PREPARED IN COOPERATION WITH THE
ARIZONA DEPARTMENT OF WATER RESOURCES, METROPOLITAN DOMESTIC WATER IMPROVEMENT DISTRICT, AND TOWN OF ORO VALLEY

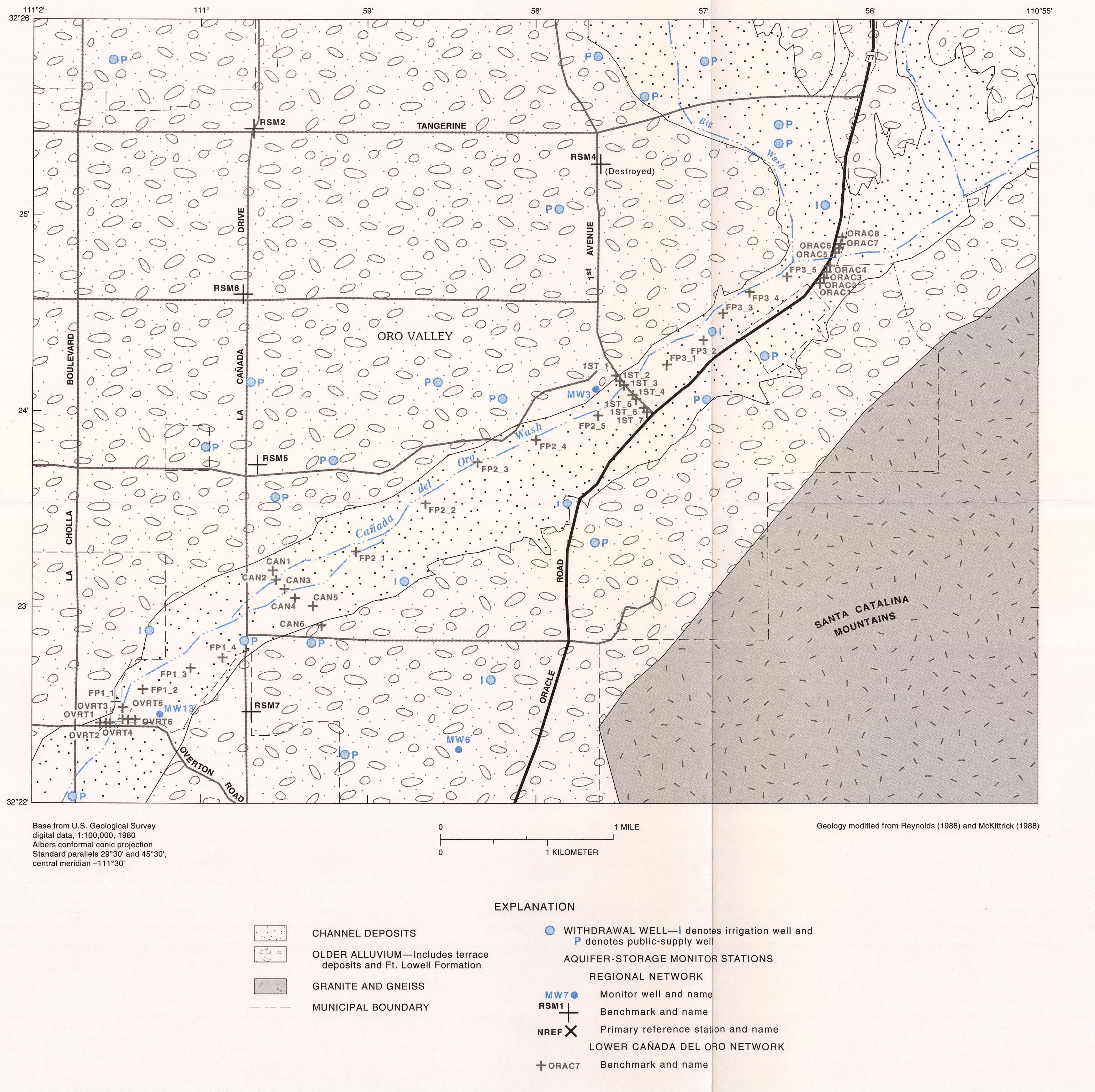

Figure 7. Network of aquifer-storage monitor stations near the Lower Cañada del Oro Wash.

