Using Video Surveys to Evaluate Land Subsidence Damage to Water Wells in the Sacramento Valley, California

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Background

Down-well video surveys are used by well-service companies to determine the cause of reduced production or other problems with water wells in California. In subsiding areas, videotapes commonly show that well casings were compressed vertically and broken, collapsing telescopically into themselves. Videotapes of 317 down-well video surveys from wells in the Sacramento Valley that were collected from cities, water districts, and well drilling and pump contractors were used to 1) characterize well-casing damage, 2) to determine if they could provide information on the amounts and location of historical subsidence (subsidence occurring prior to extensive surveying or satellite-based monitoring), and 3) if damage was related to well construction methods, age of well casing, amounts of fine-grained sediment, or water-level history. Post-Eocene continental rocks and deposits that commonly contain freshwater range in thickness from 730 m in the northern part of the Sacramento Valley to more than 975 m in the southern Sacramento Valley. All scanned wells are shallower than 450 m.

Methods

Down-well video scans were collected on video tape in three formats— ¾-in, Beta, and VHS. Tapes were reviewed to determine the type of damage to well casings, depth of damage, and the amount of vertical compression on broken casings. The amount of vertical compression at each casing break was estimated by differencing the distance between casing joints as indicated by the camera depth indicator on the video tape and the original length of each casing joint as shown on Well Completion Reports submitted to California Department of Water Resources by drilling contractors. These reports also provided information on the alluvial texture of sediments penetrated by wells, and well-construction details. Reports by the California Department of Water Resources provided groundwater-level data during the time the wells were in service.

The number of damaged wells and intact wells drilled in the southwestern Sacramento Valley by three drilling contractors and three drilling methods were compared to evaluate if construction techniques influenced damage susceptibility. Relations between the integrity of well casings and well depth, well age, sediment texture, and groundwater-level change were examined statistically by comparing a group of 80 damaged wells with a group of 88 intact wells. The Mann-Whitney rank sum test was used to determine if the two samples of data come from populations that differ significantly (p-values <0.05) in the median value of the tested variable. The Mann-Whitney p-value, the smallest level of significance that allows the null hypothesis, 'the median value of the variable for damaged and intact wells is the same," to be rejected. Rejection of the null hypothesis at $p < .05$ implies that the variable may be related to subsidence damage. Additionally, Empirical Distribution Functions were prepared for damaged and intact wells to visually determine if the distribution range of values for each variable were similar in the two groups.

Results and discussion

All wells damaged by vertical compression are in the southwestern part of the Sacramento Valley, and all except one lie between the Sacramento River and the easternmost outcrop of the Tehama Formation (fig. 1). Damaged wells are in a wide north-south band from north of Zamora through Woodland and Davis, to just east of Dixon (fig. 1). This area extends to the west, north, and south of the area that other investigators have described as a regional trough of subsidence in the southwestern Sacramento Valley. All scanned wells are located in alluvium or flood-basin deposits (fig. 1) of Quaternary age and are completed in the underlying Tehama Formation of Pliocene-Pleistocene age. All substantial damage occurred to parts of the casing string within the Tehama Formation. The median depth to the top of the Tehama Formation in the damaged wells is 28.7 m below land surface. Therefore, the Quaternary alluvium and flood-basin deposits are relatively thin in the subsiding area. A thickness (and mass) of compacting and settling aquifer materials greater than that of these deposits alone probably is required to exert compressive forces that exceed the strength of steel well casing. Where spirit leveling had quantified subsidence near damaged wells, subsidence magnitude during the life of the well always exceeded the total estimated vertical offset (shortening) of broken casing.

Most damage occurs as broken casings (119), but casing ripples (18), ovaled casing (4), and crushed or spiraled well screens (13) also were observed (fig. 2). Most casing breaks and other compressive features occur at weak points in the casing string, such as perforations and slots (68), screens (13), or joints (38). However, the number of casing breaks in blank casing (25) is relatively high. The median depth, in meters below land surface, of ruptures at casing joints (68) and casing openings (73) is about the same, but, oddly, the median depth of ruptures in blank casing is significantly shallower (48 m). The vertical offset on most compressive features was estimated to be less than 0.15 m. The greatest estimated vertical offset on a single compressive feature is 0.91 m. There is no apparent relation between the amount of vertical offset and the depth of a compressive feature below land surface. Most wells have only one compressive feature although one well was found to have six separate casing ruptures.

