Assigning Water Levels and Ground-Water Depletions in the Ogallala Aquifer

Contract Report

by

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INTRODUCTION

The purpose of this report is to evaluate the assignment of water levels in monitor wells in order to create ground-water depletion maps of the Panhandle Ground Water Conservation District No. 3 (PGWCD No. 3). Ground-water depletion maps document and quantify the decrease in ground-water resources in the PGWCD No. 3 by monitoring the historical lowstand of water levels in the Ogallala aquifer. They are used to assign water-level declines to eligible properties for Federal tax credit. Because area landowners rely on these maps for such assignments and because the maps are used in documenting ground-water resources, the procedures used in their creation should be accurate, fair, and timely. The PGWCD No. 3 currently uses a floating, 5-yr, back-calculated average to guide water-level assignments used in generating ground-water-depletion maps. This approach, however, may significantly underestimate water-level declines in individual wells and may give nonreproducible results from well to well. During this study, we assessed the limitations of this approach, described the complications of assigning water levels, and evaluated alternative approaches to define water levels used in determining depletions more accurately. Our goal was to develop a defensible approach that more accurately represents water levels in the Ogallala aquifer.

This report specifies how water levels should be assigned in monitor wells in order to minimize errors and provide the most hydrologically reasonable, defensible, and accurate water-level declines. A subsequent report will discuss an automated and statistically rigorous method for assigning depletions to individual properties. These reports will allow the PGWCD No. 3 to maximize the quality of the data used in depletion analysis and to minimize the errors and time used in assigning depletions in the district.

CURRENT APPROACH AND LIMITATIONS

The PGWCD No. 3 monitors nearly 400 wells in the Ogallala aquifer each December and January. These water-level measurements are added to a computer data base and filtered by means of a floating, 5-yr, back-calculated average to smooth out variations and fluctuations in order to minimize errors in assigning water-level depletions. This approach involves taking the average of water levels collected in the current year (h_t) and over the previous 4 yr (h_{t-1}) and assigning the average value ($\overline{h}_t$) to the current year:

$$\overline{h}_t = \frac{h_t + h_{t-1} + h_{t-2} + h_{t-3} + h_{t-4}}{5}. \qquad (1)$$

In wells that have fewer than 5 yr of previous water-level measurements, the available data are used to back average the estimate for the current year. For years that have no water-level measurements, the previous five measurements are averaged for the current year. The final water-level assignment is done qualitatively by inspection of the measured and averaged water levels and choosing a value that best represents that year's water level (fig. 1) or the previously measured lowstand (fig. 1c, for water levels measured since 1995). This assignment is then subtracted from the previous year's water-level assignment to determine the drawdown or depletion, if any.

This approach has two significant disadvantages: (1) water-level assignment is subjective and (2) estimates of water-level depletions are inaccurate. Water-level assignments are subjective because they are not consistently applied. For example, some assignments are between measured and averaged water levels (fig. 1a and 1d) and some are assigned at the measured water level (fig. 1b and 1c). Table 1 shows where assigned water levels lie relative to measured and averaged water levels. Assigned water levels are below measured and averaged water levels in 37 percent of the wells. These are wells in which water levels have dropped and have then rebounded above the historical low. Assigned water levels are above measured water levels in 40 percent of the wells.

Estimates of water-level depletion are inaccurate because the floating, 5-yr, back-calculated average under- or overestimates water levels, depending on the trend of the data. Statistically the calculated average should be assigned to the midpoint of the averaging interval, which means that