Lower Cañada del Oro Network

A detailed network consisting of 41 gravity stations was constructed along profiles oriented perpendicular and parallel to the Cañada del Oro Wash between Overton Road and Oracle Road (fig. 7). The network was designed to monitor changes in aquifer storage after streamflow infiltration. Most of the stations required construction of a stable monument in the alluvium or on soil cement, which stabilizes the south bank of the wash. Four profiles were constructed perpendicular to the wash near Overton Road, La Cañada Drive, First Avenue, and Oracle Road. Each profile consisted of 6 to 8 stations within several hundred feet of the wash. Profiles parallel to the wash included 14 stations along about 5 mi between the four perpendicular profiles.

Effects of periodic streamflow infiltration and ground-water withdrawals on aquifer-storage change dominate changes in gravity near the Cañada del Oro Wash between Overton and Oracle Roads. Gravity along the northeastern half of the reach decreased from 0.010 to 0.060 mGal during the dry period of February 1996 to November 1997 (fig. 8A) before increasing as much as 0.090 mGal after extensive runoff during 1998 (fig. 8B). In contrast, gravity along the southwestern half of the reach increased as much as 0.020 mGal before 1998; a decrease of about 0.020 mGal near La Cañada Drive may have occurred because of ground-water withdrawals at two nearby public-supply wells (fig. 7). Gravity along the southwestern half of the reach increased an additional 0.020 mGal during February to June 1998. During June 1998 to October 1998, gravity generally decreased as much as 0.050 mGal throughout the reach. Decreases in gravity that occurred along the northeastern half of the reach before November 1997 probably were caused by drainage and withdrawal of ground water that originated as infiltrated streamflow before February 1996. Several public-supply wells are in the area (fig. 7) and withdrawals from these wells probably contributed to the decreases. Increases in gravity that occurred along the southwestern half of the reach before November 1997 may have been caused by downgradient migration of ground water from the northeastern half of the reach.

The spatial distribution of gravity changes near the Cañada del Oro Wash indicate that the channel deposits beneath the wash are an important permeable ground-water reservoir that accepts streamflow infiltration and slowly transmits it to the regional aquifer. On the basis of gravity and water-level data for MW3, gravity changes after winter runoff in 1998 were apparently limited to areas of the channel deposits within the flood plain (figs. 5, 6, 8A, and 8B). MW3 is near the edge of the flood plain but completed within older alluvial sediments. Gravity and water levels at MW3 indicate only a slight response to runoff during 1998; however, gravity increased at nearby gravity stations that are on the flood plain near First Avenue (figs. 7 and 8B). Gravity changes at stations along profiles across the wash were uniform during the investigation, which indicates that the development of a subsurface recharge mound was minimal. Measurable variations in gravity across the wash occurred only along the profiles at First Avenue and Oracle Road shortly after runoff during February 1998.

Overall infiltration into the channel deposits during the winter of 1998 can be estimated by integrating the measured gravity change across the flood plain from November 1997 through June 1998. Increases in gravity along the flood plain ranged from 0 to 0.094 mGal and averaged 0.031 mGal. The total increase in storage across about 1,700 acres of flood plain along the Cañada del Oro Wash between Overton Road and Oracle Road was about 4,000 acre-ft. Total streamflow infiltration probably was somewhat larger because ground water was removed from storage near the flood plain during November 1997 and June 1998 through ground-water withdrawals from wells and ground-water flow away from the area of the flood plain.

