Groundwater

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Objectives

Quantifying and documenting groundwater resources, understanding effects of human activities on groundwater resources, understanding seasonal characteristics of groundwater flow regimes within the monument, understanding the response of groundwater storage to climate changes, providing data required for identifying long-term trends in groundwater availability and threats to surface waters.

Introduction

Groundwater is a prized resource at Organ Pipe Cactus National Monument (OPCNM). In addition to supporting plant life and supplying park facilities with potable water, groundwater is the source for important perennial surface water bodies including the Quitobaquito Springs and Pond complex, Williams Spring, Dripping Springs and Spring Arroyo Tinaja #2.

A total of ten wells are monitored quarterly by park staff for depth-to-water. Occasional monitoring occurs at park water supply wells. In the case of Pozo Salado well and Dowling Ranch well, measurement of depth to water is no longer possible due to obstruction or collapse within the well casing. Other wells, including Pozo Nuevo well and Hocker well, are of limited use at this time because water levels have declined below the bottom of the wells at these locations. Table 13-1 summarizes pertinent data for the wells discussed in this report. Locations of the wells included in the following discussion are indicated on Figure 13-1. Figure 13-2 illustrates the well locations relative to bedrock outcrop and alluvial surface geologic material.

Groundwater levels reflect water stored in void spaces between rock grains and in fractures. Volume of groundwater stored in the subsurface depends on porosity (void space) of the geologic host media, which may vary from near zero for dense igneous rocks to as high as 60% for very fine-grained sediments. Geologic conditions at OPCNM are typical of the Basin and Range geologic province, characterized by higher permeability, higher porosity alluvial deposits thickest in basin centers and thinning to the edges. The basins are bounded by mountainous uplands generally consisting of dense rock with lower porosity and permeability than the alluvium. The discussion of water levels that follows is based on this geologic paradigm.

In recent decades, research related to groundwater recharge in the arid desert regions of the Basin and Range province has greatly advanced our understanding of hydrologic processes in arid locations like OPCNM. (Hogan et al., 2004). The importance of mountain-front recharge as a predominant source of groundwater recharge to desert basins has been reinforced by determinations that where desert vegetation is present, virtually no deep percolation (recharge) occurs in basin areas away from ephemeral channels (Walvoord and Scanlon, 2004). Within basins, recharge is now understood to occur almost exclusively beneath ephemeral channels during flow events.

The following sections report monitoring results and provide brief overview interpretations of the data. The interpretations are of a general nature and are primarily based on the location of wells within the geologic setting at OPCNM. Detailed review of local geology, well geologic logs, and other pertinent data for each well where available is beyond the scope of this report. Along with graphs of depth to water at the wells, monthly total precipitation and cumulative precipitation derived from hourly data collected at the nearest climate station are plotted where available. Using

Figure 13-1. Location of monitoring wells, rain gauges and weather stations at Organ Pipe Cactus N.M.

regression analysis, trend lines were fitted to water level and monthly total precipitation data for the purpose of assessing long-term trends in the data.

When reviewing the plotted water level data and trend lines, it should be kept in mind that increasing depth to water, as plotted, indicates decreasing water level elevation. Trend lines, reported as regression coefficients, are reported in the figures and in Table 13-2 as feet per day for depth to water and as inches per month per day for monthly total precipitation. In the text discussion, regression coefficient values are reported as feet/year and inches/month/year for convenience.

Results

Alamo Wash Well

Alamo Wash Well (Alamo) is a 17-foot deep well located in a steep drainage on the west side of the rugged Ajo Mountain Range (Figures 1 and 2). Bedrock in the immediate area is volcanic in origin. Water levels as depth to water measured at Alamo Wash well are shown in Figure 13-3. The Alamo Canyon (ALAM) rain gauge is located nearby. Surface waters in Alamo Wash flow northwesterly toward Cherioni Wash. There are no known sources of anthropogenic groundwater extraction currently occurring in the vicinity of this well.

The period of record for Alamo extends from January 1987 to July 2005. As Figure 13-3 illustrates, depth to water at this well has varied between 12.7 feet and 1.7 feet over the period of record, a range of 11.0 feet. Also shown in Figure 13-3 are monthly total precipitation recorded at the nearby rain gauge (ALAM) and cumulative precipitation at that station over the precipitation monitoring period. Variability in water levels at this location is attributed to episodic down-gradient flow of precipitation infiltrated above the well within the substantial Alamo Wash watershed. The highest water levels in the well occur consistently in winter or spring, although some years do show water level increases of a lesser magnitude following the monsoon season. While an in-depth analysis is beyond the scope of this report, the availability of extended climatic, vegetation and water level data at this location is potentially useful for the analysis of mountain-front recharge at this location. Relationships between the duration and intensity of precipitation events and the effects of evapotranspirative demand on recharge are not well established for arid regions. Such an analysis would be of significant value in improving estimates of recharge to basins in arid regions. Results would have potentially wide applicability to the development of water balance components for arid region mountain-basin systems.

Regression coefficients for depth to water and monthly total precipitation at Alamo Wash well and Alamo Canyon rain gauge are shown on the lower graph in Figure 13-3. Regression coefficients for water levels at all wells and monthly precipitation data discussed here are summarized in Table 13-2. The coefficients shown on Figure 13-3 indicate that over the period of record, water levels have decreased at a rate of about 0.01 feet per year. Monthly total precipitation at the nearby rain gauge has decreased at a rate of 0.01 inch per month per year over the period shown in Figure 13-3.

Bates Well

Bates Well is a 67-foot deep well located in the alluvium of Growler Wash, west of Growler Pass on the former Bates ranch property (Figure 13-1). Bedrock in the area consists of intrusive and extrusive igneous rock types, with the Growler Mountains to the north and the Bates Mountains to the south and east. The primary source of groundwater in this area is most likely recharge originating as precipitation in the Growler Mountains. Subflow beneath Cherioni and Cuerda de Leña washes may contribute to groundwater at this location via Growler Wash. There are no known sources of anthropogenic groundwater extraction in the vicinity of this well.

Depth to water at Bates Well and monthly total

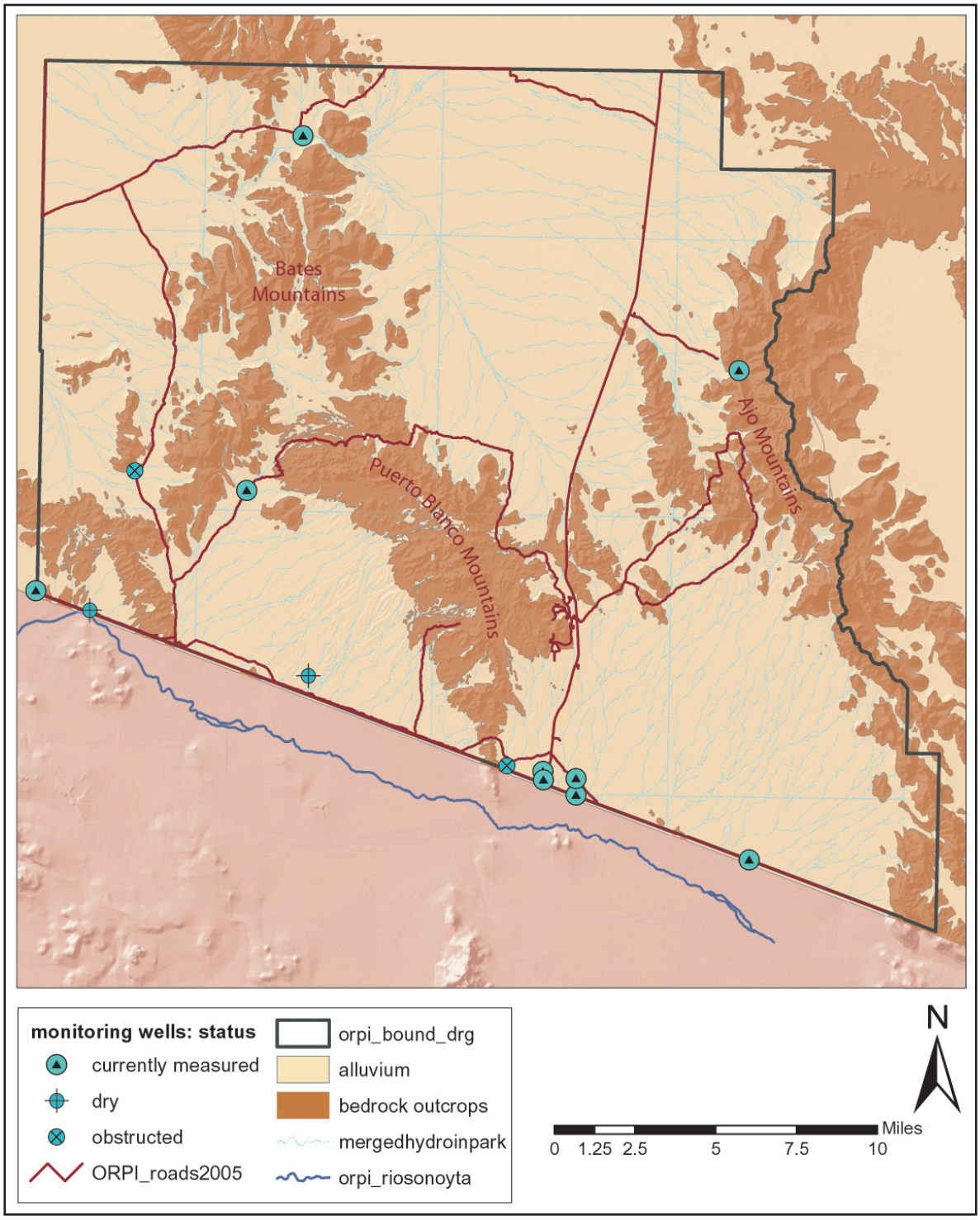

Figure 13-2. Monitoring well locations and geologic context, Organ Pipe Cactus N.M.