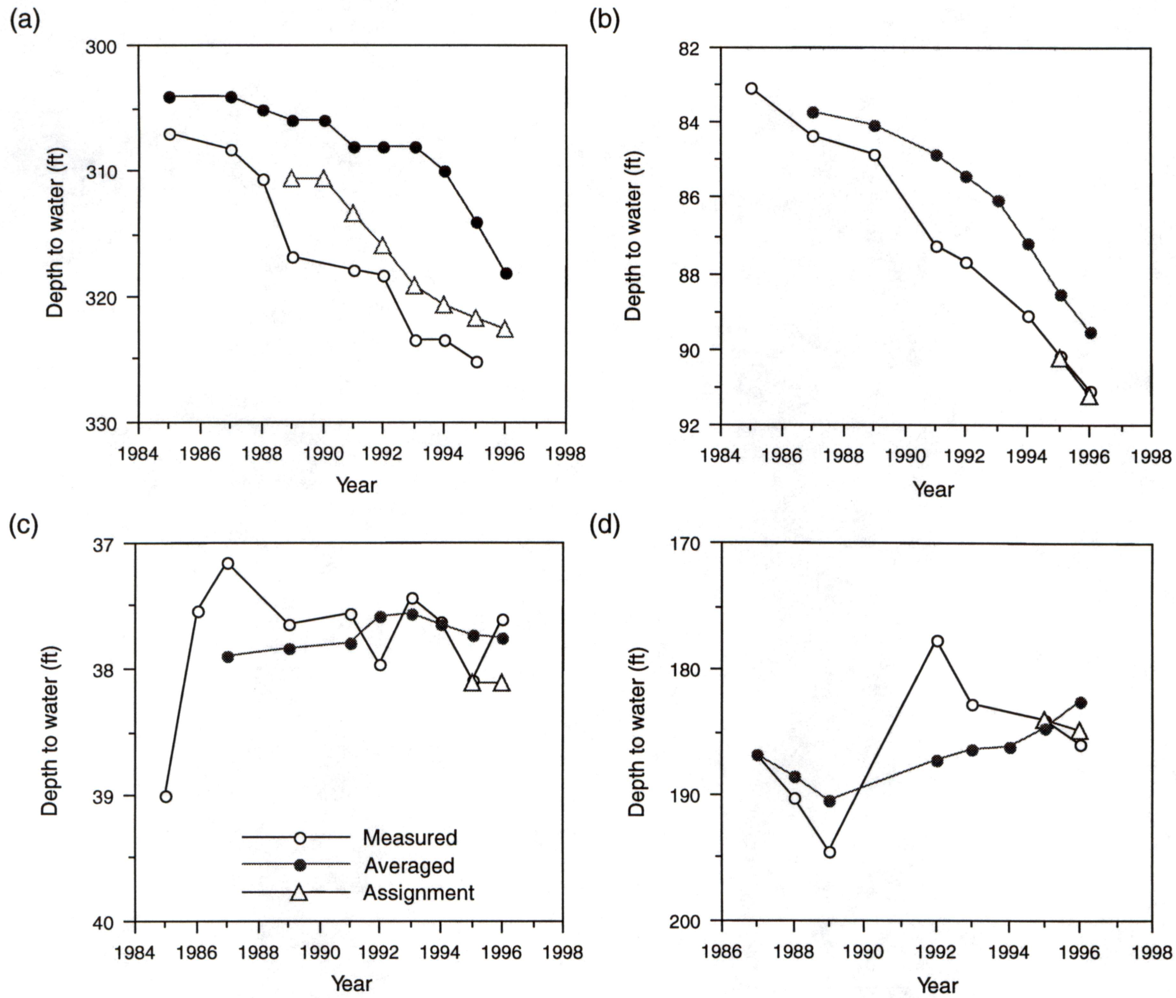

Figure 1. Hydrographs for wells (a) 06-35-602, (b) 03-64-902, (c) 05-03-201, and (d) 05-09-302 from the Panhandle Groundwater Conservation District #3 showing measured, 5-yr averaged, and assigned water levels.

Table 1. Location of assigned water level in relation to measured and averaged water level.

County	On both h_m and h_a	Between h_m and h_a	On h_m	On h_a	Below h_m and h_a	Above h_m and h_a
Roberts	2	14	12	4	19	7
Gray	1	13	2	4	55	17
Donley	1	10	2	12	33	9
Armstrong	2	13	1	18	14	13
Carson	3	32	2	22	21	25
Total	9	82	19	60	142	71

h_m = measured water level
h_a = averaged water level

current-year assignments represent average conditions 2.5 yr ago. This lag results in belated dips and peaks and underestimates of water levels beneath peaks and overestimates of water levels above dips (fig. 2). Another disadvantage of this method is that when a well is infrequently measured, the averaging can extend over several years in order to incorporate the previous five records. This averaging can lead to greater under- and overestimates of water-level fluctuations.

WATER-LEVEL VARIATIONS AND ERRORS

PGWCD No. 3 uses the 5-yr averaging and water-level-assignment procedure to filter large fluctuations in water levels that might occur in wells from year to year. These large fluctuations may be due to measurement errors, recent pumping of the well before measurements were made, and natural variations in water levels owing to hydrologic events. It is important to treat these fluctuations properly so that unrealistically large depletions are not assigned to a property. To characterize water-level fluctuations in the Ogallala aquifer, we made long-term hydrographs of selected wells, calculated annual fluctuations for the entire PGWCD No. 3 data base, and grouped hydrographs of the PGWCD No. 3 monitor wells into those "well behaved" and those "not well behaved."