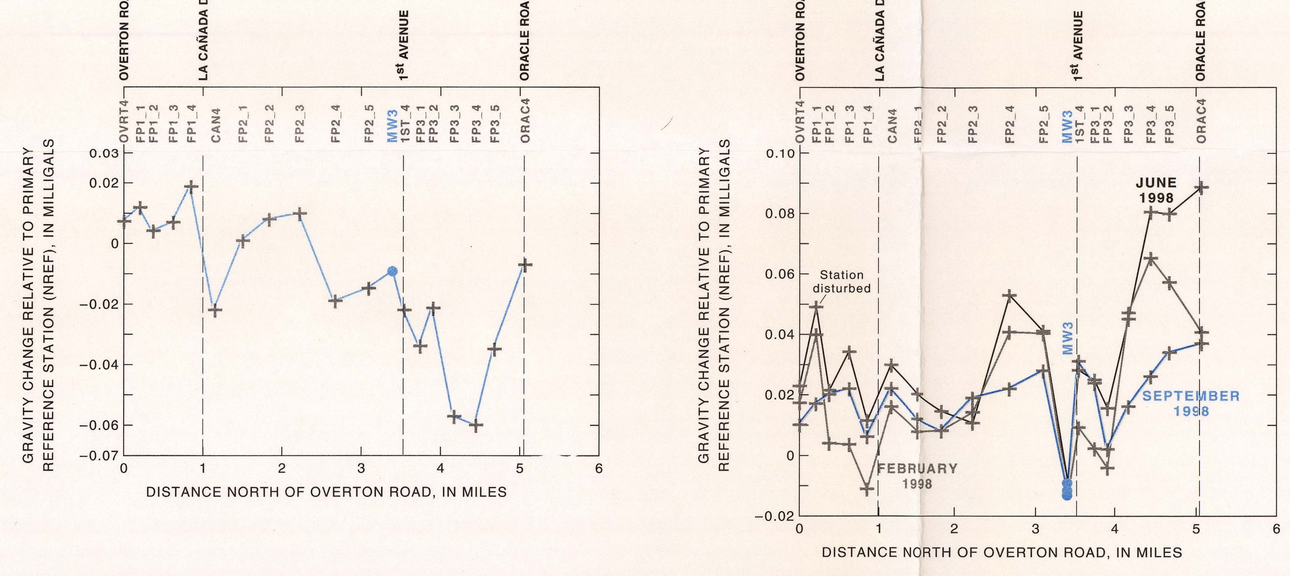

Figure 8. Gravity change along the Cañada del Oro Wash. All stations located on channel deposits within the flood plain except MW3, which is on older alluvial deposits at the edge of the flood plain.

Estimates of Specific Yield

Two gravity methods were used to estimate specific yield. One method applies equation 7 to the correlation of gravity with water levels at monitor wells within the regional aquifer-storage network. The method requires good correlation between water-level and gravity change and that the change in mass of water occurs within a slab of the aquifer that has an infinite extent and uniform thickness within the interval of water-level change. The second method estimates specific yield of the aquifer within the cone of depression around a withdrawal well by dividing the volume of water removed by the volume of the cone of depression. The volume of water removed is estimated by integration of gravity change within the cone of depression across a network of gravity stations using equation 9. The volume of the cone of the depression is determined by the distribution of water-level change around the withdrawal well. Both methods require unconfined ground-water conditions, water levels representative of the water table, and no measurable change in the volume of water in the unsaturated zone or perched aquifers above the water table.

Gravity and water levels were sufficiently correlated at only two monitor wells in the regional aquifer-storage monitoring network for estimation of specific yield (fig. 10). Specific yield of the aquifer in the interval of water-level change was about 0.22 at MW3 and 0.39 at MW7 (fig. 11). Gravity generally decreased at most other monitor wells, but the gravity changes corresponded poorly with water levels, which generally declined. Lack of good correlation could be caused by water levels that are not representative of the water table and changes in the mass of water in the unsaturated zone or perched aquifers. Water levels in wells may not be representative of the water table because of multiple perforated intervals that are open to several aquifers. Changes in the mass of water stored in the unsaturated zone or perched aquifers may have occurred at several monitor wells (MW6, MW9, MW10, MW11, and MW13) where large variations in gravity were measured (fig. 6). The general lack of correlation of gravity and water levels is consistent with results at wells with deep water levels near Rillito Creek during 1993 (Pool and Schmidt, 1997). Good correlation between gravity and water level is more likely where well depths and depth to water are shallow.