Table 13-1. Summary of well names and selected data, Organ Pipe Cactus N.M. (*the ADWR Wells 55 registry lists multiple wells with the same name. Unsure which is correct for this well at this time; *Groundwater drainage basins from NPS (1992), Figure 5.)

Well Name	Surface Elevation (ft)	Total Depth Well/Hole (ft)	Well Identifier (USGS and ADWR systems)	Well Location Hydrologic Unit Code (HUC)/ Groundwater Drainage Basin*
Alamo Canyon	~2,430(est)	17/21	ADWR 629154/ ADWR 632184*	San Cristobal Wash 15070203/ Valley of the Ajo
Bates	~1,350(est)	67/80	ADWR 629121/ ADWR 629122/ ADWR 632186*	San Cristobal Wash 15070203/ West of Bates Mountain
Pozo Nuevo	~1,260(est)	134/170	ADWR 629152/ ADWR 632185*	San Cristobal Wash 15070203/ West of Bates Mountain
Bonita	1,355	37/40	USGS 320115112573001 C-16-07 27BAD UNSURV ADWR 629153	Rio Sonoyta 15080102/West of Sonoyta Valley
Corner	1,000	97/101	USGS 315743113050201 C-17-08 09ADD UNSURV	Rio Sonoyta 15080102/West of Sonoyta Valley
Dowling	1,432		USGS 315315112501002 C-18-06 01DBB2	Rio Sonoyta 15080102/Sonoyta Valley
Hocker	981	18/18.7	USGS 315712113032101 C-17-08 11DCD UNSURV	Rio Sonoyta 15080102/West of Sonoyta Valley
Kalil	1,390	187	USGS 315254112490201 C-18-05 06DCD	Rio Sonoyta 15080102/Sonoyta Valley
Stack	1,405	206 (?)	USGS 315313112490701 C-18-05 06DBB	Rio Sonoyta 15080102/Sonoyta Valley
USGS #1 Camino Dos Republicas	1,400	250	USGS 315257112475301 C-18-05 05DDC	Rio Sonoyta 15080102/Sonoyta Valley
USGS #2 Lukeville	1,390	238/250	USGS 315232112475501 C-18-05 08ACA	Rio Sonoyta 15080102/Sonoyta Valley
USGS #3 Salsola	1,460	278/300	USGS 315056112424301 C-18-04 19AAC UNSURV	Rio Sonoyta 15080102/Sonoyta Valley
Headquarters #4 (South Well)	1,665	400/430	USGS 315655112480301 C-17-05 17ACB UNSURV ADWR 629089/ ADWR 632188	Rio Sonoyta 15080102/Sonoyta Valley
Headquarters #5 (North Well)	1,660	420	USGS 315702112480401 C-17-05 17ABC2 UNSURV ADWR 629090/ ADWR 632182*	Rio Sonoyta 15080102/Sonoyta Valley

precipitation recorded at the nearby Growler Valley rain gauge (1982-1987) and climate station (1987-2004) are shown in Figure 13-4. The period of record at Bates Well extends from January 1987 to July 2005. Over the monitoring period water levels have fluctuated over a range of 16.2 feet, with depth to water at Bates Well varying between 42.9 ft and 26.7 ft below the measuring point. Water levels at Bates well are generally higher (smaller depth to water) following the monsoon season and extending through the winter months, declining during the summer.

Groundwater levels here are sustained by subflow from recharge in the nearby watershed. Localized groundwater flow between the Valley of the Ajo and the west side of the Bates Mountains may occur beneath the wash that flows through Growler Canyon but is unlikely on a larger scale. As shown in Figure 13-4, an extended water level decline at Bates well began in January of 1991 and has continued with minor reversals to the current time. The rate of water level decline at this location is 0.7 feet/year, while the decline in monthly total precipitation at the nearby station has been only 0.03 inches/month/year.

Water levels at Bates well are currently the lowest recorded since the start of monitoring (highest depth to water). This long-term trend of decreasing water levels should be of concern to resource managers due to the accelerated rate of decline compared to other similarly situated wells (such as Bonita and Pozo Nuevo wells) and the unexplained nature of the decline. One potential cause of decreased groundwater availability at this location that should be investigated is the impact of diversion of surface flows by entrenchment of the Bates Well Road on infiltration in the watershed, both east and west of Growler Pass.

Since this well is the only long-term groundwater monitoring point in the northwestern quadrant of the park, and taking into account the observed decline of water levels, monitoring data from Bates well is considered to be extremely important to understanding long-term ecological function of the area. In particular, where depth to water in the well vicinity during the late 1980's and early 1990's may have been sufficient to marginal for the support of riparian trees, current depths to water at Bates well most likely exceed the ability of many woody species to survive.

Regression coefficients for depth to water at Bates well and monthly total precipitation at Growler Valley rain gauge/climate station are shown in the lower plot of Figure 13-4. These will be discussed in a later section.

Bonita Well

Bonita well is a 37-foot deep well located in the alluvium of Aguajita Wash east of the Cipriano Hills and west of the Puerto Blanco Mountains (Figure 13-1). Local bedrock is of volcanic origin. This well is the northwestern control point for understanding groundwater flow beneath La Abra Plain, the source waters for a very key natural resource, the Quitobaquito Spring and Pond complex. As such, water level data from this location are of especially great importance.

Depth to water at Bonita well and precipitation data from the Pozo Nuevo rain gauge and climate station are shown in Figure 13-5. The period of record at Bonita well extends from January 1987 to July 2005. During this time period, maximum depth to water was 33.7 feet and minimum depth to water was 25.0 feet, for a total range of 8.7 feet. Regression indicates that water levels at this location have declined about 0.2 feet/year during the period of record, while monthly total precipitation has declined 0.03 inches/month/year.

The quarterly monitoring indicates that the contribution of summer precipitation to groundwater at this location is substantial, with annual maximum water levels often occurring in October. This result highlights the importance of ephemeral channel and/or mountain front recharge during the summer monsoon period along Aguajita Wash to water levels at this