Water levels in the Ogallala aquifer fluctuate in response to pumping and changes in recharge. Water levels have declined steadily for decades (fig. 3a and 3b) owing to pumping of ground water that exceeds recharge, especially near large pumping centers such as the City of Amarillo Well Field in Carson County and irrigated agricultural areas. Annual variations can be as large as 20 to 30 ft, however, (fig. 3a, 1990 to 1991; fig. 3b, 1993 to 1995). Water levels in wells that have shallow depths to water might be expected to be more susceptible to variations in recharge and to show rapid declines and rises in water levels (fig. 3c). Even wells that have much deeper depths to water, however, can show similar behavior, with large declines and subsequent recovery (fig. 3d). Furthermore, water levels may vary several feet over the course of a year because of seasonal pumping or recharge of the aquifer (fig. 4). These fluctuations must be considered when a water level is assigned to a well and depletions are determined.

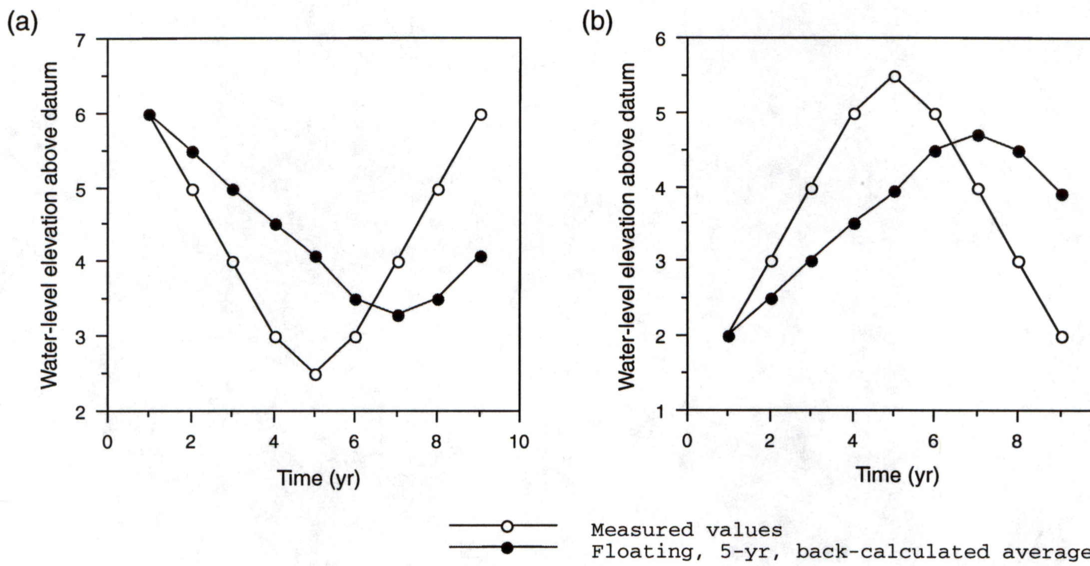

Figure 2. Difference between measured and floating, 5-yr, back-calculated averaged water-level elevations for (a) dip and (b) peak in water level.