A network of 11 gravity stations was constructed near two withdrawal wells, Magee and Matter, operated by Metropolitan Domestic Water Improvement District near the intersection of La Cholla Boulevard and Magee Road to estimate the specific yield of the aquifer within the cone of depression surrounding the withdrawal wells (fig. 9). Water levels were continuously monitored in an observation well near the Magee well (OB1; fig. 11), and gravity at the network of stations was surveyed relative to gravity at the primary-reference station WREF at intervals of 3 to 21 days from July through November 1998. Gravity stations were distributed at distances of 15 to 2,500 ft from the withdrawal wells. Two stations, OB1 and LACH, were near the Magee well at distances of 15 and about 40 ft, respectively. Nine of the stations were distributed along two perpendicular profiles. The profiles lie west to east along Magee Road (stations MAG1 through MAG4), and north to south along La Cholla Boulevard (stations LACH4 through LACH1). Station LM1, at the intersection of the two profiles and Magee Road and La Cholla Boulevard, was a local reference station directly tied to primary reference station WREF. Three additional stations (RSM9, MW5, and MW13) that were part of the regional aquifer-storage monitoring network also were surveyed to monitor background conditions in the regional aquifer.

Pumps in the withdrawal wells cycled on and off over a period of several hours. Rates of ground-water withdrawal were about 600 gal/min at the Magee well and 450 gal/min at the Matter well. The wells were used as primary and secondary wells. The secondary well was pumped when the rate of withdrawal from the primary well was insufficient to meet demand. The Magee well was the primary well before the middle of October, and the Matter well was the primary well after the middle of October.

Depth to water at the observation well varied by about 25 ft as pumps in the withdrawal wells cycled on and off (fig. 11). Maximum depth to water ranged from about 327 to 332 ft below land surface while the Magee well was being pumped. Water levels recovered following each pumping cycle to 305 to 308 ft below land surface and tended to decline during the period of low precipitation during August to the middle of October. Water levels tended to recover as much as 1 ft following periods of precipitation because of reduced water demand and reduced rates of ground-water withdrawal.

Gravity at the network of stations near the two withdrawal wells and water levels in the observation well did not display any apparent trends related to ground-water withdrawal and the development of a cone of depression during July through November 1998 (fig. 12). Specific yield could not be estimated because of insufficient development of a cone of depression. The standard deviation of individual measurements of the difference in gravity between each station and gravity at WREF ranged from about ±0.002 to ±0.008 mGal. Trends in gravity change at each station were insignificant on the basis of best-fit linear trends to the data, which resulted in total gravity change during the 4 months of surveys that was within the standard deviation of the individual measurements. Variations from a linear trend in gravity at each station generally were within the standard deviation of the measurements. Significant deviations from linear trends occurred at MW13 and MW5 during August and September and at LACH2, LACH3, and LACH4 during October and November. Possible causes of the deviation from a linear trend include lateral migration of recharge pulses through the aquifer system or unsaturated zone or complicated changes in aquifer storage resulting from changes in ground-water withdrawals. Any subsurface changes in storage that may have affected gravity at LACH2, LACH3, and LACH4 also would have caused changes at other nearby stations; however, the net effect at other stations may have been a stabilization of the declining trend in gravity and water levels during September through November. The general stability of water levels and gravity near the withdrawal wells during the period of investigation indicate that withdrawals were nearly in equilibrium with ground-water flow from surrounding areas. Equilibrium conditions would not normally be expected; however, recharge that occurred during 1998 may have provided sufficient inflow of ground water into the area to temporarily balance the local ground-water budget near the wells.

