Operational tests of wells 375W, 380W, 381W, and 382W: results from previous tests and recommendations for future tests and management

Robert Harrington
Hydrologist
Inyo County Water Department

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Introduction

Most LADWP production wells in the Owens Valley are screened throughout the saturated aquifer; however, in an effort to minimize the effect of groundwater extraction on water levels in the shallow aquifer, several newer wells were screened only in the deep aquifer and sealed throughout confining layers and the shallow aquifer. Because these wells were constructed so as to reduce their effect on the shallow aquifer, it may be feasible and advantageous to develop alternatives to the soil water and plant water requirement based management methods described in the Green Book to govern operation of these wells. "Operational tests" were conducted on four of these sealed wells during which the wells were pumped for extended periods of time and water levels in the deep and shallow aquifers were monitored within a two-mile radius of the production wells. These tests were conducted on well 375W in the Big Pine wellfield (Figure 1), and wells 380W, 381W, and 382W in the Thibaut-Sawmill wellfield (Figures 2 and 3) with the purpose of evaluating the saturated hydraulic linkage between the wells and their associated vegetation and soil water monitoring sites.

During the development of the Annual Operations Plan for 2000-2001, LADWP proposed operating wells 374W, 375W, 380W, and 381W on the basis that these wells had "no impact on [the] shallow aquifer during 1997-1998 pump test" (G. Coufal letter to G. James, April 20, 2000). Inyo County protested that these wells were in "off" status and had not been formally exempted by the Standing Committee (G. James letter to G. Coufal, May 1, 2000). In its response to Inyo County's comments, LADWP recast the operation of these wells as an operational test (G. Coufal letter to G. James, May 26, 2000). Inyo County agreed that the wells could be operated as part of a test if the Standing Committee approved a proposal for such a test (G. James letter to G. Coufal, July 28, 2000); however, the Standing Committee did not agree to conduct a test due to unresolved differences between LADWP and Inyo County staff about how the test should proceed. It was the opinion of Inyo Count staff that one of the preliminary steps in developing a viable proposal for further testing of these wells was that the data from previous tests be examined and used to assess the need for and guide the design of any further tests. Examination of data from the previous test was hampered by the absence of any kind of report from the previous test, and, at the September 14 2000 Standing Committee meeting, efforts to incorporate an operational test into the 2000-2001 Annual Operations Plan were abandoned. At that meeting, Inyo County committed to provide LADWP with a more detailed document regarding the County's views and concerns regarding operational testing of these wells. This report is that document.

The purpose of this report is to assess the need for additional operational tests, and to initiate development of alternative management for these wells. To accomplish this, data from the operational tests were examined to ascertain if any effect of the test pumping could be detected in the hydrographs of shallow and deep wells monitored during the operational tests. The proposal for the previous operational tests specified several analyses such as analytical modeling and development of drawdown contours which are not conducted here. The present report is meant only to fulfill the commitment Inyo County made to the Standing Committee to examine the data from the previous tests provide an assessment of the need for further operational testing of these wells. This report should not be construed as a final report for the operational tests conducted in 1996-1998.

Methods

Many factors cause water level fluctuations in wells at a variety of time scales. To correctly assess the effect of test pumping, fluctuations unrelated to test pumping must be identified and accounted for (Freeze and Cherry, 1979). During the operational tests, fluctuations in recharge, surface water stage, evapotranspiration (ET), water spreading, or non-test pumping may have influenced water levels in observation wells, masking the effect of the test pumping. To account for these external influences, the hydrograph for each observation well was examined and assessed qualitatively to determine the relative magnitude of test-pumping induced fluctuations versus externally-induced fluctuations.

Data. Construction details for wells 375W, 380W, 381W, and 382W and periods of test pumping are given in Table 1. Daily average flow rates for the four production wells, the

Big Pine Canal, and the Owens River are given in Figures 4 and 5. Pumping rates for wells 330W, 332W, 341W, 351W, 356W, and 409W are not given, because their monthly production rates remained fairly constant throughout the period of the operational tests. Table 2 lists the depths of observation wells monitored during the operational tests. Hydrographs for the wells listed in Table 2 are given in Figures 6 through 35. In order to assess background trends at each well, the hydrographs span the period 1996 through 2001. Though the data presented here provide a large amount of information about groundwater fluctuations during the operational tests, there are further data that could be included in a complete analysis of these tests: data from several wells that were equipped with continuous recorders are not included, and only a few of LADWP's numerous surface water measuring stations are included. Nevertheless, the data are sufficient for the qualitative and preliminary analysis undertaken here.

Table 1. Construction details and test periods for pumped wells. Capacities are from City of Los Angeles and County of Inyo, Table 9-10 (1990).