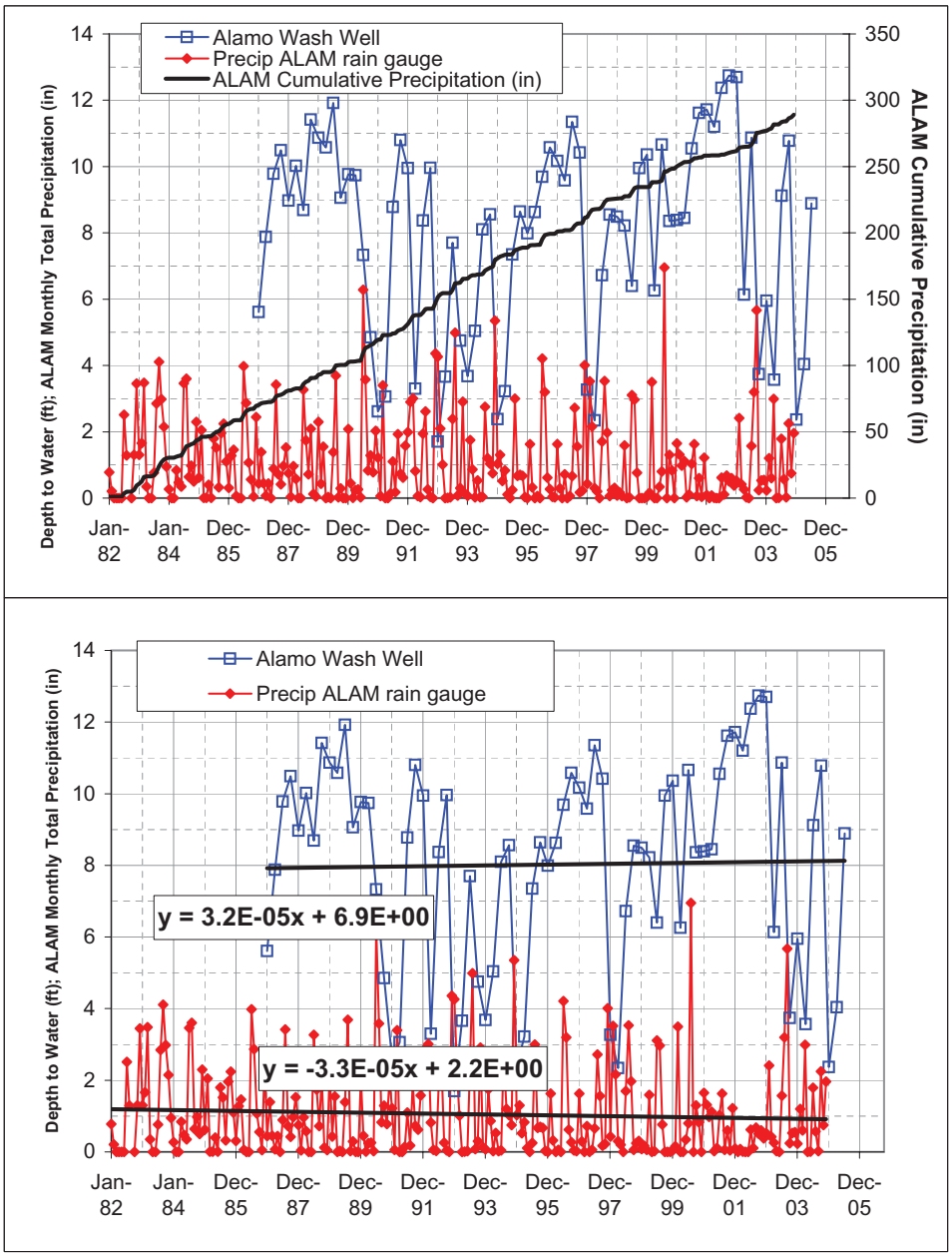

Figure 13-3. Alamo Wash well depth to water, Alamo Canyon rain gauge monthly total and cumulative precipitation data, and regression equations for each, Organ Pipe Cactus N.M.

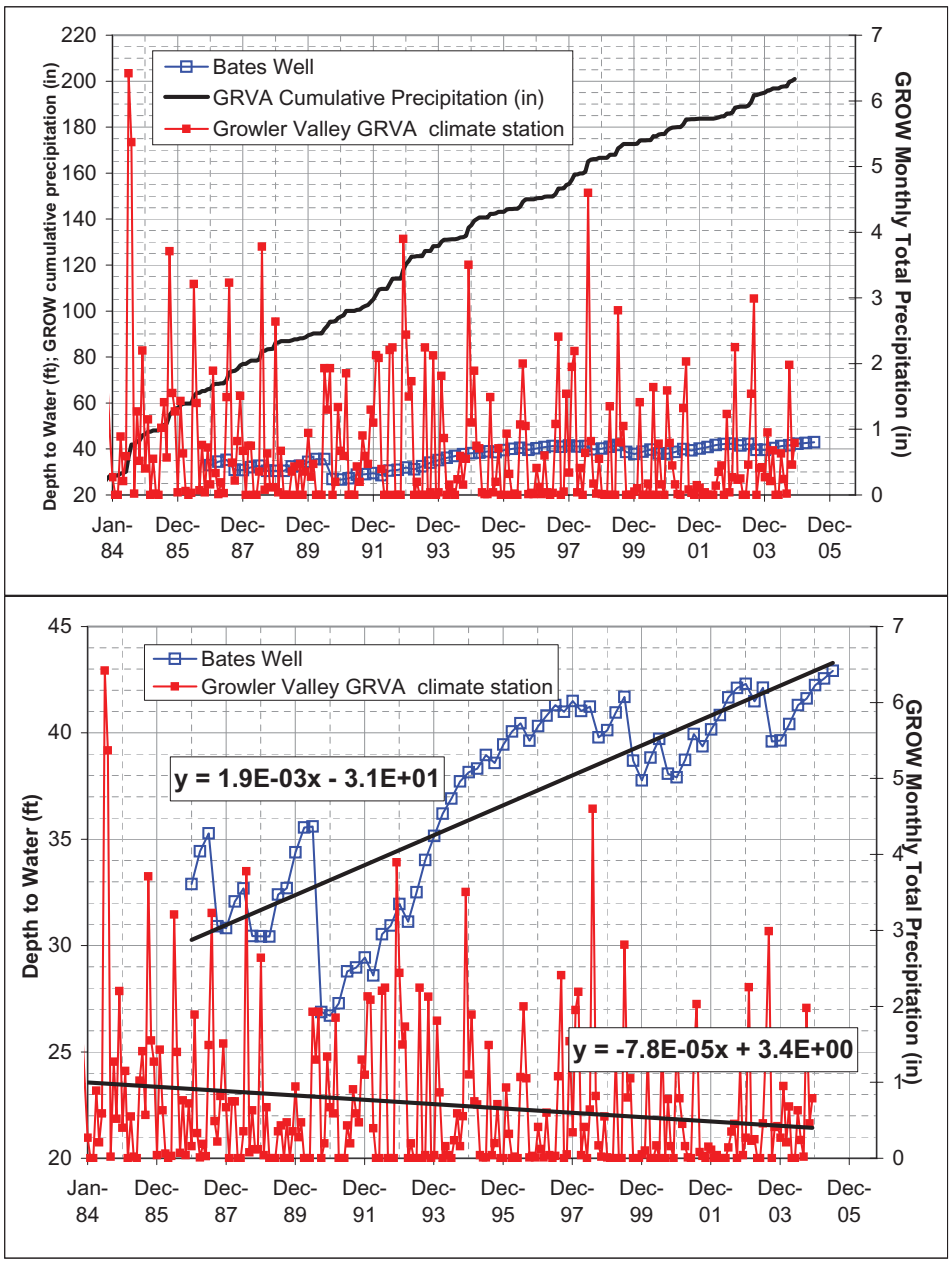

Figure 13-4. Bates well depth to water, Growler Valley rain gauge and climate station monthly total and cumulative precipitation, and regression equations, Organ Pipe Cactus N.M.

location.

Regression coefficients for depth to water at Bonita well and monthly total precipitation at the Pozo Nuevo rain gauge and climate station are shown in the lower plot of Figure 13-5. These will be discussed in a later section.

Pozo Nuevo Well

Pozo Nuevo well is a 134-foot deep well located in alluvium in the upper reaches of San Cristobal Wash, west of the Cipriano Hills (Figure 13-1). Bedrock in the area is of volcanic origin. Water level measurements were made at this well from January 1987 to October 2001, after which time the well was reported to be blocked and inaccessible for obtaining water level data. Over the period of record, depths to water at Pozo Nuevo well ranged 9 feet, between 48.2 feet and 39.2 feet below the measurement point, with an overall downward trend. Regression indicates a water level decline of 0.3 feet/year at Pozo Nuevo. Monthly total precipitation at this location was found to decline 0.03 inches/month/year.

Depth to water at Pozo Nuevo well and monthly total precipitation at Pozo Nuevo rain gauge and climate station are shown in Figure 13-6. Maximum annual water levels at the well occurred most often during the winter season, but sometimes occurred in October. Depth to water at Pozo Nuevo well fluctuates in a similar manner to Bonita well, where a combination of rapid response to channel infiltration during surface flow events and a dampened component derived from subflow and percolation of infiltrated waters from the upper drainage areas (mountain-front recharge) appears evident.

Figure 13-7 illustrates water levels for both Bonita and Pozo Nuevo wells. Water level fluctuations over time at both of these wells share many characteristics, not an entirely surprising result since they similarly situated geologically. The range of water levels at both wells is around nine feet, although the difference in the surface elevations of the wells themselves is nearly 100 feet. Neither of these wells is known to be impacted by groundwater pumping.

Regression coefficients for depth to water at Pozo Nuevo well and monthly total precipitation at the Pozo Nuevo rain gauge and climate station are shown in the lower plot of Figure 6 and are summarized in Table 13-2. These will be discussed in a later section.

Corner Well

Corner well is a 97-foot deep well located in the southwest corner of Organ Pipe Cactus National Monument (Figure 13-1). Corner well is situated in alluvium nearer the basin center than any of the wells dicussed above. Bedrock outcropping at the nearby Quitobaquito Hills is granitic. Depth to water at Corner well and monthly total and cumulative precipitation at the nearby Quitobaquito rain gauge are shown in Figure 13-8. Groundwater pumping south of the U.S. border with Mexico is an unknown and unquantified potential impact at this location.

Water levels at this well show the smallest range of the monitoring wells at 3.9 feet. The greatest depth to water measured at this location during monitoring to date is 62.58 feet, while the smallest depth to water (highest water level) during the same period was 58.65 feet. In most years, the highest water levels occur in April. Relatively stable water levels here likely result from the lack of substantial mountains that could contribute mountain-front recharge and the fact that the well is not located near a major wash. There is a wash nearby, but that channel drains a relatively minor area of the low-relief Quitobaquito Hills compared with the substantial relief and drainage area contributing to washes at which Alamo, Bonita, Pozo Nuevo and Bates well are located. In addition, surface geology at this location does not suggest a confluence of groundwater flow passing through this area as is the case for those wells.