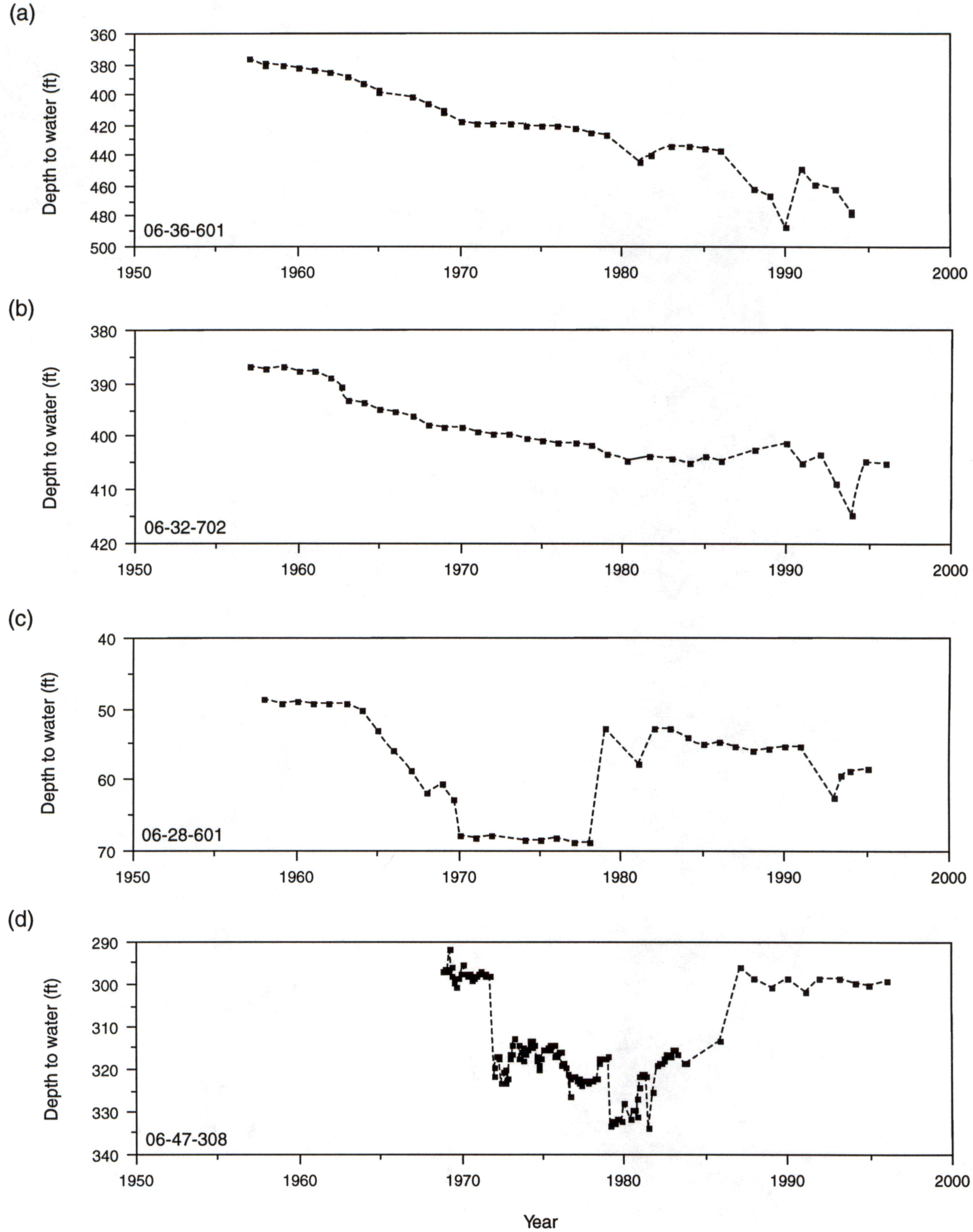

Figure 3. Hydrographs of wells (a) 06-36-601, (b) 06-32-702, (c) 06-28-601, and (d) 06-47-308 in the Ogallala aquifer.