Well	Casing size (inches)	Depth (feet)	Screened interval (feet)	Seal depth (feet)	Capacity (cfs)	Test period
375W	18	450	260-440	240	5.6	11/3/97-6/16/98
380W	18	730	250-690	230	3.2	10/1/96-1/29/97; 4/6/97-4/21/98
381W	20	700	250-690	230	3.4	10/1/96-1/29/97; 4/6/97-4/21/98
382W	20	625	275-615	232	1.8	11/3/98-4/21/98

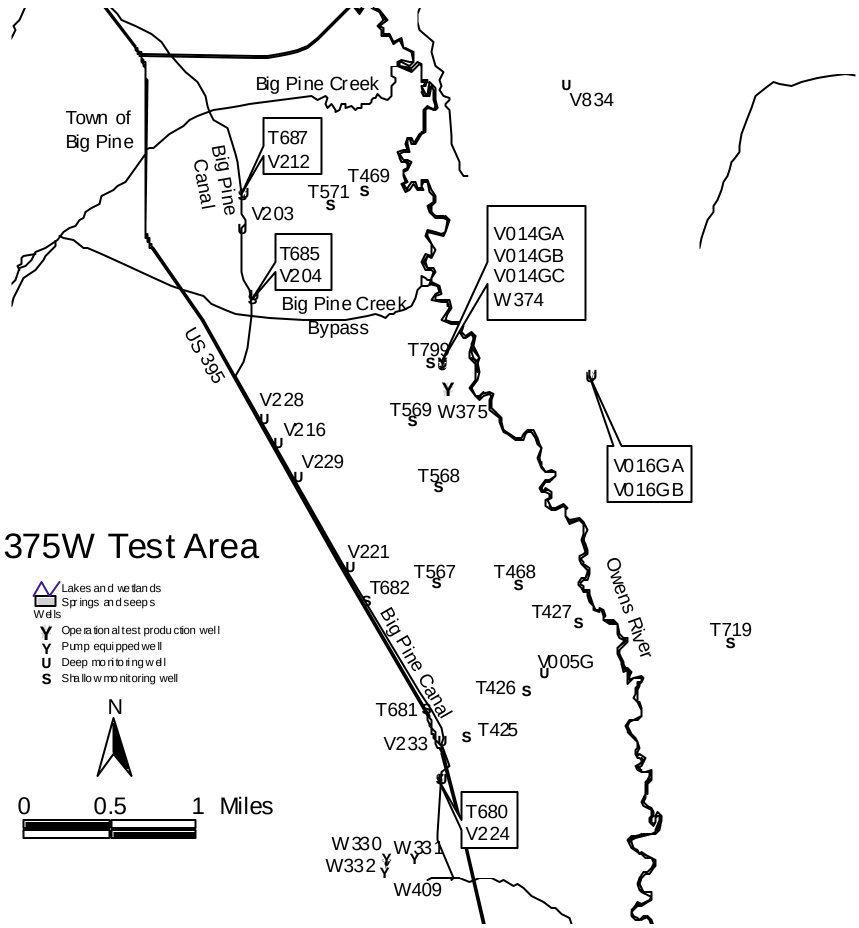

Figure 1. Map of 375W area, Big Pine wellfield.

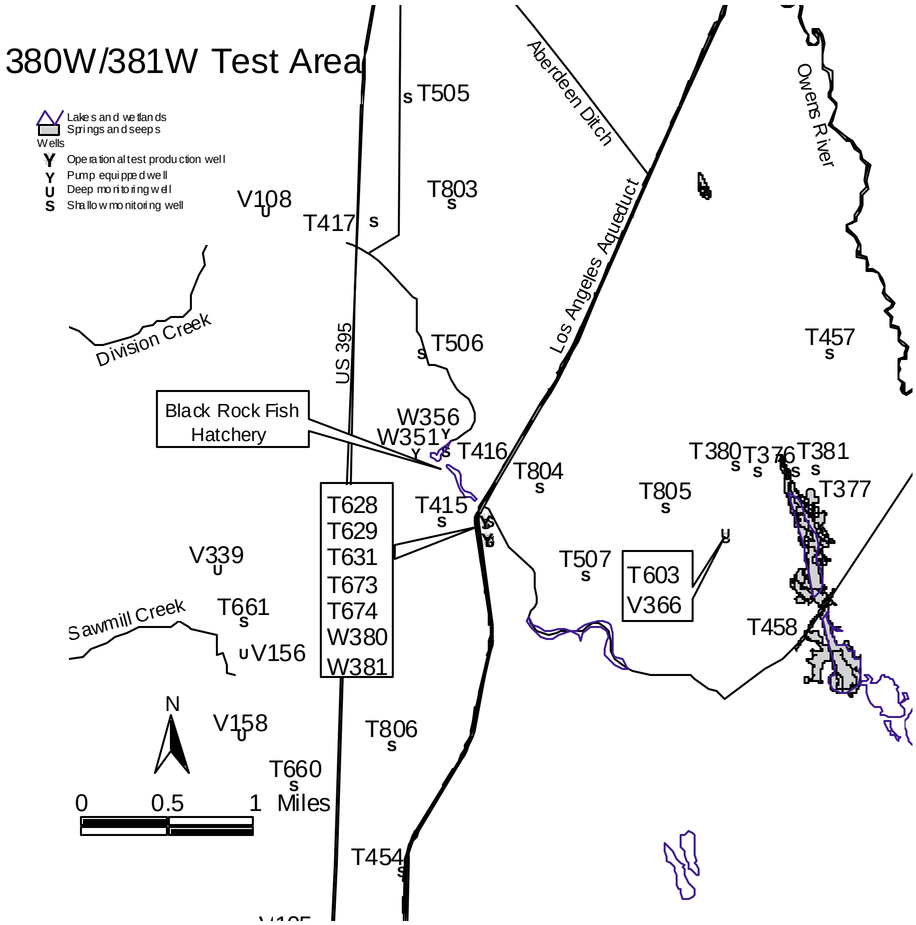

Figure 2. Map of 380W/381W area, Thibaut Sawmill wellfield.

