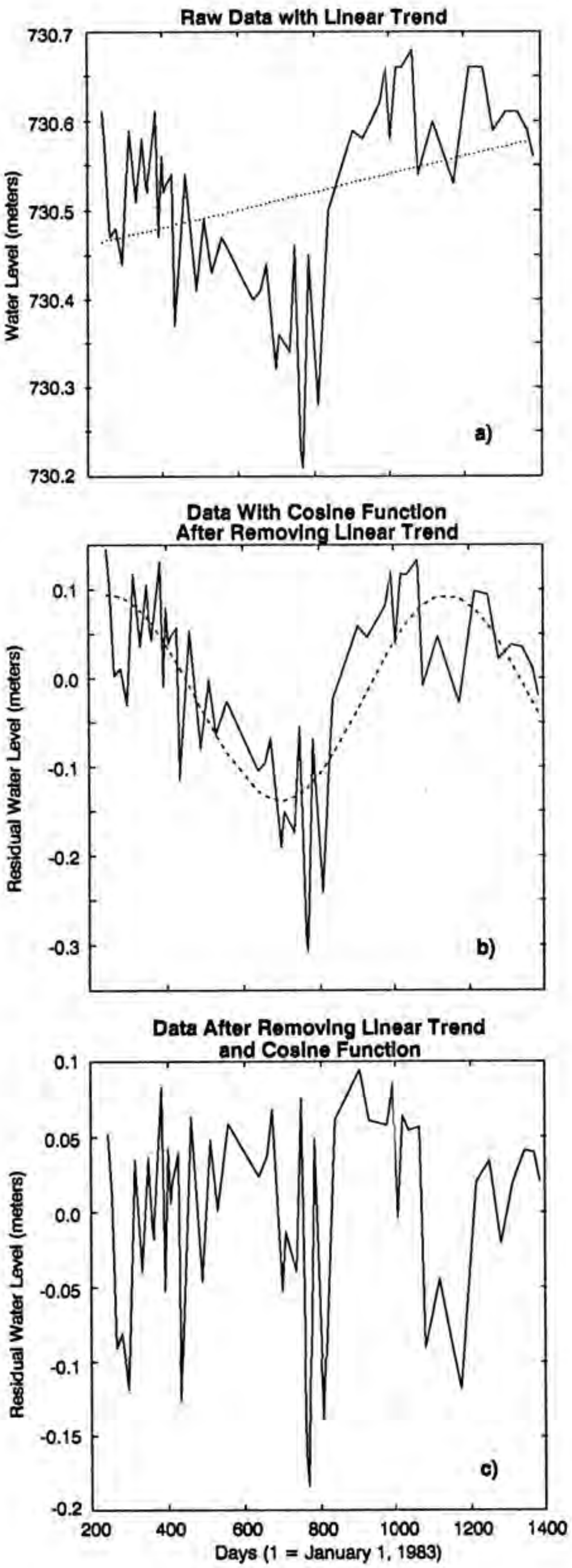

Fig. 1. FIT.M Results for WT-11.