As the lower plot in Figure 13-8 illustrates, water levels are declining very consistently over the

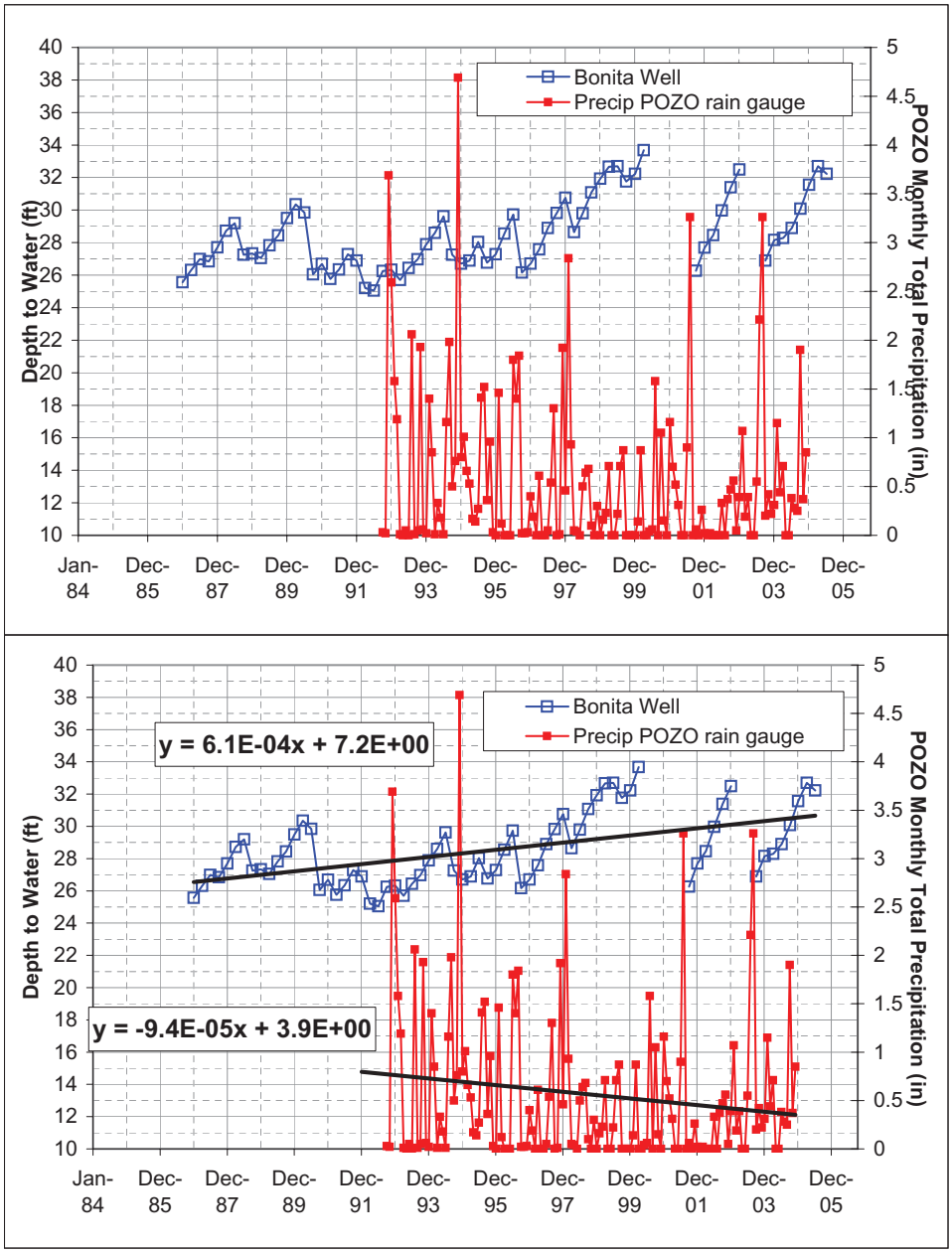

Figure 13-5. Bonita well depth to water, Pozo Nuevo rain gauge and climate station monthly total precipitation, and regression equations, Organ Pipe Cactus N.M.

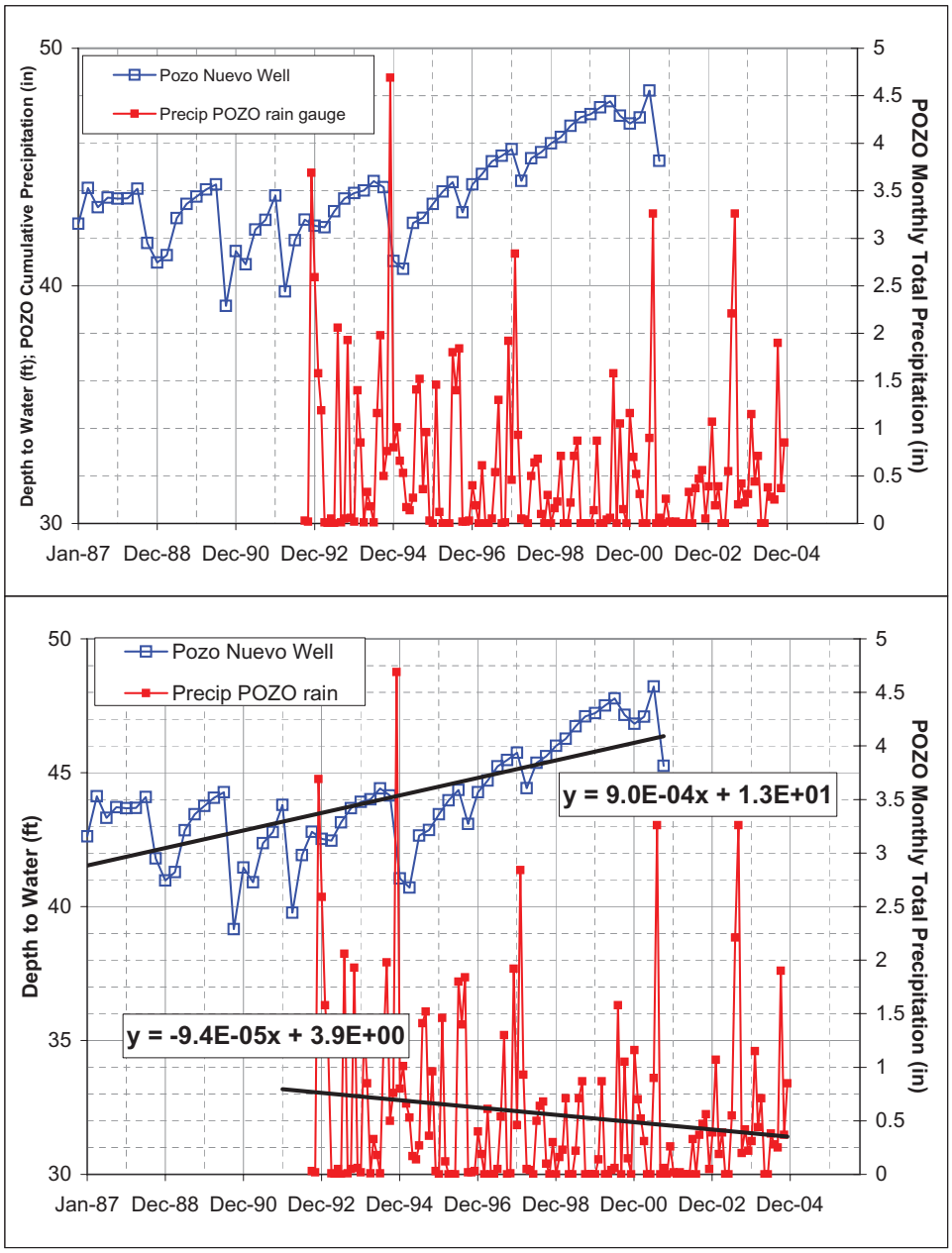

Figure 13-6. Pozo Nuevo well depth to water, Pozo Nuevo rain gauge and climate station monthly total precipitation, and regression equations, Organ Pipe Cactus N.M.

monitoring period. The declines are persisting at a rate of 0.2 feet/year. Monthly total precipitation decreases over the monitoring period at a rate of about 0.03 inches/month/year. Regression coefficients for depth to water at Corner well and monthly total precipitation at Quitobaquito rain gauge are summarized in Figure 8 and in Table 2. These will be discussed further in a later section.

Lukeville area wells

As shown in Figure 13-9, four wells are located in the immediate vicinity of the border city of Lukeville. Unlike Alamo, Bates, Bonita and Pozo Nuevo wells, the Lukeville area wells are located away from bedrock outcrops toward the interior of the Sonoyta Valley basin. Depths to water for these four wells are plotted in Figure 13-10. As Figure 13-10 illustrates, all of these wells show cyclic decreases in water levels (increases in depth to water) during the summer months, followed by partial recovery in the winter months. Minimum annual water levels (maximum depths to water) at these wells are typically recorded during the July monitoring cycle. Since water table recovery due to recharge at these wells is not sufficient to return water levels to former elevations from year to year, long-term water table declines at all of the Lukeville area wells are pronounced as shown in Figure 13-10. Long-term declines indicate a net loss of storage in the groundwater system, attributable to an imbalance between recharge and losses from the groundwater system. Groundwater pumping in the immediate area north and south of the U.S. –Mexico border is believed to be the major cause of summertime water table declines in this area.