Nonparametric statistical analysis of quantitative factors that might be related to subsidence indicated that the following have a greater than 95 percent chance of being significantly different between a group of 80 damaged wells and a group of 88 intact wells: age of a well at the time it was scanned; maximum change in hydraulic head and the decline of the preconsolidation head during the active life of the well; year the well was drilled; year the well was scanned; fatigue factor (a measure of potential strain hardening and embrittlement calculated by multiplying the days in service by the average annual change of hydraulic head). Other factors, such as well depth, texture (meters of fine-grained sediment), relative texture (percent fine-grained sediment), altitude of land surface, and average annual change of hydraulic head were not significantly different between the groups, implying these factors likely were unrelated to subsidence that damaged wells.

The categorical variables drilling method and drilling contractor were examined by comparing the number of damaged wells with the number of intact wells in each category, as shown in table 1. A relation between drilling contractor and well damage might be inferred from table 1. For contractor I, the numbers of intact and damaged wells are about equal; for contractor II, most wells sustained damage; and for contractor III, most wells remained intact. Other factors being equal, this might indicate contractor III drills good wells. However, a comparison of broken and intact wells by drilling method (table 1) implies that reverse rotary wells are less likely to be damaged than wells drilled by other methods, and that a relation between drilling method and well damage may be the underlying reason for the apparent relation between drilling contractor and well damage. That is, wells drilled by contractor II that were mostly damaged were drilled primarily by the conventional-rotary method.

To determine if the apparent relation between drilling method and well damage is real or coincidental, data on hydraulic-head change and well age were analyzed separately for wells drilled by cable-tool, conventional-rotary, and reverse-rotary methods. In addition, and because of the relative abundance of data for conventional-rotary wells, data from damaged and intact wells drilled by this method were used preferentially to determine if well age or change in hydraulic head were related to well damage (table 2).

As a group, the cable-tool and conventional rotary wells are older than those drilled by the reverse-rotary method (table 2), which is a newer technique. However, because there seems to be little difference in the length of time that damaged and intact conventional rotary wells have been in service it is likely unimportant that the age of cable-tool and conventional-rotary wells (median for both methods, about 6200 days) greatly exceeds the age of reverse-rotary wells (median, 2900 days, table 2). The apparent relation between well age and damage probably reflects a relation between well damage and the timing of subsidence, rather than a weakening of well casing by corrosion or other time-dependent process.

Similarly, the fatigue factor is higher for cable tool and conventional rotary wells than for reverse rotary wells, but because there is not a statistical difference in this variable between damaged and intact wells drilled by the conventional rotary method (p=0.209, table 2) it is likely that strain weakening of well casing is not significantly related to the occurrence of damage.

The average annual change of hydraulic head at wells drilled by the conventional rotary method also is not significantly different in damaged and intact conventional-rotary wells and therefor this variable likely is unrelated to well damage.

Likewise, the median maximum change in hydraulic head during the service time of damaged conventional-rotary wells is slightly higher than that for intact wells in the same group (median, 19.5 and 18 m, respectively; table 2), but the differences are not statistically significant at the 0.05 level (p = 0.0975). Hydraulic-head variables in table 2 are not independent. The weak relation between the average annual change of hydraulic head or the maximum change in hydraulic head, and damaged wells likely results from a more direct relation between well damage and decline of the preconsolidation head.