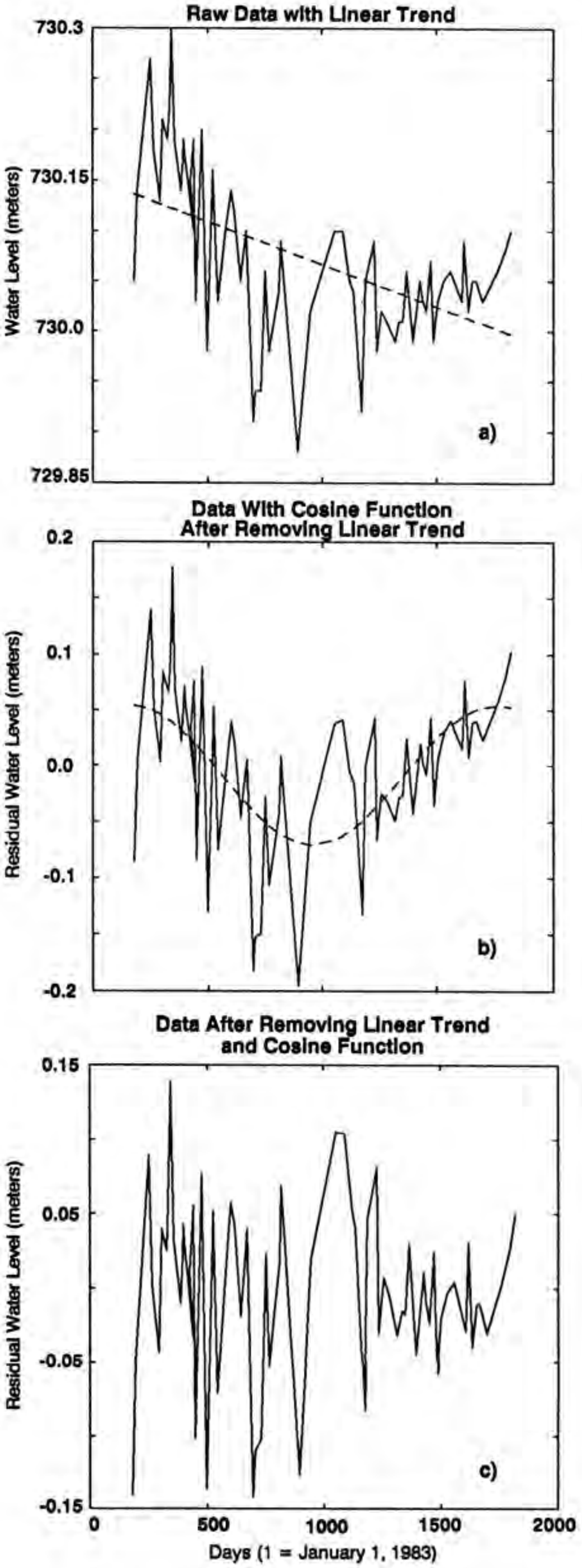

Fig. 2. FIT.M Results for WT-1 (with offsets).

TABLE I
Cosine Fits for Selected Wells.

Well #	Period	Phase Shift	Amplitude	r^2	Slope	Cycles
WT-7	1012.2	177.7	0.09	0.47	0.000107	1½ cycle
WT-10	925.4	182.4	0.7	0.22	0.000074	~ 2 cycles
WT-12	1240.0	169.8	0.7	0.35	0.000101	~ 1¼ cycles
WT-1	889.2	249.5	0.1	0.44	.000191	almost 2 cycles
WT-11	887.7	253.4	0.115	0.58	0.000100	~ 1¼ cycles
WT-16	860.6	266.9	0.11	0.68	0.000240	~ 1¼ cycles
WT-6	2975.2	738.1	1.3	0.75	.00323	~ ½ cycle
H-5	1936.8	416.6	0.54	0.45	-0.000044	< ½ cycle
H-5	1888.4	417.9	0.31	0.28	-0.00033	~ ½ cycle
WT-1*	1597.8	159.5	0.0625	0.32	-0.000085	~ 1 cycle
WT-10*	935.5	163.3	0.0565	0.22	0.000083	~ 1¾ cycles
WT-16* Fit 1	226.4	279.7	-0.0365	0.24	-0.000130	~ 5¼ cycles
WT-16* Fit 2	1229.4	143.2	0.0385	0.22	-0.000130	¾ cycle

*Indicates offsets were subtracted from original data.