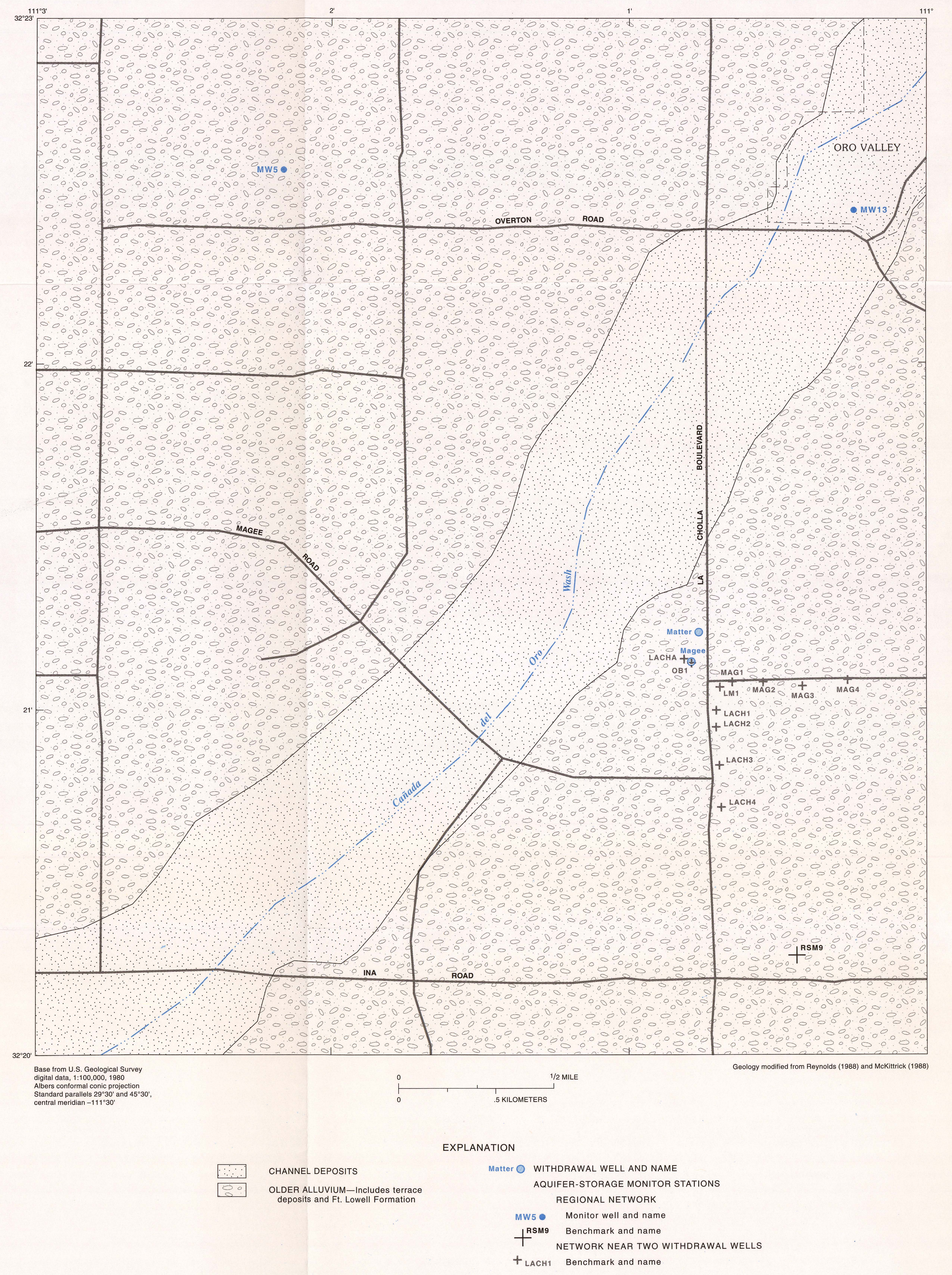

Figure 9. Network of aquifer-storage monitor stations near two withdrawal wells.