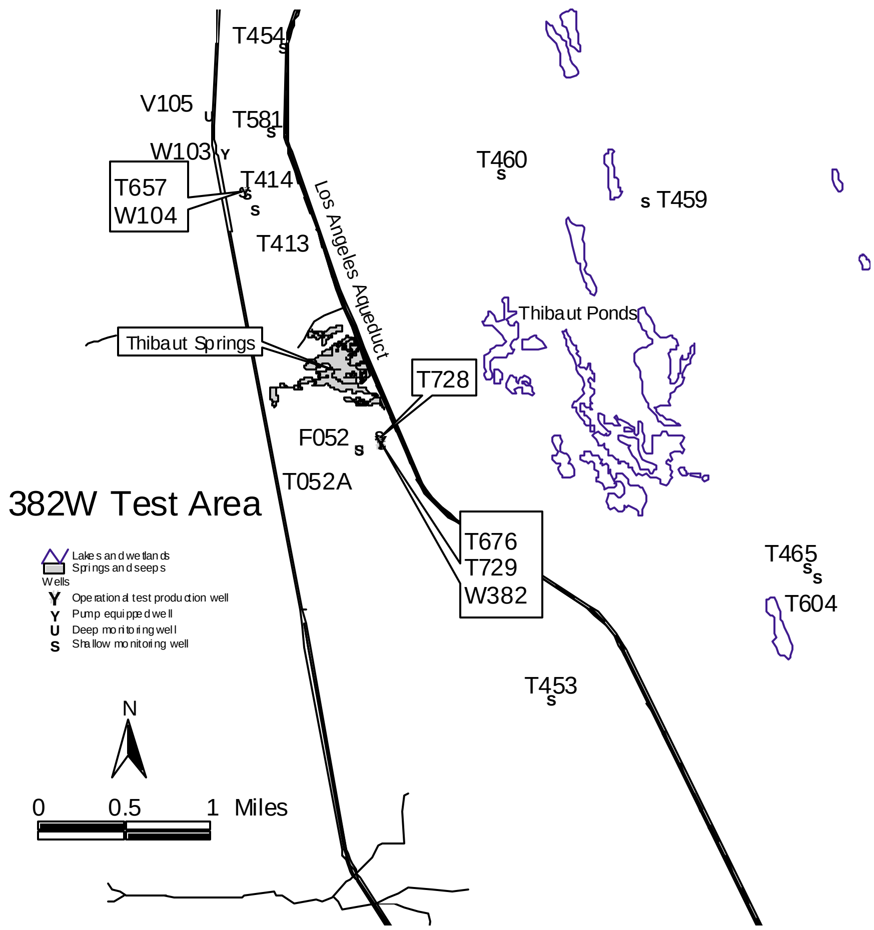

Figure 3. Map of 382W area, Thibaut Sawmill area.