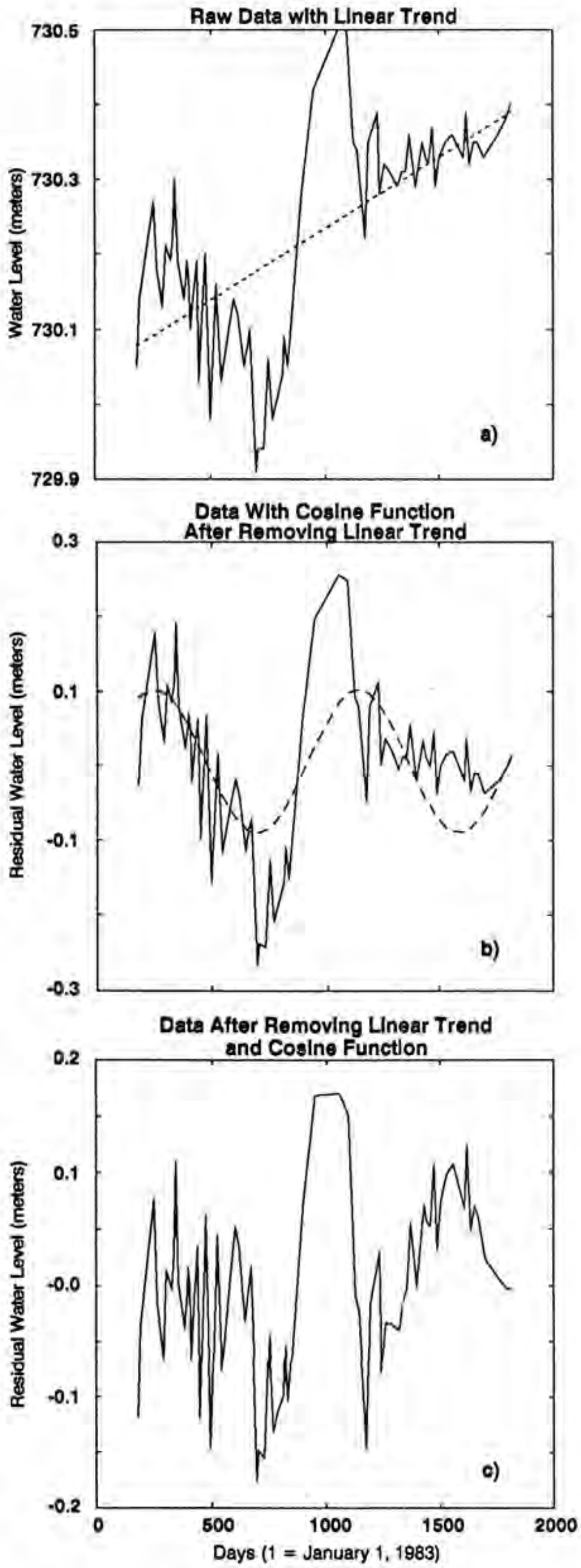

Fig. 3. FIT.M Results for WT-1.

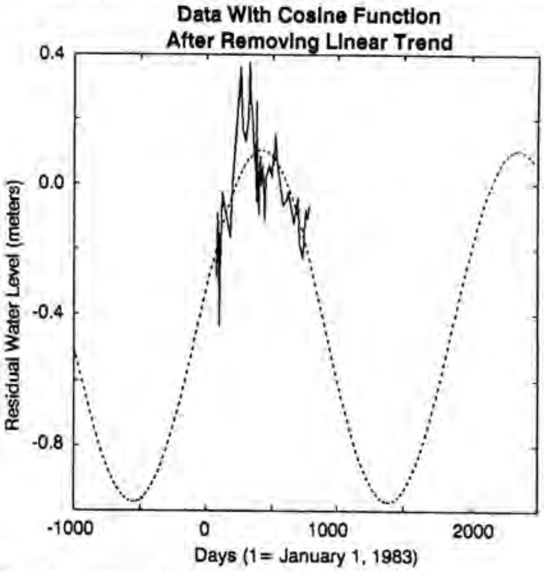

Fig. 4. FIT.M Results for H-5 9 (low interval).

addition, the results of four analyses of water-level data sets that were modified by removing the reported offsets are also listed on Table I. For the offset data of WT-16*, two different cosine components were evident in the data; Fit 1 has a short period whereas Fit 2 has a long period.

DISCUSSION AND INTERPRETATION

Most water-level records from wells at Yucca Mountain have similar characteristics. During 1983 and 1984, most wells record similar declines in water levels that are followed by relatively high values in 1985. During 1986, water levels remain fairly constant or may have slightly upward or downward trends.

The water level records can roughly be grouped according to the parameters of the cosine function that fits the data. As shown on Table I, two main groups are apparent. Wells WT-7 and WT-10 have an average period of about 970 days and phase shift of approximately 180 days. Another group composed of wells WT-1, WT-11, and WT-16 have an average period of 879 days and average phase shift of 257 days. Other wells, such as WT-12, may not be clearly assigned to either of these groups, although it is not too different from the parameters for well WT-7 and WT-10. Also presented on Table I are the parameters from analyses of records that had offsets subtracted from the original data. None of these four (WT-1*, WT-10*, WT-16* Fit 1, WT-16* Fit 2) had combinations of period and phase shift similar to the two groups.