The Lukeville area wells will be discussed in conjunction with the Dowling Ranch rain gauge. Dowling rain gauge is located at the Dowling Ranch area, west of Lukeville and east of the Sonoyta Mountains. Monthly total and cumulative precipitation for this rain gage are plotted in Figure 13-11. Regression analysis for the Dowling monthly total precipitation record indicates a long-term decline in monthly total precipitation of 0.016 inch/month/year (-4.4×10^{-5} inch/month/day).

Stack Well

Stack well is an approximately 200-foot deep well located in alluvium west of State Highway 85 near Lukeville. The monitoring record at Stack well spans the time period from January 1987 to the present. Depth to water at Stack is greatest of the four area wells, varying between 98.2 and 115.3 feet, for a total range of 17.1 feet over the period of record. The data record indicates a consistent annual water table rise in the winter months and fall in the summer months. As noted above, winter water table recoveries in the Lukeville area are not sufficient to attain the previous year's water levels. This annual deficit results in sustained long-term decline in water levels at this location of 0.9 feet/year.

Kalil Well

Kalil well is a 187-foot deep well located near Lukeville, south of Stack well and just east of State Highway 85 as shown on Figure 13-9. The monitoring record at Kalil well begins in January 1977 and continues to the present, providing the longest data record for the Lukeville area wells. Depth to water at Kalil well has varied from 66.0 to 96.3 feet, ranging over a total of 30.3 feet during the period of record. Regression analysis indicates that long-term water table elevation decline at Kalil well is 0.8 feet/year.

USGS #1 Camino Dos Republicas Well

The 250-foot deep USGS #1 Camino Dos Republicas well is located one-half mile north of the international boundary and one mile east of Lukeville along the Camino de Dos Republicas road (Figure 13-9). The NPS monitoring record at USGS #1 spans the time period from January 1993 to the present. The USGS-designated wells were continuously monitored in 1989 by U.S. Geological Survey (USGS) staff (NPS, 1992), but those data are not currently in hand for including in this report. Depths to water at this location have varied from 85.7 to 103.0 feet, a total range of 17.3 feet. Regression analysis of data from this well indicate a long-term water table decline of

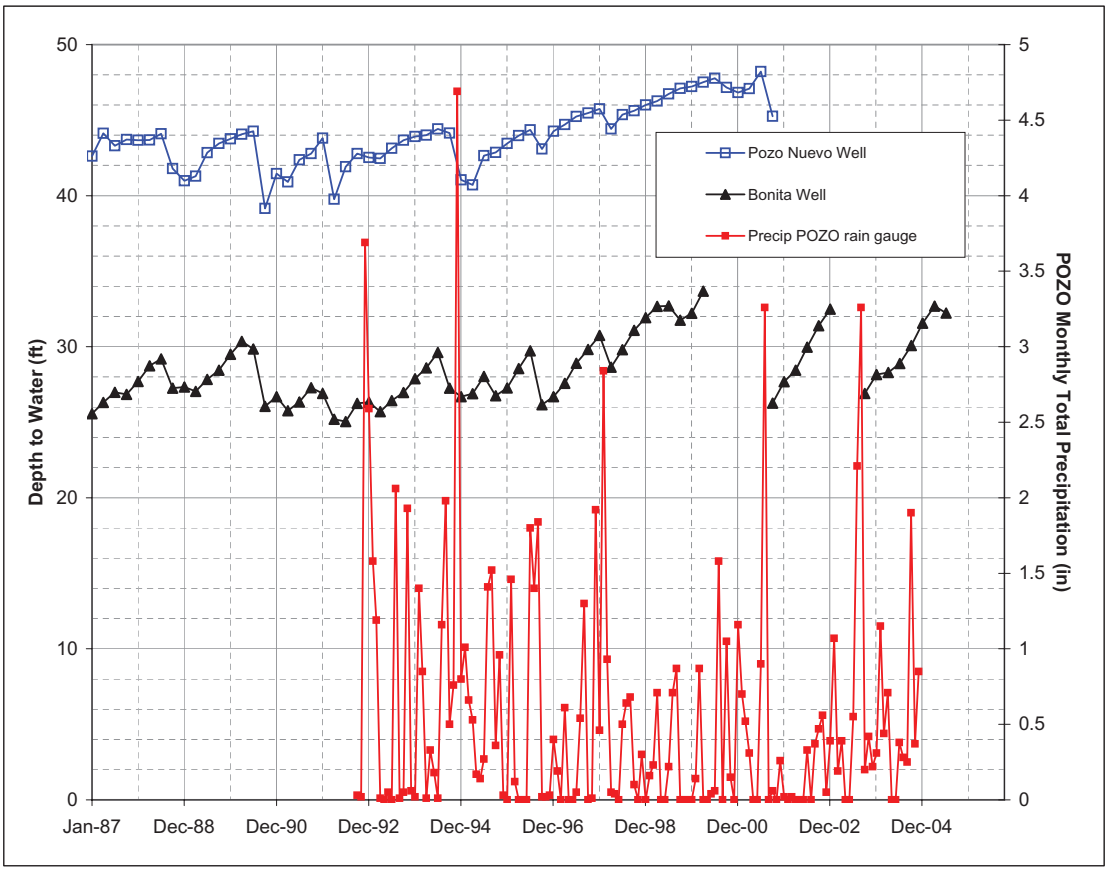

Figure 13-7. Pozo Nuevo and Bonita wells depth to water and Pozo Nuevo rain gauge and climate station monthly total precipitaion.

1.0 foot/year at Camino Dos Republicas.

USGS #2 Lukeville Well

The 238-foot deep USGS #2 Lukeville well is located along the international boundary one mile east of Lukeville (Figure 13-9). The well is reported to be about 238 feet in depth. Monitoring records at this well are similar to those at USGS #1, discussed above. Organ Pipe Cactus National Monument staff monitor this location on a quarterly basis since 1993. Depth to water at USGS #2 Lukeville well over this period have ranged between 72.2 and 91.5 feet, a range of 19.3 feet. Continuous monitoring data from this well for 1989 were reported in NPS (1992) but are not available for inclusion here. Regression analysis for data from this well indicate a long-term water table decline of 1.0 foot/year at USGS #2 Lukeville well.

USGS #3 Salsola

The 278-foot deep USGS #3 Salsola well is located 6.5 miles southeast of Lukeville along the international border. As shown in Figure 2, this well is more central to a basin interior than any other well discussed here. Monitoring history of USGS #3 Salsola is similar to that of the previous two USGS-designated wells. Depth to water at this location, shown in Figure 13-12, has ranged from 94.6 to 99.5 feet over the period of NPS monitoring beginning in 1993. The USGS continuous monitoring record in 1989 indicates a depth to water of 102 feet below ground surface in December 1988 (NPS 1992). The nearest precipitation record to this well is available at the Salsola climate station, shown in Figure 13-9.

Depths to water at the USGS #3 Salsola well show a long-term water level increase, the only location