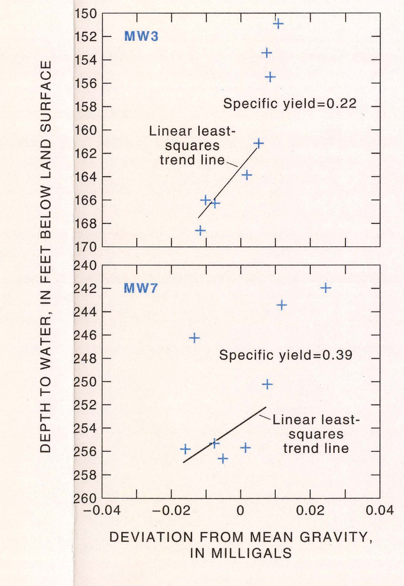

Figure 10. Gravity and water-level relations at selected monitor wells, February 1996 through September 1998. Linear least-squares fit line represents trends for data collected during July 1997 through November 1998.

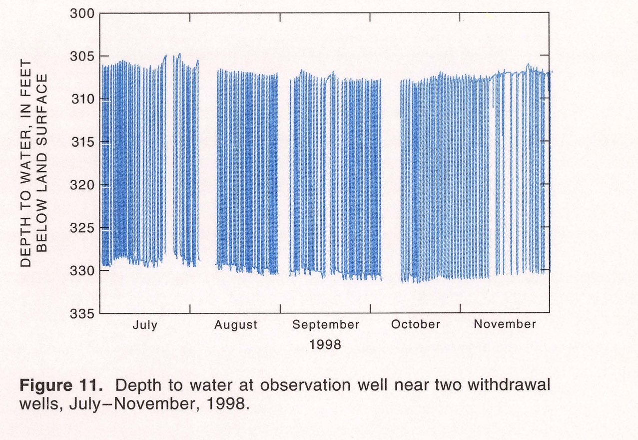

Figure 11. Depth to water at observation well near two withdrawal wells, July–November, 1998.