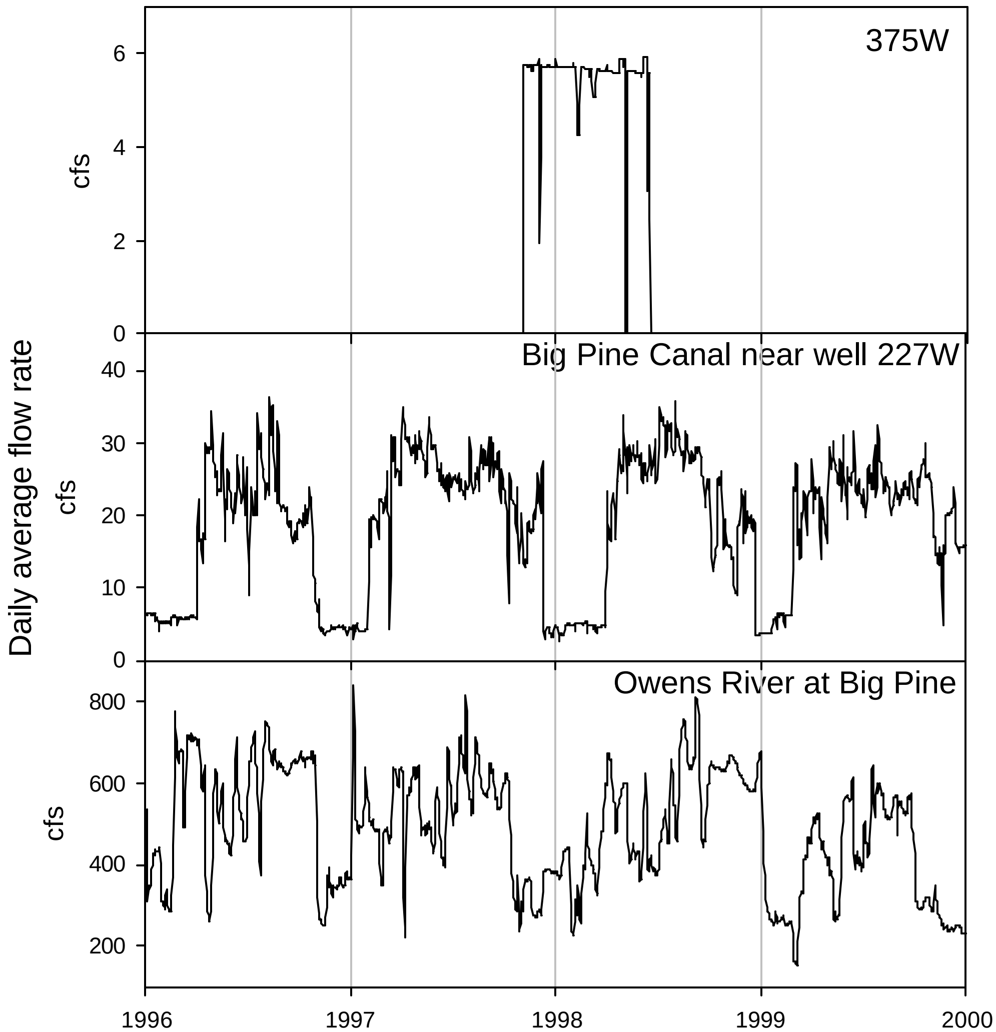

Figure 4. Daily average flow rates for well 375W and surface water conveyances near Big Pine during the operational test.

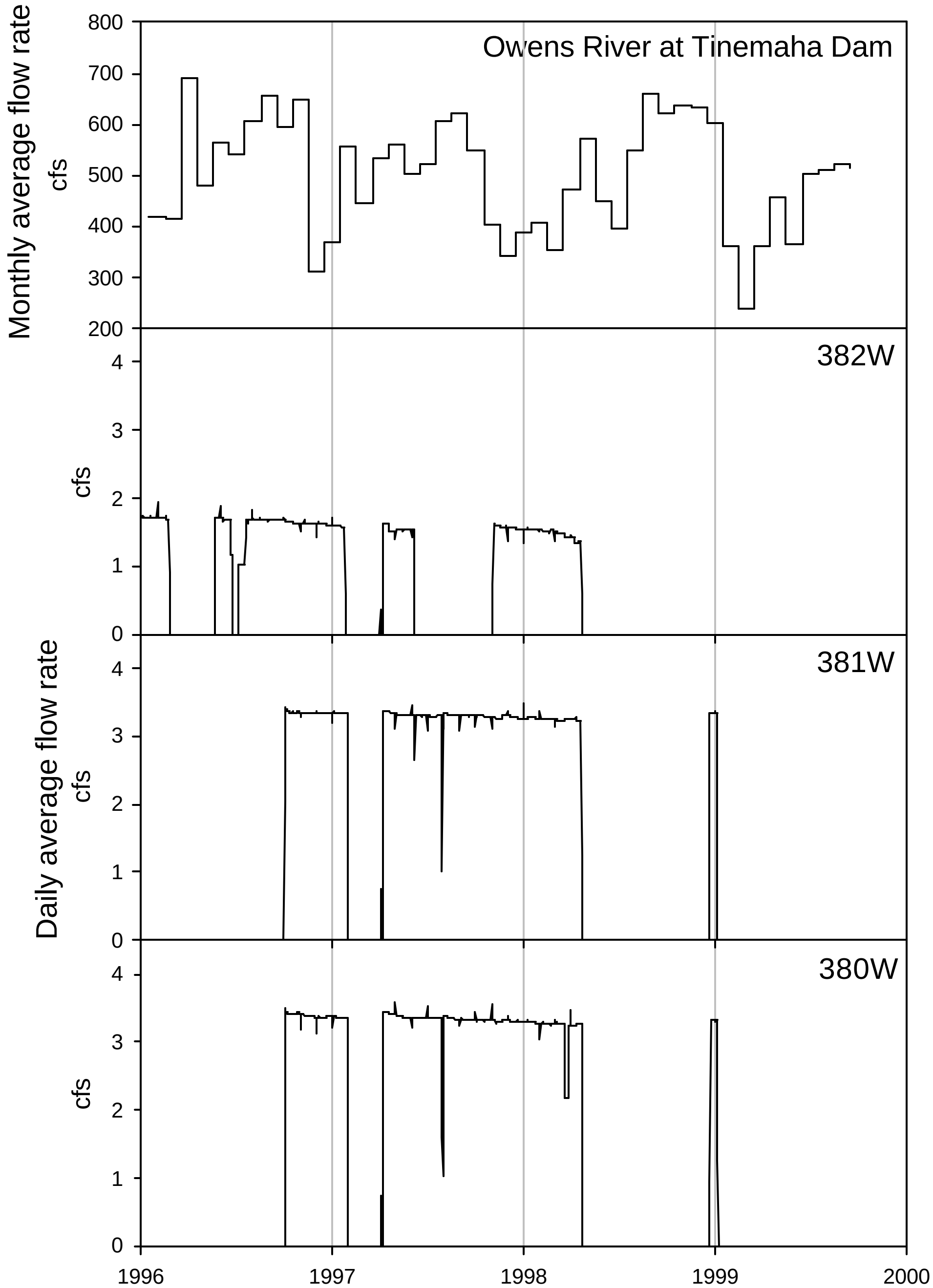

Figure 5. Daily average flow rates for wells 380W, 381W, and 382W; monthly average flow rate for Owens River at Tinemaha Dam.