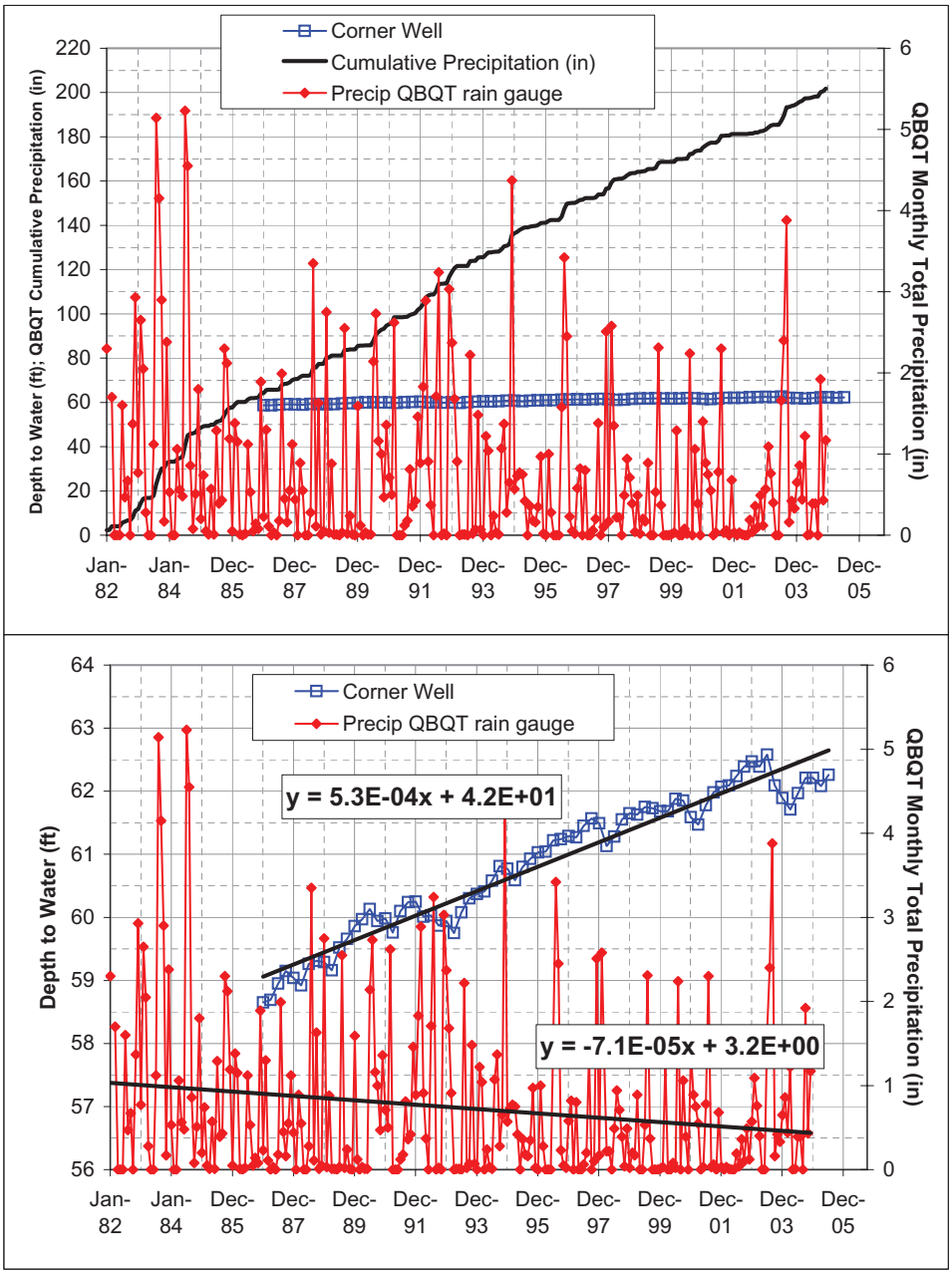

Figure 13-8. Corner well depth to water, Quitobaquito climate station monthly total and cumulative precipitation, and regression equations, Organ Pipe Cactus N.M.

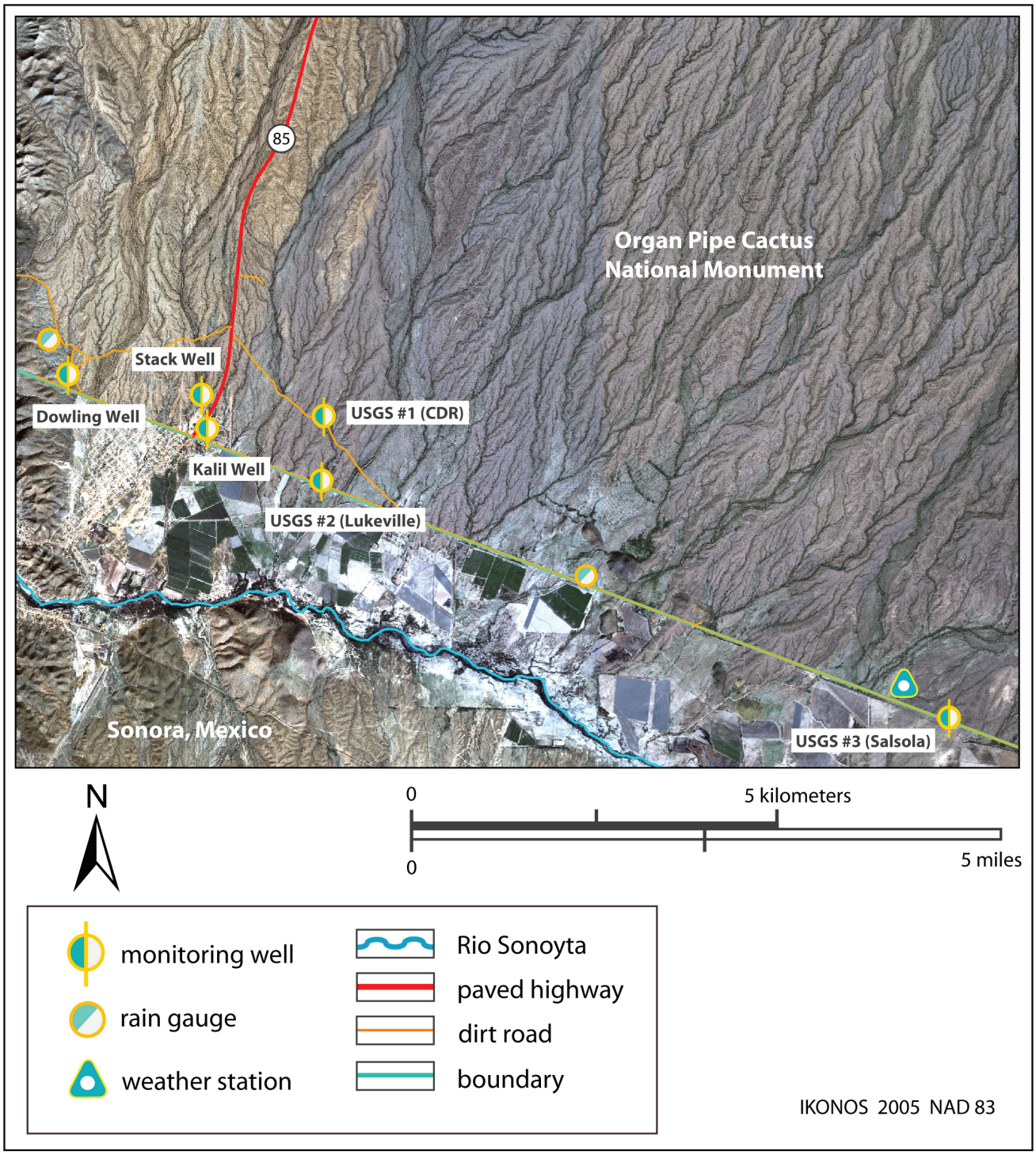

Figure 13-9. Lukeville area wells, Organ Pipe Cactus N.M.

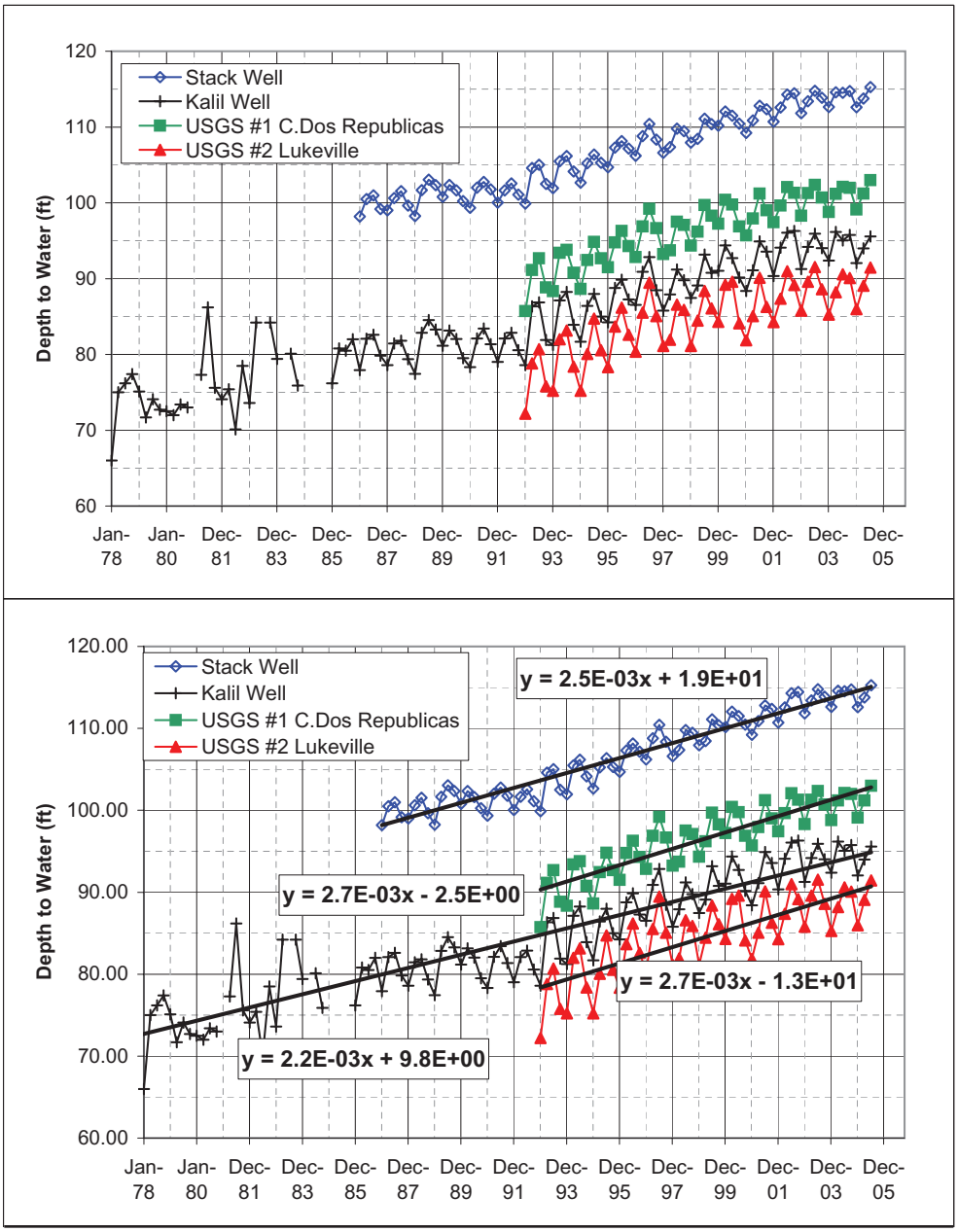

Figure 13-10. Lukeville area wells: Stack, Kalil, USGS #1 and USGS #2 wells depth to water and regression equations, Organ Pipe Cactus N.M.