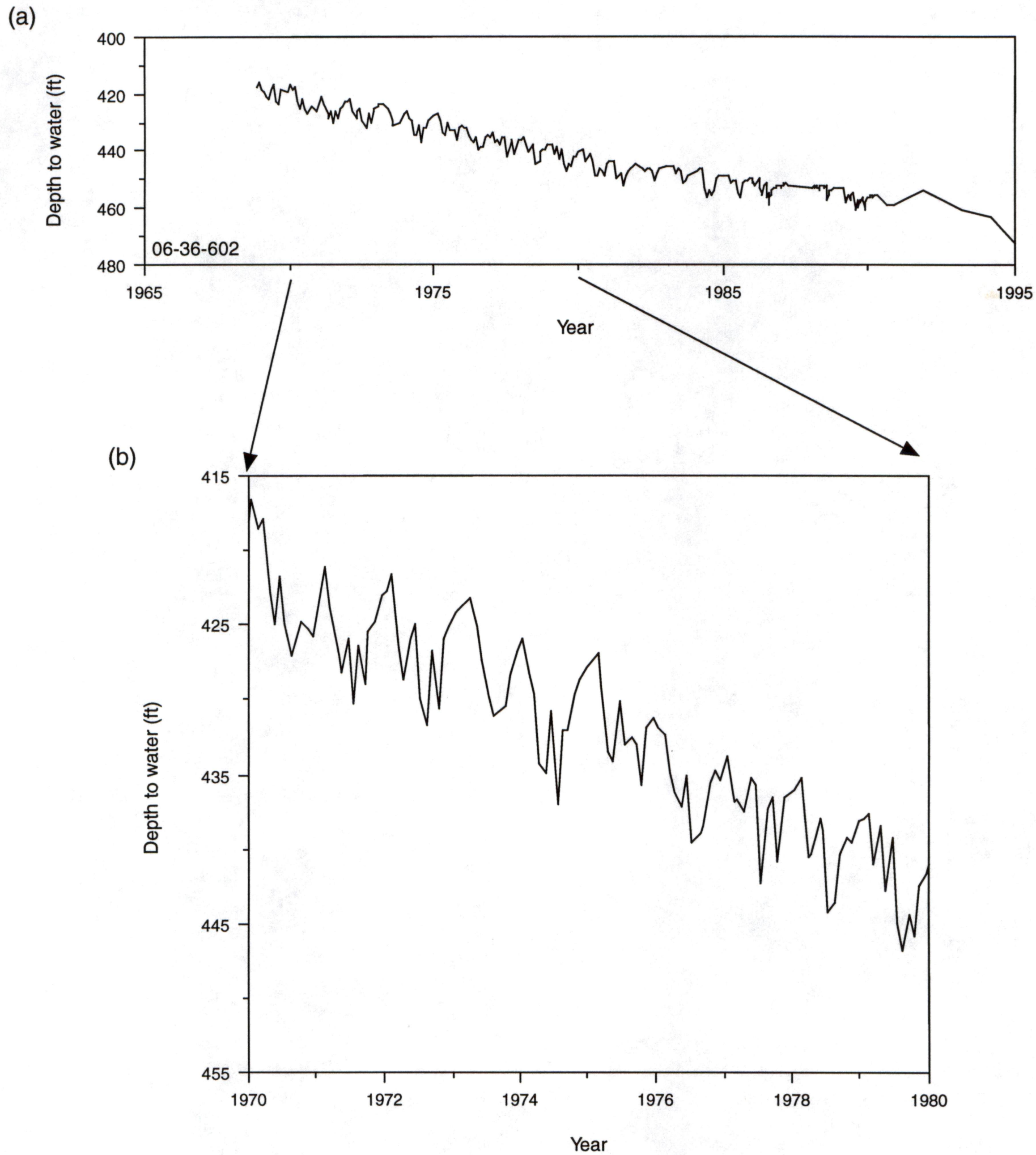

Figure 4. Detailed hydrograph of well 06-36-602 in the Ogallala aquifer showing (a) long-term water-level trend and (b) yearly variations in water level.

To quantify annual water-level fluctuations, we inspected each measurement in the PGWCD No. 3 water-level data base and calculated a water-level change for every pair of measurements separated by 10 to 14 mo. Our final data base included 2,426 year-to-year water-level fluctuations, values going as far back as 1950. Because recent water-level fluctuations might be greater due to more pumping, we looked at water-level changes for years 1994 through 1996 separately. Year-to-year water-level changes appear to be normally distributed, slightly skewed toward negative values (fig. 5). Mean annual water-level change is less than zero (–1.24 ft for 1950 through 1996 and –1.31 ft for 1994 through 1996), reflecting long-term water-level decline. Water-level fluctuations do not appear to be strongly dependent on depth to water, although measurements at depths to water greater than 100 ft appear more variable than those less than 100 ft (fig. 6).

We found decreasing water-level changes to be greater in the post-1993 data and to differ from county to county. Looking only at negative water-level changes (the part of the data in fig. 5 that is less than zero), we calculated 1, 5, 10, 15, 50, and 75 percentiles for all data, values for 1994 through 1996, and values for each county except Roberts County, which had only four data points (table 2). Percentiles represent the percent of data that lies below the water-level decline at that percentile. For example, the tenth percentile for the annual water-level fluctuation in Armstrong County is –8.0, which means that 10 percent of the water levels declined more than 8 ft. The fiftieth percentile, or the median, is greater for the 1994 through 1996 values than for the entire data base since 1950. This most likely reflects increased ground-water pumpage in recent years. Also, water-level declines for any given percentile are generally greater for Carson and Armstrong Counties, in which more pumping has occurred than in other counties. Median values range from –1.28 to –2.51 ft of decline from one year to the next in those wells having declining water levels.