Preconsolidation head is the hydraulic head (groundwater level) that triggers inelastic, permanent compaction of aquifer sediments and initiation of substantial subsidence. For the aquifer system in the study area the preconsolidation head is roughly equivalent to the lowest hydraulic head aquifer sediments have experienced. The aquifer near damaged, conventional-rotary wells has undergone a significantly greater decline in preconsolidation head than has the aquifer near intact conventional-rotary wells during the time the wells were in service (median, 6.1 and 0.91m, respectively, p = 0.0148; table 2, fig. 2). The decline of the preconsolidation head during the service time of wells drilled by the conventional-rotary and cable-tool methods is greater than that for wells drilled by the reverse-rotary method (fig 3.). In fact, the preconsolidation head in the aquifer near most reverse-rotary wells has not declined between the date the wells were constructed and the date they were scanned (median = 0 m, table 2; fig.3).

Conclusions

Data gleaned from video tapes of downwell video surveys suggests that the drilling method has little effect on ability of a well to resist subsidence. However, because most reverse-rotary wells probably have not been subjected to the high rates and amounts of subsidence that have occurred near many wells drilled by other methods, the ability of reverse-rotary wells to resist vertical compression has not been adequately tested in the field. Therefore, relations between drilling method and well damage cannot be evaluated until more data are available to describe the reaction of reverse-rotary wells to compressive forces in actively subsiding areas. The decline of preconsolidation head in the aquifer system is likely the primary cause of inelastic subsidence that exerted downward compressive force on well casings that was sufficient to collapse casings telescopically into themselves, bending, ripping, and shortening casing strings. Conclusions relating vertical shortening of the casing string to subsidence magnitude are subject to error because neither casing protrusion or subsidence rate have been considered in the analysis.

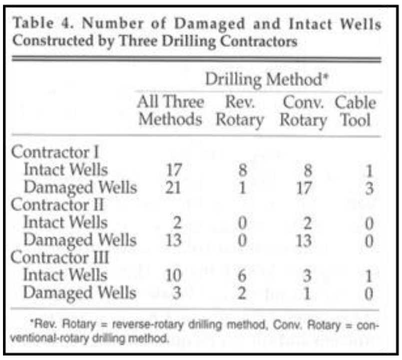

Table 4. Number of Damaged and Intact Wells Constructed by Three Drilling Contractors

	Drilling Method* All Three Methods	Rev. Rotary	Conv. Rotary	Cable Tool
Contractor I				
Intact Wells	17	8	8	1
Damaged Wells	21	1	17	3
Contractor II				
Intact Wells	2	0	2	0
Damaged Wells	13	0	13	0
Contractor III				
Intact Wells	10	6	3	1
Damaged Wells	3	2	1	0

*Rev. Rotary = reverse-rotary drilling method, Conv. Rotary = conventional-rotary drilling method.

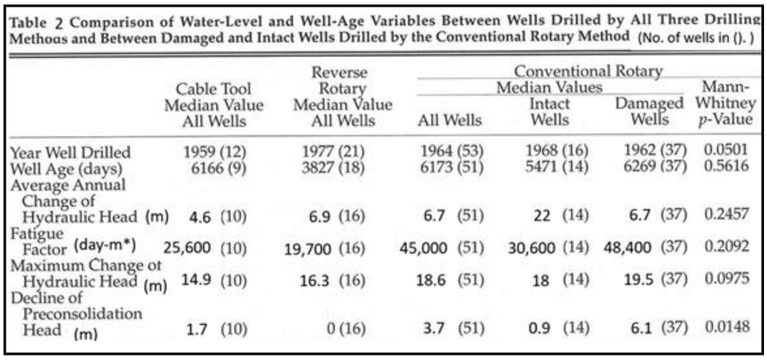

Table 2 Comparison of Water-Level and Well-Age Variables Between Wells Drilled by All Three Drilling Methoas and Between Damaged and Intact Wells Drilled by the Conventional Rotary Method (No. of wells in ().)