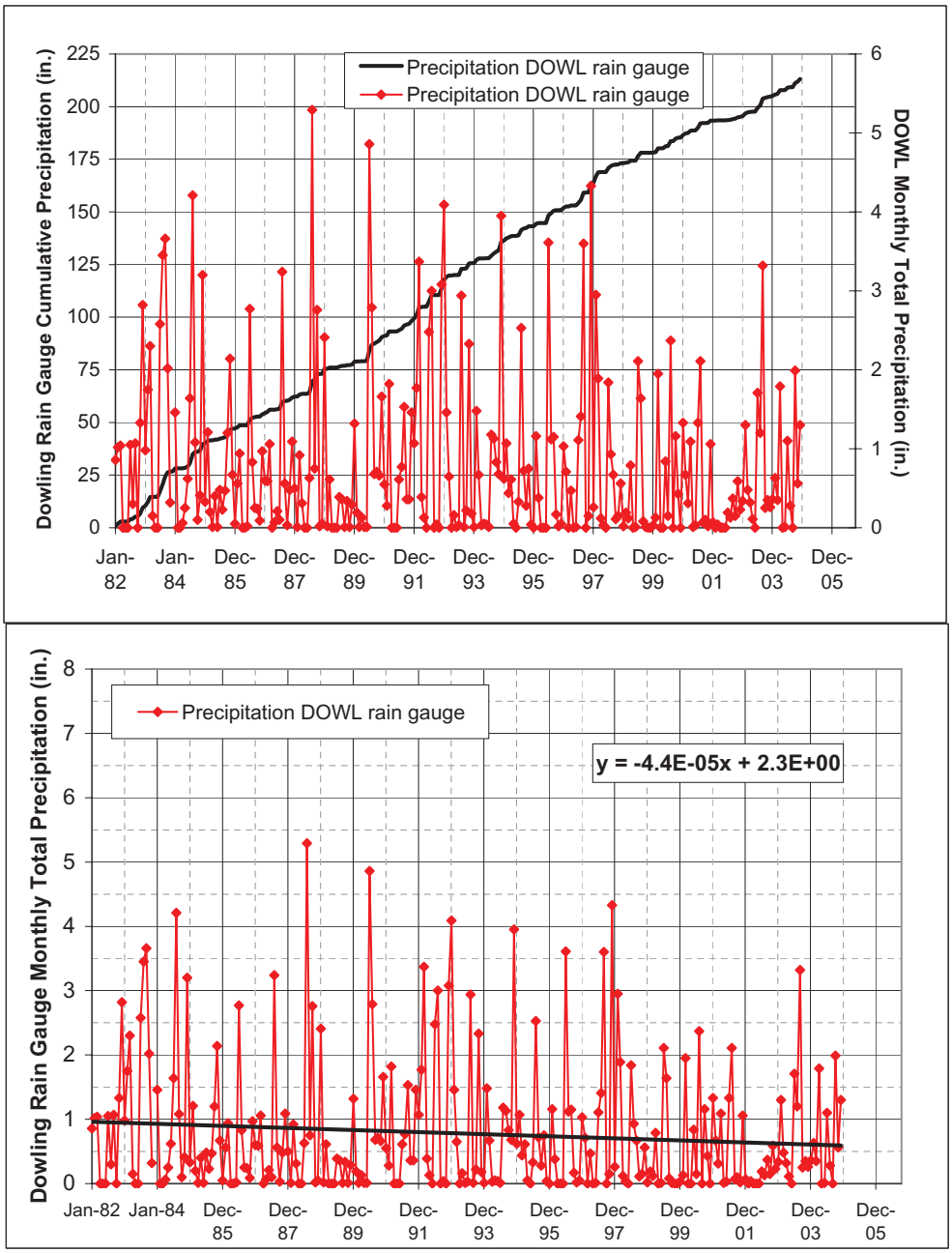

Figure 13-11. Dowling rain gauge monthly total and cumulative precipitation and regression equation, Organ Pipe Cactus N.M.

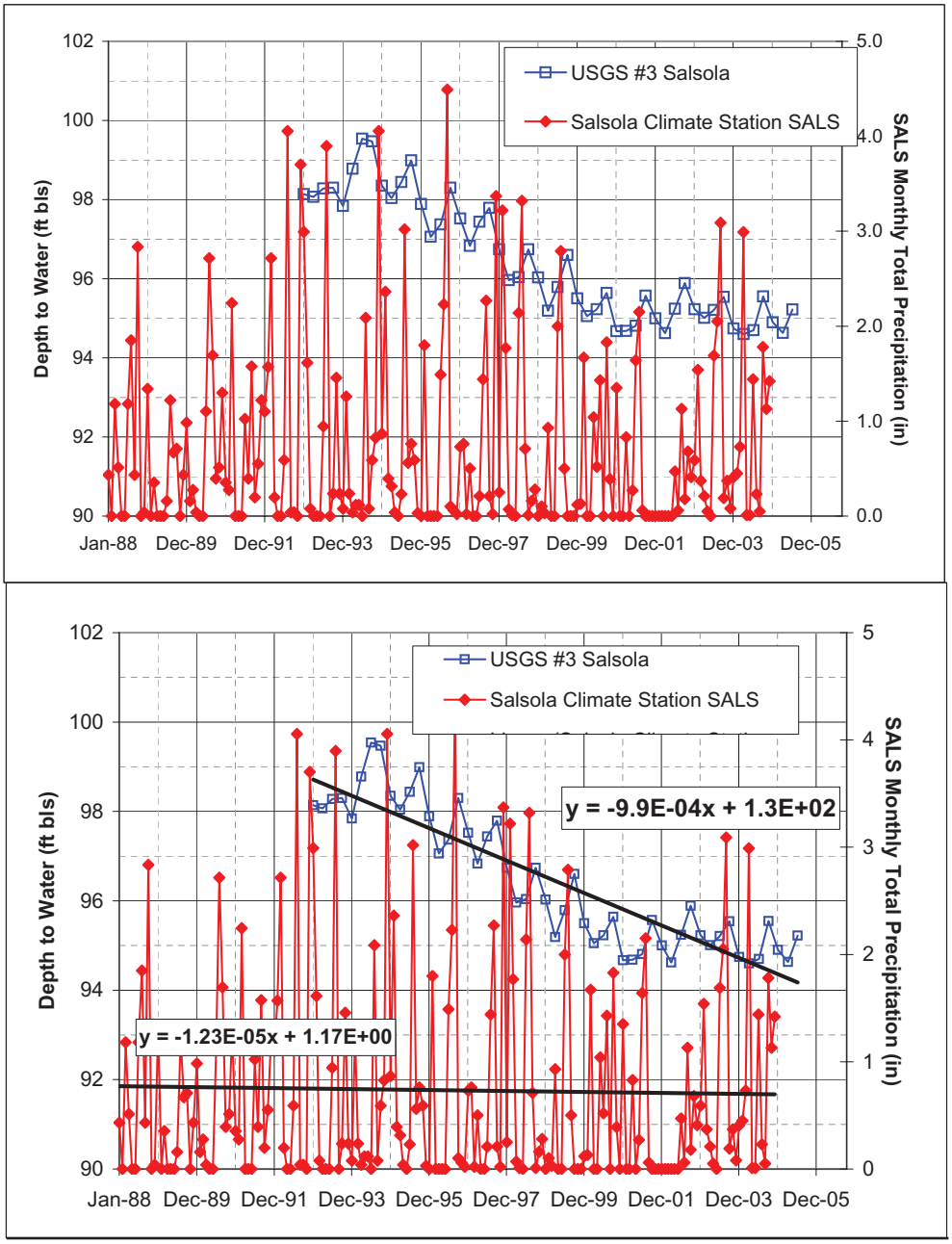

Figure 13-12. USGS #3 Salsola well depth to water, Salsola climate station monthly total precipitation and regression equations, Organ Pipe Cactus N.M.

of all the monitoring wells to do so. Minimum annual water level (maximum depth to water) at this well is typically recorded during the October monitoring cycle. Regression for the data shown in Figure 13-12 indicates a rate of increase of 0.4 feet/year since 1993. This increase indicates a net gain in storage within the groundwater system at this location. This gain could indicate increased recharge, decreased losses, or a combination of these.

Park Headquarters Wells

The park headquarters wells supply the park housing and administrative areas. These wells are located in alluvium adjacent to the maintenance complex southeast of Twin Peaks at the east end of the Puerto Blanco Mountains. Exposed rock types in the nearby mountains are of volcanic origin. At the current time, it is believed that depth to water at these wells is not regularly monitored, although it is recommended that at least one of these should be included in the monitoring program.