We inspected all hydrographs provided by the PGWCD No. 3 and divided the hydrographs into "well behaved" and "not well behaved" groups. Well-behaved hydrographs were defined as measured water levels that showed steady trends in water levels over the observed record. These included hydrographs that showed smooth year-to-year depletions without large fluctuations (for example, fig. 1a and 1b). Well hydrographs classified as not well behaved had erratic water-level

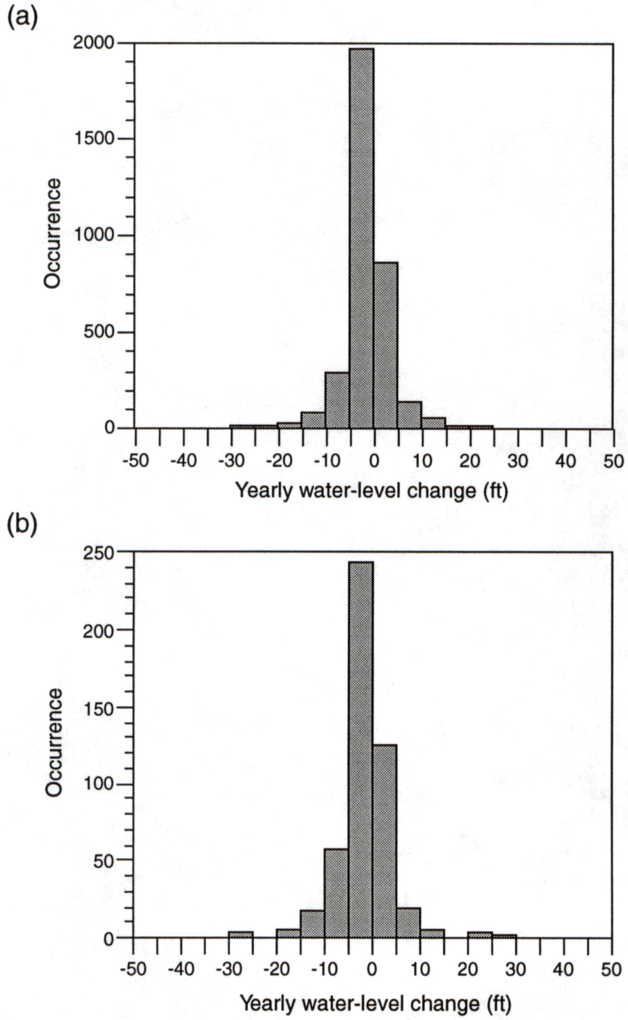

Figure 5. Year-to-year water-level changes in Ogallala aquifer water wells measured in wells from (a) 1950 to 1996 and from (b) 1994 to 1996.

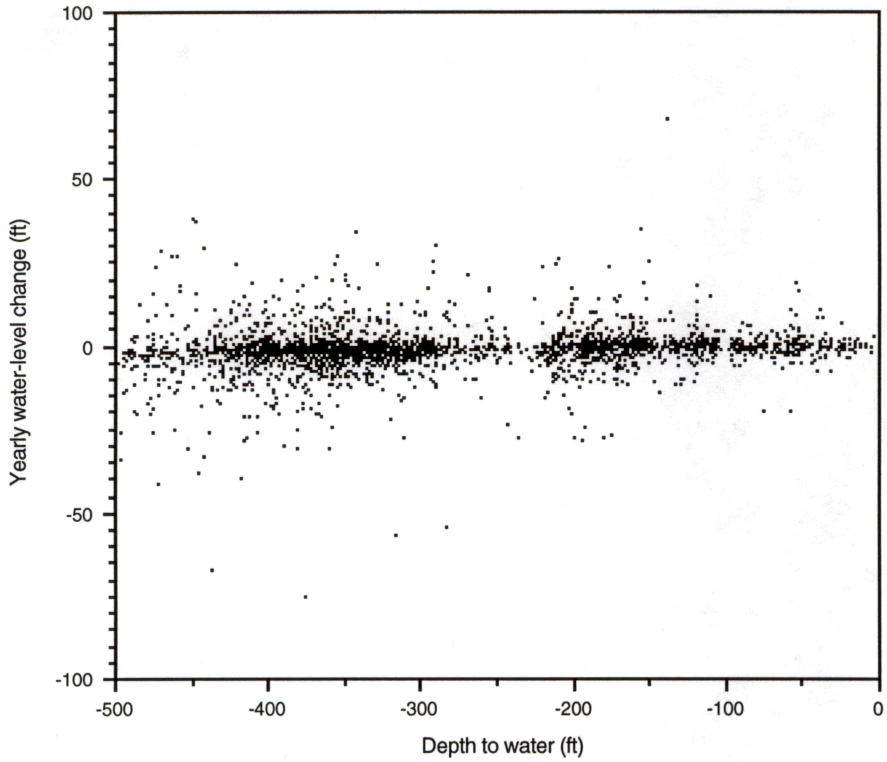

Figure 6. Scatter plot of yearly water-level changes as a function of depth to water.

Table 2. Water-level declines for different years and different counties defined at different percentiles.