The two groups of wells with similar periodicities have a spatial distribution. Wells WT-7 and WT-10 are located to the west of the crest of Yucca Mountain. Wells WT-1, WT-11, and WT-16 are located to the east. This pattern has also been reported for the chemistry of ground water at

Yucca Mountain (9,10). According to Matuska (10), "There is a division of eastern (WT-12, WT-14, WT-15) wells and western (WT-7, WT-10) wells with respect to Ca2+."

The spatial distribution of the periodic behavior, also reflected in the ground water chemistry, suggests a physical cause. Although precipitation has a strong random component, it is common for there to be seasonal or annual periodicity. In southern Nevada, a bi-annual periodicity of precipitation has occurred in the past as indicated in Fig. 5 from Cochran et al. (11). Ground water recharge is commonly correlated with periodicity in precipitation. In the arid environment of the Yucca Mountain area, the distribution of recharge in time and space is poorly known. Specifically, how long does it take for precipitated water to be transmitted through the unsaturated zone to the water table? Is recharge restricted to intermittent stream areas? Is there a long lag time between when precipitation infiltrates and when the water reaches the water table? At Rainier Mesa, which is similar geologically to Yucca Mountain, but receives greater precipitation, discharge from springs emerging from the unsaturated zone apparently has an annual cycle.

From this analysis, it appears that systematic water-level fluctuations may be occurring at Yucca Mountain. Amplitudes of the fitted cosine functions are relatively small, ranging from about 0.1 - 0.7 m. Why the amplitudes should be this variable is uncertain, although it may relate to local hydraulic conditions, or may indicate that the cause of the periodicity has significant spatial variation. Further analysis of Yucca Mountain well data would be very beneficial, but is not currently possible because of funding cutbacks. If the geographic distribution of periodic water-level fluctuations is supported by further analyses, then a physical cause is strongly indicated. The fitted cosine functions have periods between 2 and 3 years and could be responding to a periodicity in precipitation. Cursory comparison of monthly precipitation at Beatty, Nevada, with well WT-10 water levels suggests that its water-level decline occurs after a period of higher rainfall in 1983-1984 and the water-level rise in 1985 might be related to a period of high precipitation.

A difference in phase shift is easier to understand than variation in periodicity. Phase shift could be correlated with a time lag, where water that recharged in one location was translated downgradient resulting in peak water levels at progressively later times, similar to that documented by Winter (12), and Nevulis (13). If periods of water-level fluctuations vary geographically then this implies that these areas are responding either to different stimuli, or respond to similar stimuli, but in a different manner, possibly because of a difference in the physical system in these areas. An example of this could be that runoff water may be relatively more concentrated in the deeper drainages on the west flank of Yucca Mountain, or that somewhat greater