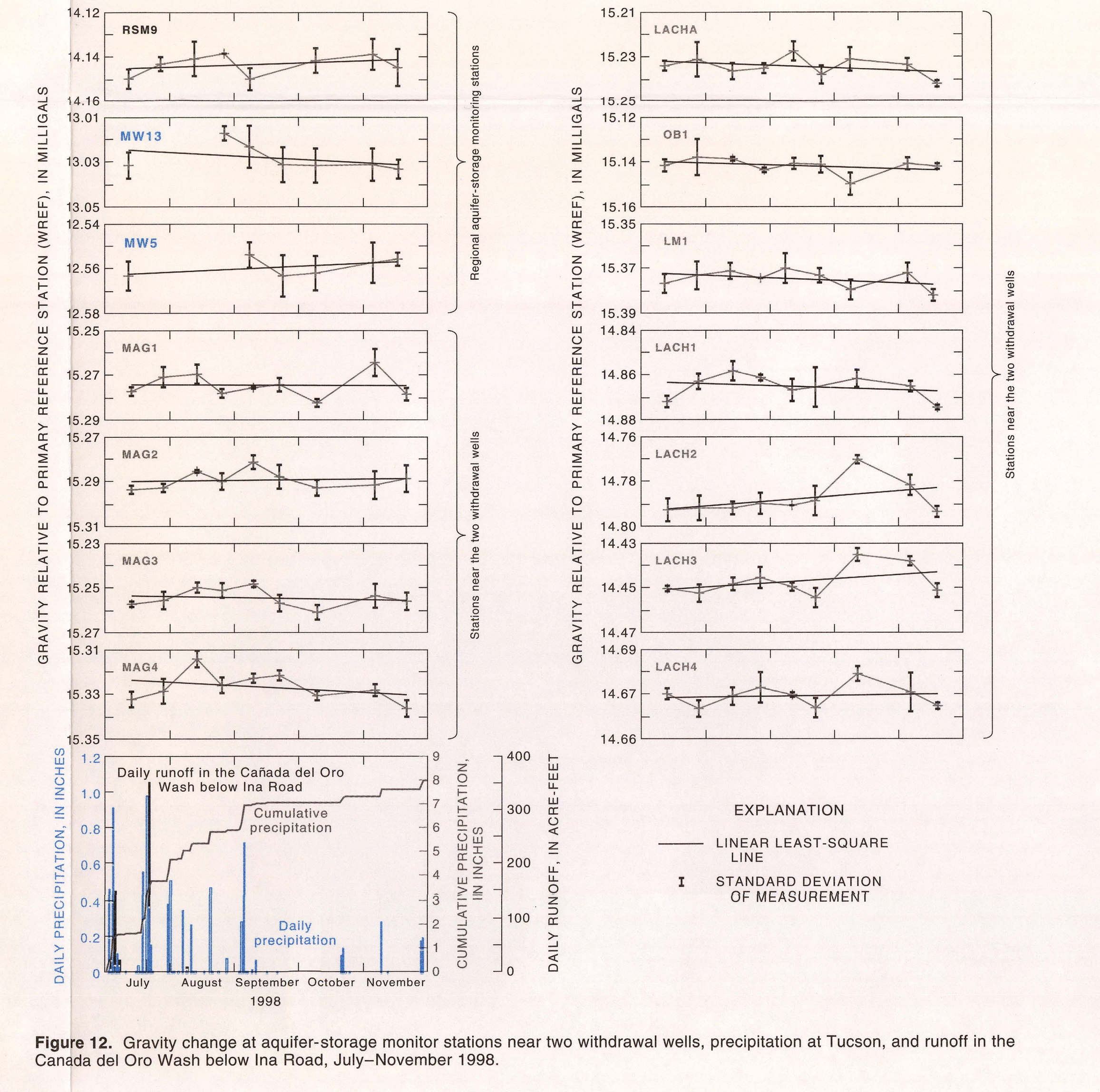

Figure 12. Gravity change at aquifer-storage monitor stations near two withdrawal wells, precipitation at Tucson, and runoff in the Cañada del Oro Wash below Ina Road, July–November 1998.

SUMMARY AND CONCLUSIONS

Gravity methods were used to estimate aquifer-storage change and specific yield in the Lower Cañada del Oro subbasin from February 1996 through October 1998. A regional network of 22 gravity stations including 13 monitor wells was designed to monitor changes in aquifer storage across an area of about 50 mi². A network of 41 closely spaced gravity stations near the Cañada del Oro Wash was designed to monitor changes in aquifer storage after streamflow infiltration. A network of 11 closely spaced gravity stations was constructed near 2 withdrawal wells to estimate the specific yield of the aquifer within the cone of depression surrounding the withdrawal wells. Gravity at stations in the regional and Cañada del Oro Wash networks was surveyed on a quarterly basis relative to gravity at three primary-reference stations on or near crystalline rock where change in aquifer storage and gravity was expected to be minimal. Gravity at the network near the withdrawal wells was surveyed repeatedly from July through November 1998 relative to gravity at one primary-reference station.

Drought and losses in aquifer storage dominated the period of investigation before February 1998. Above-normal precipitation during 1998 resulted in increased aquifer storage along the Cañada del Oro Wash and near the Santa Catalina Mountains. Water levels in wells generally declined and gravity generally decreased at greater rates before February 1998. Significant variations in gravity at several stations indicate the occurrence of nearby recharge and changes in the subsurface storage of water. The gravity variations generally were large in comparison to water-level changes in monitor wells, which resulted in a poor correlation of gravity and water levels at most monitor wells. Causes of the poor correlation may be water levels that are not representative of the water table and changes in the storage of water in the unsaturated zone or perched aquifers. Surveys of the regional network indicated that losses in aquifer storage occurred at a rate of about 9,500 acre-ft/yr from July 1997 through September 1998, which is slightly less than the ground-water deficit estimated using water-budget calculations. Losses were greatest at the west and northeast margins of the study area.

Surveys of the network near Cañada del Oro Wash indicate that channel deposits that underlie Cañada del Oro Wash are an important permeable reservoir that accepts and slowly transmits infiltrated streamflow to the regional aquifer. Aquifer storage in the reach of the Cañada del Oro Wash above about La Cañada Drive was changing throughout the period of investigation because of periodic recharge and ground-water withdrawals. Aquifer storage in the reach declined before February 1998, recovered after precipitation and streamflow in February, and resumed a declining trend as ground water was withdrawn by wells and gradually flowed away from the network of gravity stations from July through November 1998. Recharge during 1998 resulted in an increase of about 4,000 acre-ft of water stored within the channel deposits beneath the flood plain.