Table 2. Wells monitored during operational tests.

Well	Depth (feet)	Well	Depth (feet)	Well	Depth (feet)	Well	Depth (feet)
375W test							
Shallow wells				Deep wells			
425T	20.9	681T	33.1	203V	200+	228V	100.0
426T	19.7	682T	58.9	204V	137.6	229V	131.0
427T	19.3	685T	----	212V	200+	233V	149.0
468T	19.6	687T	53.0	216V	101.0	834V	----
469T	21.0	719T	20.7	221V	79.4	V014GA	315.0
567T	29.5	799T	29.3	224V	322.0	V016GA	----
568T	32.0	V005G	----				
569T	42.3	V014GB	166.0*				
571T	39.4	V014GC	41.0				
680T	41.0	V016GB	31.3				
380/381 test							
Shallow wells				Deep wells			
376T	63.5	507T	52.0	108V	128.9	366V	210.0
377T	52.6	603T	19.8	156V	----	628T	----
380T	41.8	630T	----	158V	173.0	629T	----
381T	52.4	660T	31.7	339V	140.0	631T	----
415T	42.3	661T	79.8				
416T	23.3	673T	19.7				
417T	63.0	674T	----				
454T	21.7	803T	29.0				
457T	31.6	804T	28.8				
458T	19.4	805T	27.0				
505T	52.8	806T	26.5				
506T	42.3						
382W test							
Shallow wells				Deep wells			
052AT	20.0	460T	42.1	728T	156.6	105V	206.9
413T	42.3	465T	20.2	729T	202.9	052F	----
414T	20.2	581T	11.0				
453T	21.0	604T	13.4				
454T	21.7	657T	20.7				
459T	20.1	676T	17.3				

*V014GB's depth suggests it should be considered a deep well, but its hydrograph more closely resembles V014GC, a shallow well at the site, than it resembles V014GA.

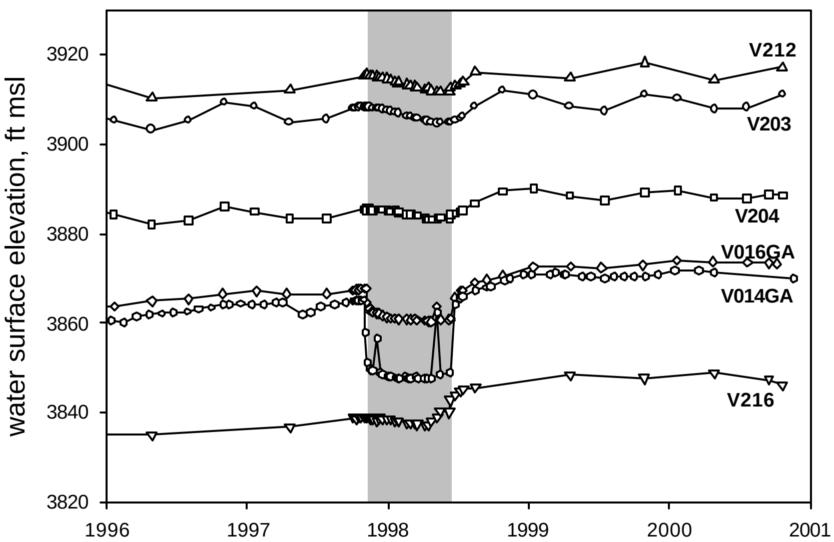

Figure 6. Deep wells near 375W. Gray indicates when 375W was on.

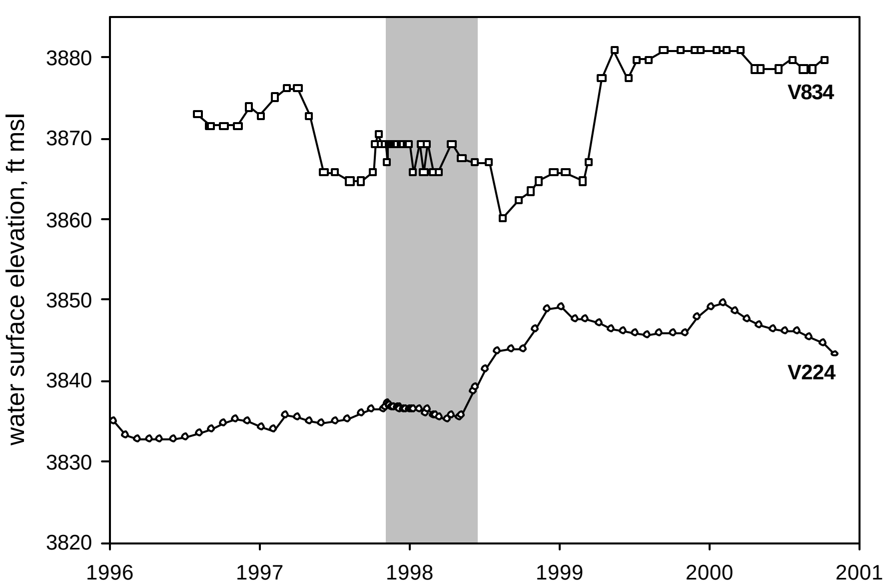

Figure 7. Deep wells near 375W. Gray indicates when 375W was on.