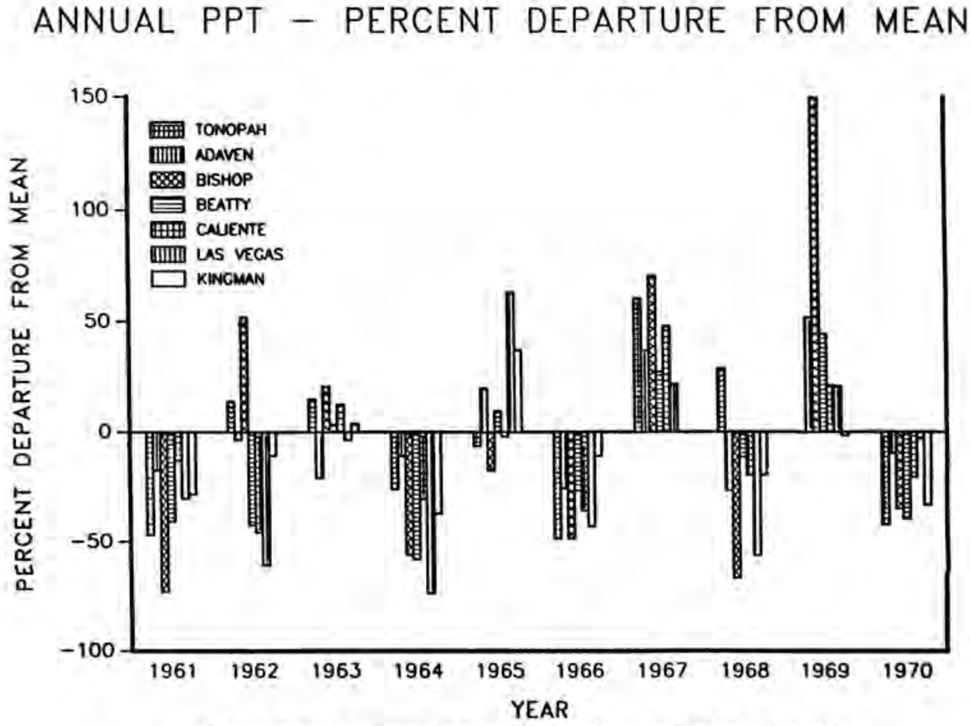

Fig. 5. Annual Precipitation Totals During Years 1961-1970.

than average precipitation occurs in this area resulting in a stronger more noticeable recharge pulse in this area. Runoff on the eastern flank of Yucca Mountain could collect in depressions and be subject to greater evaporation so that only larger differences in precipitation over a few years are reflected in the ground water fluctuations. Another possibility is that there is a hydraulic barrier that separates the areas so that the fluctuations are caused by recharge that is occurring in different regions.

SUMMARY

Study of the saturated ground water system at Yucca Mountain is underway to evaluate the suitability of this site for containing high-level radioactive waste in a repository in the unsaturated zone. Besides using these data for determination of ground water travel time to the accessible environment, these data could suggest that recharge is occurring locally and indicate its distribution of recharge. Periodic water-table fluctuations also may be difficult to explain if matrix flow is expected to be essentially steady deep in the unsaturated zone. If periodicity is evident that cannot be explained by variations in atmospheric pressure or tidal effects, then another cause such as recharge may be indicated. Currently, little is known about the distribution of recharge in this arid setting.

The available water-level data were collected at irregular intervals and frequencies. These data appear to be relatively accurate and display similar fluctuations in a number of wells. Changes of measurement equipment may have caused offsets in measurements, but from the reported data, evidence for this is far from conclusive. In fact, careful review of data provided in Robison (3) indicates that a significant water-level rise in mid-1985 did actually occur and is not an offset related to measurement equipment changes.

A variation of the general least squares approximation method was used to numerically determine whether ground water-level data from Yucca Mountain, Nevada contain periodic cosine components. The method iteratively finds optimal values for the amplitude, period, phase shift and intercept for a general cosine function.

For this preliminary study, we analyzed nine water-level data sets from eight wells. Raw data were fit with a general cosine curve. Typical periods appear to be between 2 and 3 years. Short records or those with less than one full cycle should not be evaluated with this method.

From the limited number of wells investigated, it appears that the periodic component in water level records may be classified by period and phase shift, and these groups display a spatial distribution as well. Interestingly, ground water chemistry at Yucca Mountain displays a similar spatial distribution (10). Because two natural aspects of the ground water system show a similar spatial distribution, a spatially-distributed natural physical cause is suggested.

Periodicity in precipitation and associated ground water recharge could be a reasonable cause of this periodic water-level fluctuation. Although precipitation has a strong random component and episodic events do occur, it is common for there to be an annual periodicity to precipitation. In southern Nevada, a bi-annual periodicity of precipitation has been observed. In fact, precipitation in southern Nevada has displayed a crude two-year cycle in the past. Cursory comparison of monthly precipitation at Beatty, Nevada, with well WT-10 water levels suggests that water-level declines occur after a period of higher rainfall in 1983-1984 and water-level rises in 1985 might be related to a shorter period of relatively high precipitation. The two groups of water-level periodicities may also indicate that a hydraulic barrier separates the two regions, and possibly that the periods and phase shifts relate to recharge that occurs in different areas.

Although a variety of natural processes could conceivably cause periodic behavior in ground water levels, many of these such as tectonic stress field adjustments, may be more episodic in nature, or cyclical with very irregular periods. Further careful analysis of water-level and precipitation records, especially precipitation measured at Yucca Mountain, to confirm the spatially-distributed nature of the periodicity in water-levels and possible correlation with precipitation is warranted.

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