Specific yield of the aquifer was estimated at two monitor wells where decreases in gravity correlated with water-level declines. Specific yield of the aquifer in the interval of water-level change was about 0.22 near MW3 and 0.39 near MW5. Specific yield of the aquifer near a pair of withdrawal wells could not be estimated by using repeated surveys of a network of gravity stations from June through November 1998 because of insufficient changes in gravity and water level. The general stability of water levels and gravity near the withdrawal wells indicates that withdrawals were in equilibrium with inflow of ground water from surrounding areas during the period of investigation. Growth of a cone of depression may have been minimized temporarily by increased inflow of ground water that resulted from recharge during 1998.

REFERENCES CITED

Anderson, S.R., 1988, Potential for aquifer compaction, land subsidence, and earth fissures in the Tucson basin, Pima County, Arizona: U.S. Geological Survey Hydrologic Investigations Atlas, HA-713, 3 sheets.
Cole, K.C., 1990, Estimation of mass flux and aquifer properties using global-positioning system and micro-gravity in the Tucson Basin, southern Arizona: Tucson, University of Arizona doctoral dissertation, 193 p.
Davidson, E.S., 1973, Geohydrology and water resources of the Tucson Basin, Arizona: U.S. Geological Survey Water-Supply Paper 1939-E, 81 p.
Hanson, R.T., and Benedict, J.F., 1994, Simulation of ground-water flow and potential land subsidence, upper Santa Cruz basin, Arizona: U.S. Geological Survey Water-Resources Investigations Report 93-4196, 47 p.
Longman, I.M., 1959, Formulas for computing the tidal acceleration due to the moon and sun: Journal of Geophysical Research, v. 64, no. 12, p. 2351–2355.
McKittrick, M.A., 1988, Surficial geologic maps of the Tucson metropolitan area: Arizona Geological Survey Open-File Report 88-18, 5 p.
Montgomery, E.L., 1971, Determination of coefficient of storage by use of gravity measurements: Tucson, University of Arizona doctoral dissertation, 144 p.
Montgomery and Associates, 1995, Hydrogeologic investigation for assured water supply, Metropolitan Domestic Water Improvement District, Pima County, Arizona: Tucson, Montgomery and Associates consultant's report, 2 volumes.
National Weather Service, Tucson office, monthly climate reports, 1995–1999: accessed January 2, 1999, at URL http://www.wrh.noaa.gov/Tucson/climate/climo.html/
Pool, D.R., and Eychaner, J.H., 1995, Measurements of aquifer-storage change and specific yield using gravity surveys: Ground Water, v. 33, no. 3, May-June 1995, p. 425–432.
Pool, D.R., and Schmidt, Werner, 1997, Measurements of ground-water storage change and specific yield using the temporal-gravity method near Rillito Creek, Tucson, Arizona: U.S. Geological Survey Water-Resources Investigations Report 97-4125, 30 p.
Remondi, B.W., 1985, Global Positioning System carrier phase—Description and use: Rockville, Maryland, National Oceanic and Atmospheric Administration Technical Memorandum NOS NGS-42, 21 p.
Reynolds, S.J., 1988, Geologic map of Arizona: Arizona Geological Survey Map 26, 1 sheet.
Telford, W.M., Geldart, L.P., and Sheriff, R.E., 1990, Applied geophysics, 2d ed.: Great Britain, Cambridge University Press, 770 p.
Zohdy, A.A.R., Eaton, G.P., and Mabey, D.R., 1974, Application of surface geophysics to ground-water investigations: U.S. Geological Survey Techniques of Water Resources Investigations, book 2, chap. D1, 116 p.

AQUIFER-STORAGE CHANGE NEAR THE LOWER CAÑADA DEL ORO WASH AND ESTIMATES OF SPECIFIC YIELD

AQUIFER-STORAGE CHANGE IN THE LOWER CAÑADA DEL ORO SUBBASIN, PIMA COUNTY, ARIZONA, 1996–98

By D.R. Pool