Headquarters #4 (South Well)

Headquarters well #4 (South well) is the primary water supply well for the park administrative area. The well was constructed in 1957 to a depth of 430 feet and was serviced in 2004 for the purpose of restoring production and removing sediment that had accumulated in the well bottom. Depth to water at this well in 1957 is reported as 310 feet below ground surface. Depth to water in 2003 was reported to be about 337 feet. It is not known at this time what other records of water levels at the South well, if any, are available in park files.

Headquarters #5 (North Well)

Headquarters #5 (North well) was drilled in 1974. Depth to water at that time was reported to be 308 feet at this well. The existence of more current depth to water data at this well is unclear, but it is recommended that this be investigated and this well be included in the regular monitoring program.

Review of regression coefficients for water level and monthly total precipitation

As discussed in the preceding section and shown on the accompanying figures, regression analyses of the depth to water and monthly total precipitation data were conducted using the regression function in Microsoft Excel software. This function applies a least-squares best-fit line to the data. The purpose of this analysis was to aid in assessing whether or not trends were present. Results of the regression analyses are summarized in Table 13-2 as water level regression coefficients (negative of depth to water regression coefficients) and monthly total precipitation regression coefficients. These coefficients represent the slopes of the lines fit to the data record using a least-squares approach, providing a measure of rate of change of the data over time.

In addition, the ratio of the water level regression coefficient to the monthly total precipitation regression coefficient is shown in Table 13-2 as a means of comparing rate of change of water levels to rate of change of precipitation at each location. An underlying assumption associated with making this comparison is that changes in precipitation will have an impact on groundwater storage as reflected by water levels in wells. While it is understood that the magnitude of groundwater level response to changes in precipitation is complex and will vary from place to place due to variation in local conditions, the set of data taken together allow preliminary comparison of this response for wells in relatively similar settings.

A nonzero regression coefficient for long-term data is indicative of a state of nonequilibrium. Values of the regression coefficient nearer to zero indicate that the data record is derived from a system nearer to equilibrium than one with values deviating more from zero, either positive or negative. Examination of the values presented in Table 2 indicates the following:

- Water levels declined over time at all monitoring wells except for the USGS

Table 13-2. Summary of regression coefficients for water level and monthly total precipitation with depth to water/precipitation ratio, Organ Pipe Cactus N.M. (*Water table elevation regression coefficient is equal to the negative of the depth to water regression coefficient.)

	Water Level (WL) Regression Coefficient* (ft/day)	**Monthly Total Precipitation (MTP) Regression Coefficient* (inch/month/day)**	**Regression Coefficient Ratio WL/MTP (ft/inch/month)**
Alamo Wash/Alamo Canyon precipitation	-3.2E-05	-3.3E-05	1.0
Bates Well/Growler Valley precipitation	-1.9E-03	-7.8E-05	24.4
Bonita Well/Pozo Nuevo precipitation	-6.1E-04	-9.4E-05	6.5
Pozo Nuevo Well/Pozo Nuevo precipitation	-9.0E-04	-9.4E-05	9.6
Corner Well/Quitobaquito precipitaton	-5.3E-04	-7.1E-05	7.5
Dowling precipitation		-4.4E-05	
Kalil Well	-2.2E-03	-4.4E-05	50.0
Stack Well	-2.5E-03	-4.4E-05	56.8
USGS #1 C. Dos Republicas	-2.7E-03	-4.4E-05	61.4
USGS #2 Lukeville	-2.7E-03	-4.4E-05	61.4
USGS #3 Salsola/Salsola precipitation	9.9E-04	-1.2E-05	-80.5

#3 Salsola location, where water levels showed an increasing trend

- Monthly total precipitation rates declined at all stations. Variability is attributed primarily to orographic effects and differences in length of station records.
- The ratios of rate of change in water levels to rate of change in monthly total precipitation (WL/MTP) range from -80.5 ft/inch/month (at Salsola) to 61.4 ft/inch/month at the USGS wells near Lukeville
- WL/MTP ratios with high absolute values suggest anthropogenic impacts on groundwater reserves as observed at the Lukeville area wells and at Salsola

The rate of water level decline is greatest at the Lukeville area wells, where declines at the four wells range from 0.8 ft/year (-2.2 x 10^{-3} ft/day) to 1.0 ft/year (-2.7 x 10^{-3} ft/day). Due to the known presence of groundwater extraction for potable and irrigation water supply on both sides of the border, these declines are attributed to groundwater mining at this location. Monthly total precipitation in the Lukeville area has declined also, but at a medium rate (-0.016 inch/month/year) compared to precipitation declines at the other stations. WL/MTP ratios for these four wells are the highest of the monitoring areas.

Water level declines at Alamo Wash well are about

0.012 feet/year (-3.2 x 10^{-5} feet/day). Monthly total precipitation rates declined at 0.012 inch/month/year (-3.3 x 10^{-5} inch/month/day). This well is relatively high in its watershed and is not impacted by human groundwater withdrawals.

Bonita well, Pozo Nuevo well and Corner well show very similar water level declines over the monitoring period, ranging from 0.19 ft/year (-5.3 x 10^{-4} ft/day) to 0.33 ft/year (-9.0 x 10^{-4} ft/day). Declines in monthly total precipitation rates were also similar in the area of these wells, at 0.026 inch/month/year (-7.1 x 10^{-5} in/month/day) to 0.034 inch/month/year (-9.1 x 10^{-5} inch/month/day). WL/MTP ratios for these three wells were all between 5 and 10 ft/inch/month.

Rate of water level decline at Bates well is nearly as great as that observed in the Lukeville area at 0.7 feet/year (-1.9 x 10^{-3} feet/day). This is an unexpected result due to the absence of sustained groundwater extraction by humans in that area. Monthly total precipitation in the area declined at a rate of 0.028 inch/month/year (-7.8 x 10^{-5} inch/month/day). WL/MTP ratio for Bates well and the Growler Valley precipitation record is significantly higher than that for the three wells discussed in the preceding paragraph at 24.4 feet/inch/month. It would be expected that Bates well data would show greater similarity to those wells than was shown by this analysis.

Table 13-2 indicates that the USGS #3 Salsola well exhibits a positive rate of change of water levels over the period of record, increasing at 0.36 feet/year (+9.9 x 10^{-4} feet/day). Monthly total precipitation at the Salsola climate station shows the smallest rate of decline for all of the stations reported here, at 0.004 inch/month/year (- 1.9 x 10^{5} inch/month/day). The WL/MTP ratio for this site is negative due to the differences in the slopes of the water level and monthly total precipitation trend lines. Increasing water levels at Salsola since at least 1988 indicate that a decrease in groundwater extraction or an increase in recharge, or both, in the vicinity of the monitoring well has occurred. Water level rise since that time reflects an extended adjustment of the water table in the area. It should be noted that long-term changes in groundwater levels can result from very distant impacts over extended periods of time, from years to decades. The rate of water level adjustment at Salsola is retarded by annual cycles of net deficit in the summer months.

Discussion

Quarterly depth to water monitoring at OPCNM provides a valuable data record needed to understand subsurface groundwater dynamics at regional and local scales within and adjacent to park boundaries. The data set, when analyzed in combination with long-term precipitation records, makes it possible to assess changes in groundwater levels relative to seasonal, annual and long-term climatic trends.

As discussed in the preceding sections, the availability of the data set as a whole allows estimation of what may be natural water level response to declining precipitation rates over the monitoring period. The analysis of data from these sites provides an order-of-magnitude estimate of what may be occurring to groundwater levels within similar unmonitored settings that are also experiencing declining precipitation rates. Factors that influence rate of water level decline in any specific area include:

- Area of contributing watershed (ft^2)
- Recharge deficit rate (gal/day/ft^2)
- Aquifer storage as a function of water level elevation (gal/ft)
- Other physical and biological factors – possibly nonlinear – that potentially reduce infiltration – increased evaporation, increased plant water capture, decreased permeability to infiltration, increased runoff

Significantly higher rates of water level decline in wells in the Lukeville area and to a lesser extent at Bates well, suggest the possible presence of impacts to groundwater resources over

and above what is occurring naturally due to reduced precipitation. A more in-depth analysis is recommended to better understand how differences in local conditions may be impacting the discrepancies in water level trends between these wells.

The widespread decline of water level elevations at wells in and near OPCNM should be of concern to resource managers for several reasons. The concept of sustainability rests fundamentally on a system in equilibrium. Decline in water level elevations on the widespread scale presented here clearly reflects a system out of equilibrium. This condition is the result of, and in turn has the potential to impact, nonequilibrium in conditions above and below the ground surface.

Due to a lack of long-term data records, for the arid southwest it is unknown how water level elevation trends can be expected to fluctuate over very-long time scales under the influence of climatic variability at scales of decades to centuries. Groundwater levels are influenced by surface conditions including climate, flora and fauna, soils and geology. The relationships between climate, flora, fauna, surface water and groundwater interact in complex ways. The groundwater monitoring program at OPCNM provides an invaluable opportunity to increase our understanding of these relationships so vital to the fundamental mission of the park.

Acknowledgements
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