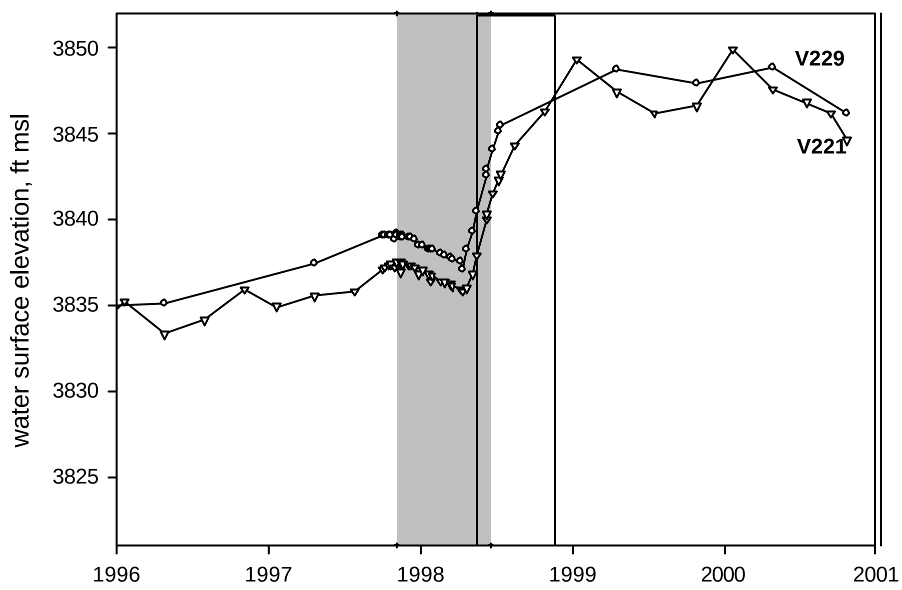

Figure 8. Deep wells near 375W. Gray indicates when 375W was on.

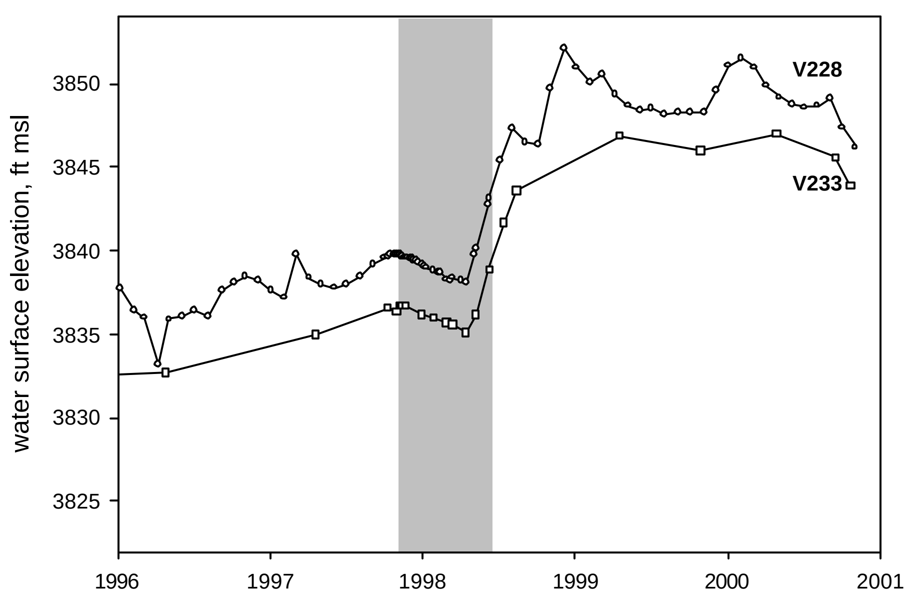

Figure 9. Deep wells near 375W. Gray indicates when 375W was on.

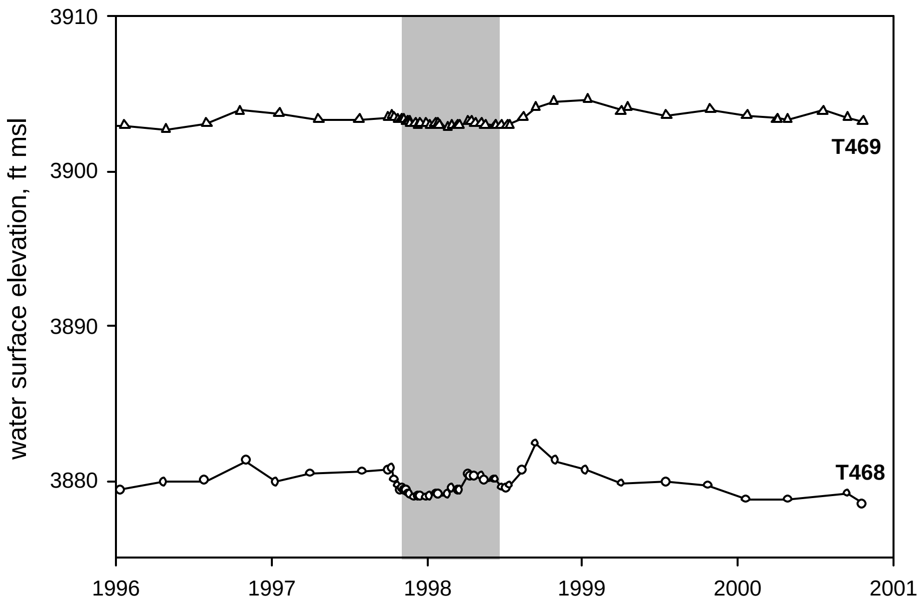

Figure 10. Shallow wells near 375W. Gray indicates when 375W was on.

