

IS THERE A CASA GRANDE BULGE AND WILL IT CAUSE EARTHQUAKES IN ARIZONA?

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INTRODUCTION

Heavy groundwater pumping in south-central Arizona has caused groundwater overdraft and extensive water-level declines, particularly in the Picacho Basin (U.S. Bureau of Reclamation, 1976; Laney and others, 1978). Earth fissuring and widespread land subsidence have accompanied the removal of groundwater (Laney and others, 1978). Holzer (1979) stated that the land surface rose 6 cm in part of the Picacho Basin in response to groundwater pumping.

Holzer (1979) theorized that unloading of the earth's crust by removal of large amounts of groundwater in south-central Arizona causes the land surface to rise in the same way that loading by large reservoirs causes the land surface to depress. He also speculated that in tectonically active areas, unloading may cause earthquakes. This concept suggests the possibility of earthquakes in the Picacho Basin site of part of the Central Arizona Project aqueduct (Figure 3, p. 6), an area of greatest groundwater level decline in Arizona. Because of the potential for seismic activity in the vicinity of the aqueduct, Holzer's theory required further analysis by the U.S. Water and Power Resources Service. However, after reviewing his work, the authors question Holzer's interpretation of surveying and seismic data, as discussed below.

ELASTIC EXPANSION AND LOADING

Based on leveling surveys in 1905, 1948-49, 1967, and 1977, Holzer (1979) estimated that the land surface rose (elastic expansion) 6 cm from 1948 to 1967 in the areas northwest and northeast of the town of Casa Grande. He suggested that this rise was the result of removal of more than 43.5×10^{12} kg of groundwater and subsequent diminishment of surface stresses.

Holzer (1979) stated that the rise or elastic expansion (mass loss) in areas of groundwater depletion, such as south-central Arizona, is comparable to the depression or elastic compression (mass increase) of the earth's surface caused by loading in reservoir impoundments such as Lake Mead, Arizona. Applying the theory of elasticity, he compared deflection of the earth's surface (W_{\max}) in terms of depression or expansion in areas of loading and unloading (see Table 1). Because of the $\text{MASS}/(\text{AREA})^{1/2}$ ratio for south-central Arizona (8.93×10^{11} kg/km) is approximately one-half the value of the ratio for Lake Mead (15.3×10^{11} kg/km), Holzer (1979, p. 4690) stated that man-induced uplift in south-central Arizona from 1915 to 1973 should equal approximately one-half the depression of 17.8 cm measured at Lake Mead. In fact, the predicted uplift (W_{\max}) for south-central Arizona is 13.2 cm (see Table 1), significantly greater than one-half the depression at Lake Mead.

SURVEY DATA

There are several reasons to question the interpretation of leveling data by Holzer. In determining crustal expansion, Holzer (1979) used unadjusted data from two long level lines. The data were collected over a period of 72 years by various agencies (U.S. Geological Survey—1905 and 1977; National Geodetic Survey—1948, 1949 and 1967). Although all of the surveys (except 1977) were performed to First-Order standards, the data may be less accurate in the early surveys due to limited precision of leveling instruments. Thus, comparison of unadjusted leveling data may not be sufficient to determine the minimal rise in the land surface reported by Holzer.

Data points in the early surveys were widely spaced and many of the early bench marks were disturbed or destroyed before later surveys. The NGS survey of 1948 reported that bench mark 1338 (set in 1905 in alluvium) was leaning. At this time it was labeled T277. Apparently this monument had been disturbed, perhaps by subsidence, yet Holzer used the 1948 leveling at 1338 to determine a 6.2 cm rise in the land surface from 1948 to 1967. In fact, published adjusted values for bench marks 1338 (T277) and nearby W277 show continual subsidence (no uplift) in this area (Table 2).

Holzer (1979, p. 4692) computed all elevational changes in relation to bench mark 1283 which was set in alluvium. The absolute elevation of 1283 was unknown; however, it was considered stable by Holzer on the basis of only one other point, bench mark Enid, which was set in bedrock 1 km away. The authors suggest that bench mark 1283 should not be considered absolutely stable as Holzer suggested, unless the stability of 1283 and Enid are evaluated by reference level data to several other stable points outside the area or by large scale evaluation as part of the national level net data adjustments in Arizona.

In evaluating data errors, Holzer (1979) used the "nominal accuracy between points" formulae published by the Federal Geodetic Control Committee (1974) for the National Geodetic Network. These standards specify limits of allowable misclosure (error) for each class of level line. However, nominal accuracy criteria are applicable to only the most precise data. Assuming First-Order, Class II leveling, the allowable misclosure (nominal accuracy) between bench marks 1283 and 1338 is $\pm 2 \text{ mm } \sqrt{K} = 1.2 \text{ cm}$, where K is the distance between bench marks in kilometers (Holzer, 1979, p. 4695). In practice, the surveyed data can be more realistically evaluated by the "permissible error of closure" technique (Federal Geodetic Control Committee, 1974). An appropriate accuracy of within $\pm 4 \text{ mm } \sqrt{K}$ (twice the nominal accuracy) is

TABLE 1. Comparison of Potential for Expansion or Depression of the Crust Beneath Selected Areas With Mass Changes*