Percentile	All values	Values for 1994,95,96	Armstrong County	Carson County	Donley County	Gray County	Potter County
1	–26.18	–26.35	–27.44	–26.18	–19.19	–19.69	–
5	–11.46	–13.90	–10.54	–12.50	–5.80	–10.36	–13.00
10	–7.93	–9.52	–8.00	–8.44	–4.60	–6.97	–5.50
25	–3.94	–5.12	–3.66	–4.16	–3.13	–3.55	–2.85
50	–1.94	–2.51	–1.61	–2.05	–1.44	–1.28	–1.95
75	–0.78	–1.03	–0.63	–0.90	–0.63	–0.45	–1.20
# of values:	2,426	328	493	1,625	91	189	24

Roberts County had only four values: –4.07, –1.33, –0.61, and –0.45 ft.
- = not enough data to define

variations that exceeded a few feet (for example, fig. 1d). Of the PGWCD No. 3 hydrographs, 174 were considered well behaved and 214 not well behaved. In other words, more than half the hydrographs were erratic or not smoothly changing. Any approach that assigns water levels for depletion calculations should carefully account for assignments in wells having erratic hydrographs.

A RECOMMENDED APPROACH

A rigorous approach demands that water-level assignments be reproducible and independent of who makes the assignment. However, the assignment technique must also be able to predict potential errors in water-level measurements and avoid assignment of unrealistic depletions. We recommend that, wherever possible, measured water levels be used to determine ground-water depletions. To minimize errors, we suggest reviewing and repeating measurements in the field, statistically identifying errant measurements, justifying the errant measurement, and assigning provisional water levels until the measured water level is verified. This approach is less subjective and more accurate than the current system. Also, because only those wells with a history of errant water-level measurements receive special attention, this approach should save time and effort in the office. A detailed, step-by-step description of our proposed approach follows.

1. Review of Measurements in the Field

Monitoring technicians should have historical water-level measurements available at the well during annual monitoring surveys. They will thus be able to determine immediately whether a measurement is reasonable, at least in terms of significant deviations from previous years. In extreme cases, if a measurement is off by +/–20 ft from the previous year's measurement, the technician should suspect an error (perhaps the reading was wrong or the line hung up on something in the well). After a measurement is made, the technician should calculate the difference between the current measurement and the previous year's measurement. This difference will be used in the next step.

We recommend that the limit for what is considered a reasonable (or suspect) measurement be defined by the fifth-percentile of the year-to-year water-level measurements defined for each county (table 2). For example, in Donley County, water-level changes less than or equal to 5.8 ft would be considered reasonable and entered into the data base, and water-level changes greater than 5.8 ft would be considered suspect.

For water-level changes greater than the historical fifth-percentile water-level change, the well should be immediately remeasured. If the two measurements agree, then it should be noted that the measurement was verified. If the measurement is different, the well should be measured again to verify the new measurement.

2. Verification of Suspect Measurements

Water-level changes may exceed the fifth percentile because of (1) a consistent error in measurement, (2) recovering water levels due to recent pumping of the well, or (3) a true water-level change due to a hydrologic event or regional water-level declines. Just because a water-level change exceeds the fifth percentile does not necessarily mean that the measurement is in error. For example, wells near the City of Amarillo Well Field may consistently have water-level declines greater than the fifth percentile because of large, local, ground-water withdrawals from the aquifer. If the variation reflects true static water levels in the aquifer, then neighboring wells should also show somewhat similar change. If they do, the measurement should be considered verified and added to the data base. Another piece of evidence to justify a measurement is to inspect the historical behavior of individual hydrographs. For example, if the hydrograph of a particular well has large variations—10 to 20 ft over the past several years for instance (fig. 1d)—then a large fluctuation might be reasonable.

If a well was recently pumped, its water levels might still be recovering at the time of measurement. In this case, the owner/operator of the well should be contacted to establish whether the well was pumped before measurement. The well should be remeasured after 2 weeks of no further use. If an erratic measurement cannot be explained by any of these factors, then the measurement should not be used in the depletion analysis (see following discussion). Reasons for which an erratic measurement could not be justified include: a consistent measurement error, inability to verify whether a well was pumped, and insufficient number of nearby wells to gauge local water-level declines.