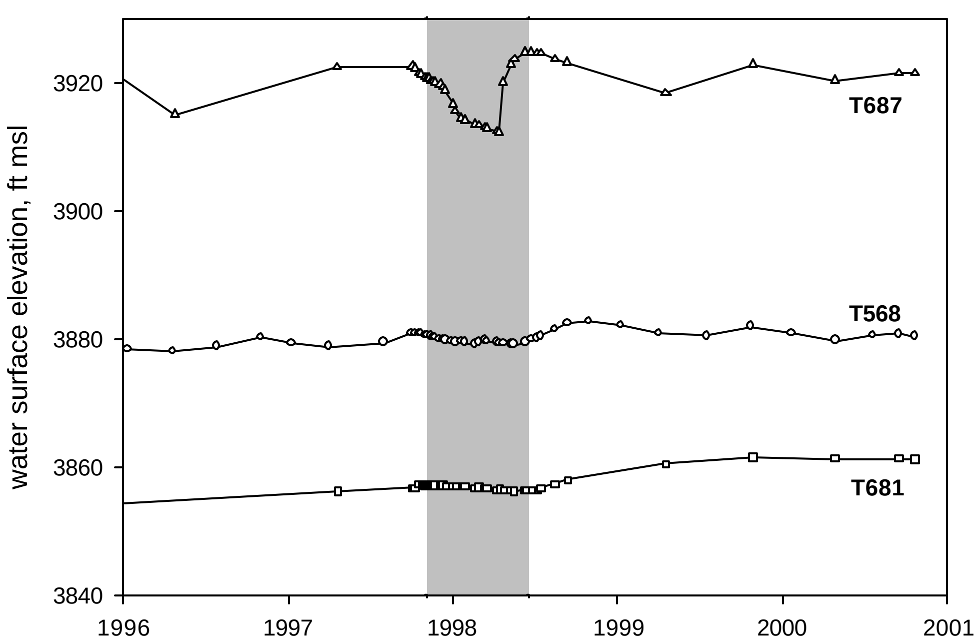

Figure 11. Shallow wells near 375W. Gray indicates when 375W was on

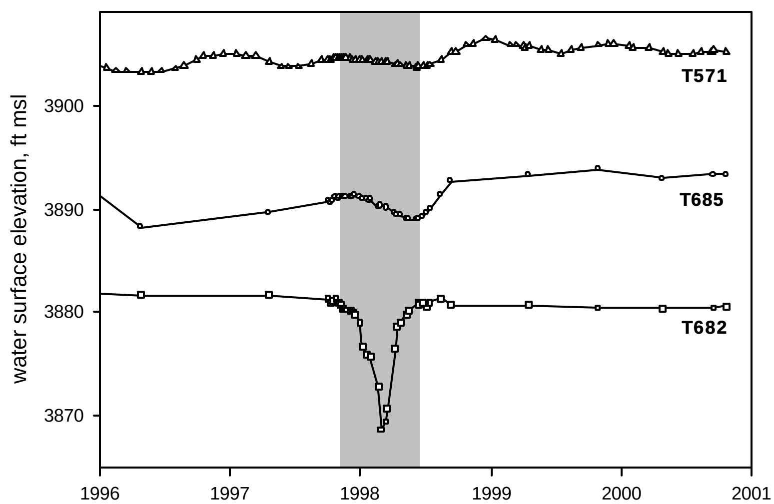

Figure 12. Shallow wells near 375W. Gray indicates when 375W was on.

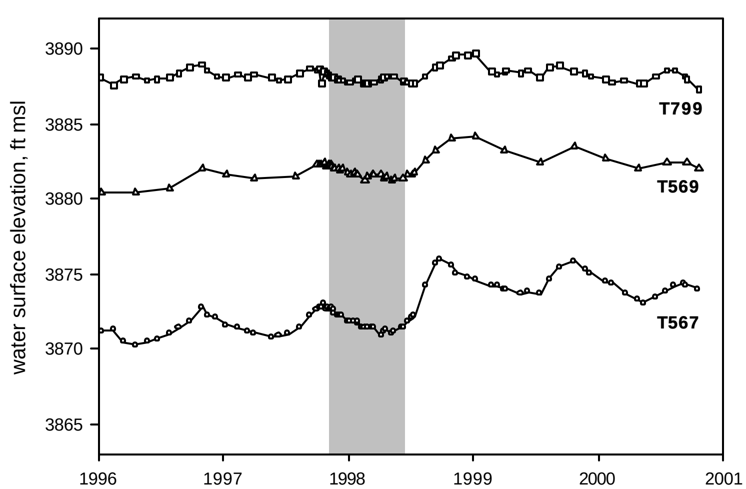

Figure 13. Shallow wells near 375W. Gray indicates when 375W was on.