Location	Mass Loss 10^{12} kg	Area km^2	Time Period	Calc†† W_{\max} , cm	Mass/(Area) ^{1/2} 10^{11} kg/km	References
South-central Arizona	43.5	8,070	1948-67	7.3	4.84	AWC (1975)
South-central Arizona	80.2	8,070	1915-73	13.2	8.93	AWC (1975)
Lake Mead, Arizona-Nev.	37.6**	601	1935-40	22.7	15.3	Longwell (1960), Raphael (1954)
Lake Powell, Arizona	26.1**	579	July 1975	—	10.8	USGS (1978)

*Modified from Holzer (1979)

**Reservoir impoundment (mass increase)

††Calculated $W_{\max} = \frac{2(1-\nu^2)g}{\pi^2 E} \frac{m}{(\pi R)^{1/2}}$ where: W_{\max} = deflection at center of circle
E = Young's modulus
 ν = Poisson's ratio

m = mass of load
g = acceleration of gravity
R = radius of circular area

indicated by this method. Thus, for the 36.6 km distance between bench marks 1283 and 1338 (where Holzer interpreted 6.2 cm of crustal expansion), a misclosure of as much as ± 2.4 cm would be acceptable for any single unadjusted run between these two points, and the maximum acceptable misclosure between unadjusted data run along this line in different years (i.e. 1948 and 1967) could be as much as ± 4.8 cm. Similarly, for bench mark 1283 to D367 (87 km away), using unadjusted data from runs in two different years, a maximum misclosure of as much as ± 7.46 cm is permissible for First-Order, Class II standards. This value for error is greater than the "significant elastic expansion" of 6.2 cm cited by Holzer (1979, p. 4693) in the Picacho Basin, northwest of Casa Grande. A similar situation occurs at bench mark Poston, where Holzer (1979, p. 4695) reported 7.52 cm of uplift (1948–1967) with respect to 1283. Using the permissible error formula cited above for 1948 and 1967 level data, the uplift value is within the range of acceptable misclosure.

TABLE 2. Adjusted Level Values for Bench Marks 1338 and W277*
(Altitude above mean sea level in feet)

Bench Mark	1905	1948–49	1967	1977
1338 (1905) = T277 (1948)	1338.705	1338.462	1338.442	1338.400
W277	—	1340.562	1340.555	1340.545

*Marshall, (1915); NGS (1948–49, 1967); U.S.G.S. (1977).

SEISMICITY

Holzer (1979, p. 4698) theorized that earthquakes may be caused by unloading because of groundwater withdrawal in the Picacho Basin. If earthquakes may result from unloading, and the alleged unloading is similar to reservoir loading at Lake Mead and comparable areas, as Holzer stated, then earthquakes should have followed loading at Lake Mead and comparable areas. In fact, the evidence is to the contrary. The areas of greatest loading and subsidence at Lake Mead were notably aseismic. Anderson and Laney (1975), and Mickey (1973), concluded that seismicity was not a direct result of loading by the mass of the lake. Rather, it was a result of rapid changes in water level.

Similarly, a comparison of MASS/(AREA)^{1/2} values from the Lake Powell reservoir, Arizona, and south-central Arizona further confirms that loading (and comparable unloading) does not cause earthquakes. Lake Powell at Glen Canyon Dam, 523 km from the Picacho Basin, has a ratio value of 10.8×10^{11} kg/km (Table 1); similar to the value for south-central Arizona of 8.93×10^{11} kg/km. However, Mickey (1973) showed a definite decrease in local seismic activity following loading at Lake Powell.

It is particularly significant to note the absence of measurable seismic events within an 80-km (50 mile) radius of the Picacho Basin (Figure 3, p. 6). Holzer (1979) suggested the possibility of seismic activity due to unloading in this area. If Holzer is right then the substantial unloading which has occurred since World War II should have caused earthquakes in the Picacho Basin. Several ground tremors were reported by the BIA supervisor at Picacho Reservoir in early 1975 (Yerkes and Castle, 1976), one of which was coincident with a rapid drop of 150 mm in the reservoir water level; however, Peirce (1975) suggested that many of the low intensity "seismic events" in this area were the result of atmospheric phenomena related to supersonic jet booms. In addition, Holzer and others (1979) cited a microearthquake investigation conducted in 1977, north of Eloy, which confirmed that the Picacho Basin was not subject to seismically-active tectonic processes.

CONCLUSIONS

Elastic expansion or rise in the land surface as reported by Holzer (1979) is questioned on the basis that 1) unadjusted data

with varying degrees of accuracy are compared, 2) data points are widely spaced and may have been disturbed or destroyed in some cases, 3) elevational changes are computed in relation to a single bench mark, and most importantly, 4) leveling errors were evaluated by nominal accuracy methods which yield minimal values of one-half of the permissible error.

Unloading due to groundwater withdrawal is unlikely to induce earthquakes in south-central Arizona. Comparable crustal loading at Lake Mead and Lake Powell has not triggered seismic activity, and, more important, no significant earthquake epicenters have been recorded within an 80-km (50 mi) radius of the Picacho Basin (Figure 3, p. 6). In fact, the area is notably aseismic in contrast to the seismically-active areas to the southwest and north-northeast. The evidence indicates that south-central Arizona is not subject to seismic activity as a result of groundwater unloading. In addition, more precise leveling data will be required in order to accurately determine if crustal expansion is indeed occurring as a result of groundwater withdrawal.

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