	Cable Tool Median Value All Wells	Reverse Rotary Median Value All Wells	Conventional Rotary Median Values All Wells	Intact Wells	Damaged Wells	Mann-Whitney p-Value
Year Well Drilled	1959 (12)	1977 (21)	1964 (53)	1968 (16)	1962 (37)	0.0501
Well Age (days)	6166 (9)	3827 (18)	6173 (51)	5471 (14)	6269 (37)	0.5616
Average Annual Change of Hydraulic Head (m)	4.6 (10)	6.9 (16)	6.7 (51)	22 (14)	6.7 (37)	0.2457
Fatigue Factor (day-m*)	25,600 (10)	19,700 (16)	45,000 (51)	30,600 (14)	48,400 (37)	0.2092
Maximum Change ot Hydraulic Head (m)	14.9 (10)	16.3 (16)	18.6 (51)	18 (14)	19.5 (37)	0.0975
Decline of Preconsolidation Head (m)	1.7 (10)	0 (16)	3.7 (51)	0.9 (14)	6.1 (37)	0.0148

Table 1 & 2 1) Number of damaged and intact wells constructed by three drilling contractors, 2) Comparison of water-level and well-age variables between wells drilled by all three drilling methods and between damaged and intact wells drilled by the conventional rotary method.

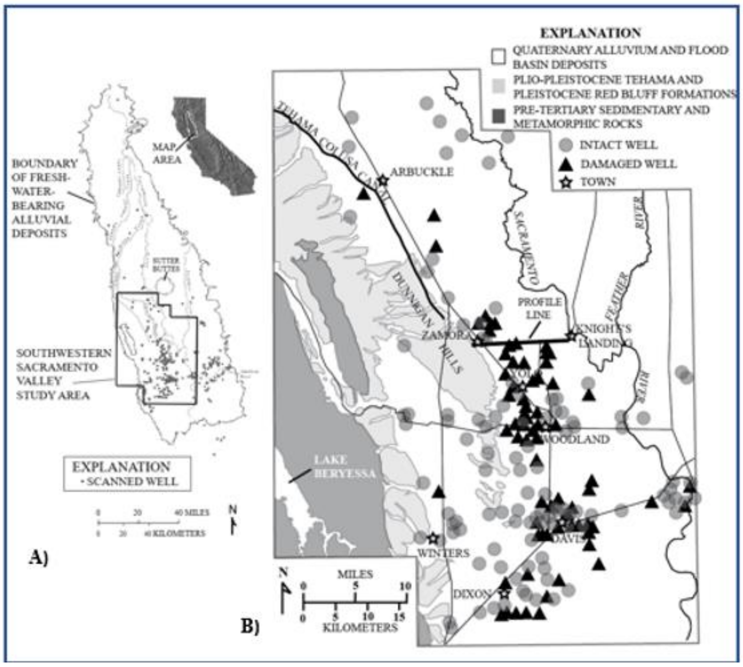

Figure 1 A) Location of the study area and video scanned wells, and B) Geology and location of damaged and intact wells.

Figure 2 A) Ovaling and rippling, B) Ripping and tearing, C) Crushing/Spiraling of well screen.

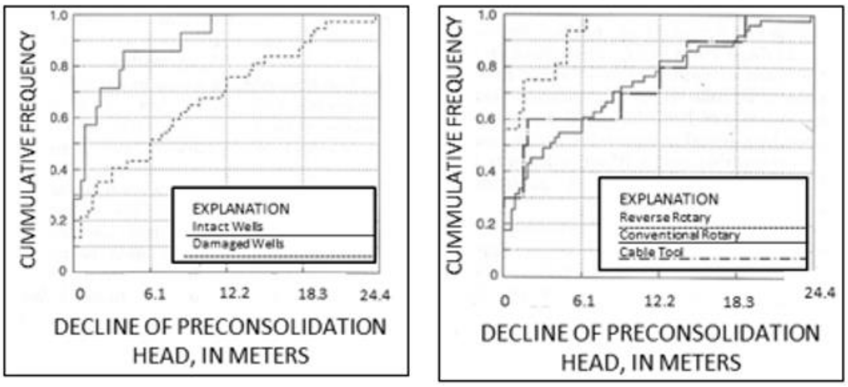

Figure 3 & 4 3) Empirical distribution functions of the decline of the preconsolidation head in the aquifer near damaged and intact wells drilled by the conventional rotary method, 4) Empirical distributions functions of the decline of the preconsolidation head in the aquifer near wells drilled by the reverse-rotary conventional rotary, and cable-tool methods.