3. Assignment of Provisional Water Levels

If the suspect water-level measurement cannot be justified as described earlier, then the water level should be classified as provisional and not used in depletion calculations for that year. In the following year, these provisional wells should be remeasured to assess the validity of the previous year's measurement. If the new measurement agrees or is deeper than the provisional measurement, then the provisional and new measurement should be considered justified, added to the official data base, and used in depletion calculations. Figure 3d shows an example in which 1972 water levels declined more than 20 ft. Perhaps this decline should not have been initially validated and should have been considered provisional until the following year, when the water level would have been found to agree with the provisional measurement. The data then would have been added to the data base and used to determine depletion in the well and the surrounding area.

If the water-level change measured in the new year differs by more than the tenth-percentile water-level change, the provisional water level should be considered questionable and excluded from the data base (marked not publishable). The new measurement should then be compared with the value measured 2 yr previously and verified, if within twice the fifth-percentile water-level decline for the county.

Our recommended procedure uses actual water-level measurements as much as possible, in order to avoid arbitrary assignment of water levels in wells. Potential errors are identified according to a statistical description of historical year-to-year water-level changes calculated for each county. Large water-level declines that cannot be justified by similar declines in neighboring wells or historical water-level changes in a particular well are assigned as provisional and not included in that year's depletion analysis. To do so minimizes the effects of these factors on overall depletion analysis. If the measurements truly reflect declining static water-level conditions in the respective areas, then measurements made the following year should reflect the decline. If they do, the declines will be considered in that year's depletion analysis. The result may be a 1-yr delay in depletion assignments for several properties, but it is necessary to ensure that erroneous assignments are not made in any given year.

Effect on Water-Level Depletions

If the PGWCD No. 3 switches to the recommended procedure, a 1-yr "correction" in water-level depletions would have to occur in order to move currently assigned water levels to the measured values for those wells. On the basis of hydrographs provided by the district, figure 7 shows how currently assigned water levels compare with measured water levels in 1995. If our procedure is used, 223 wells will receive some correction. Most wells will receive a between 0 and 5 ft one-time decline, and about 50 wells will receive more than 5 ft of depletion; the average water-level correction will be 3.64 ft. We did not verify the validity of measured values as compared with previous years' data when we did this analysis. Any correction of current data will require careful inspection of previous water-level data.

CONCLUSIONS

The PGWCD No. 3 monitors water levels in an array of about 400 wells to create water-level-depletion maps for tax purposes. Water-level fluctuations due to true declines and potential measurement errors complicate any procedure for assigning average water-level declines in the aquifer. We reviewed the PGWCD No. 3 current water-level-assignment procedures and found that they could be improved upon by adoption of a less subjective and more accurate approach. We

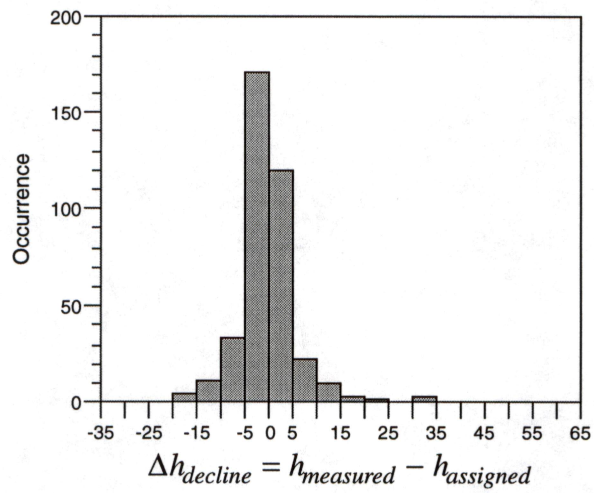

Figure 7. How water levels differ from assigned water level as measured and assigned in 1995. Positive values correspond to measured water levels above the assigned level, and negative values correspond to measured water levels below the assigned water level.

recommend that measured water levels be used to determine ground-water-depletion levels as much as possible. To minimize errors, the PGWCD No. 3 should:

- review water-level measurements in the field,
- statistically identify errant measurements according to the tables provided,
- try to verify the errant measurements, and
- assign a provisional status to water levels until measured water levels are verified.

This approach minimizes the effects of errant measurements on overall depletion analysis. It also bypasses the disadvantages of current procedures and is more hydrologically reasonable, defensible, and accurate. Because only 20 to 40 wells will require the above review, additional cost to the district should be minimal.

A subsequent report will describe a statistically rigorous method for automatically assigning water-level depletions to properties. This method also assesses and minimizes measurement errors in the data. In addition, we will investigate this method for identifying and filtering errors in the data. In any case, the goal of any water-level-monitoring program should be to collect the highest quality data possible. We believe the method that we have outlined will ensure that this goal is met.