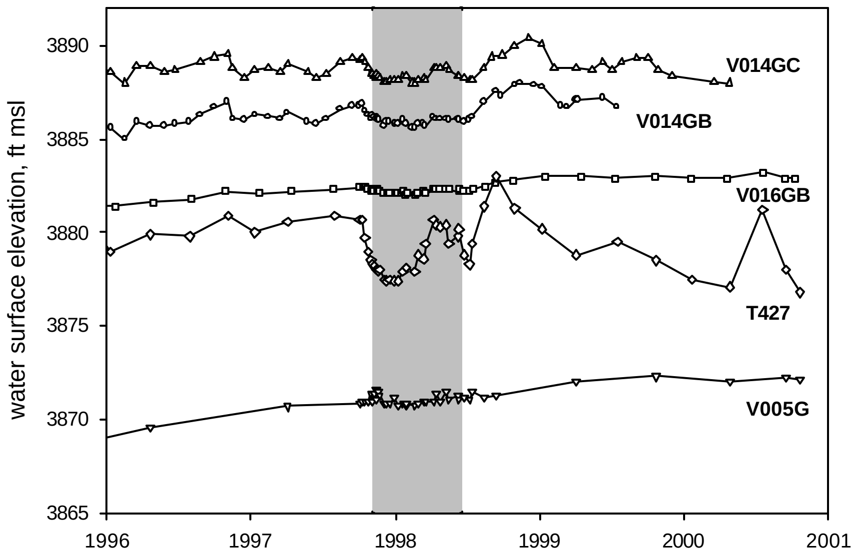

Figure 14. Shallow wells near 375W. Gray indicates when 375W was on.

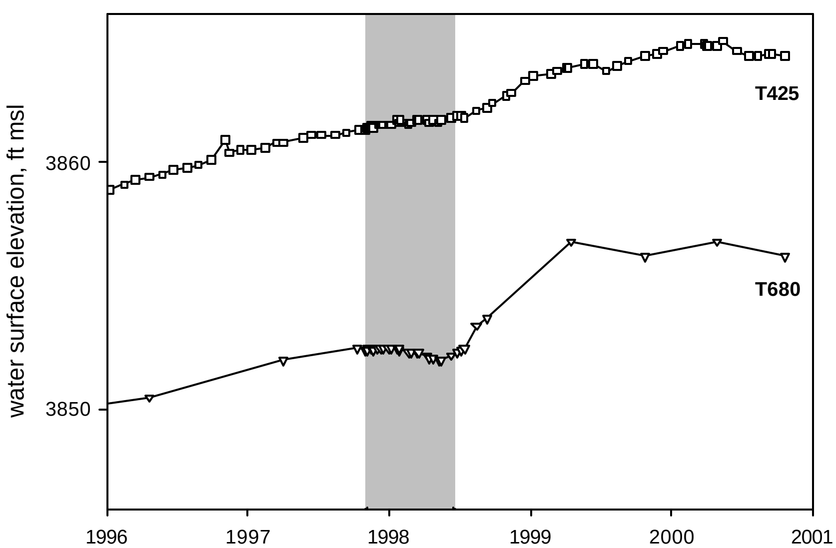

Figure 15. Shallow wells near 375W. Gray indicates when 375W was on.

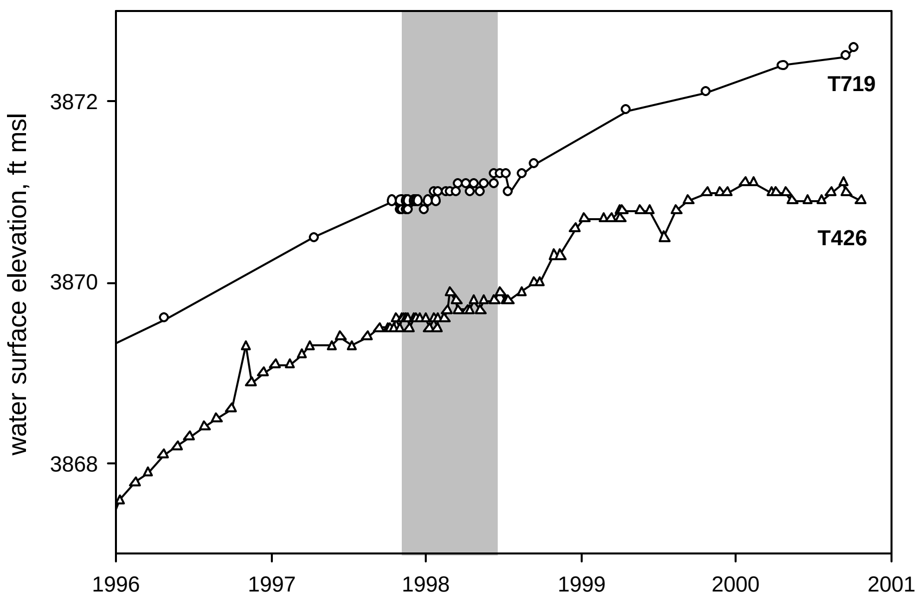

Figure 16. Shallow wells near 375W. Gray indicates when well was on.

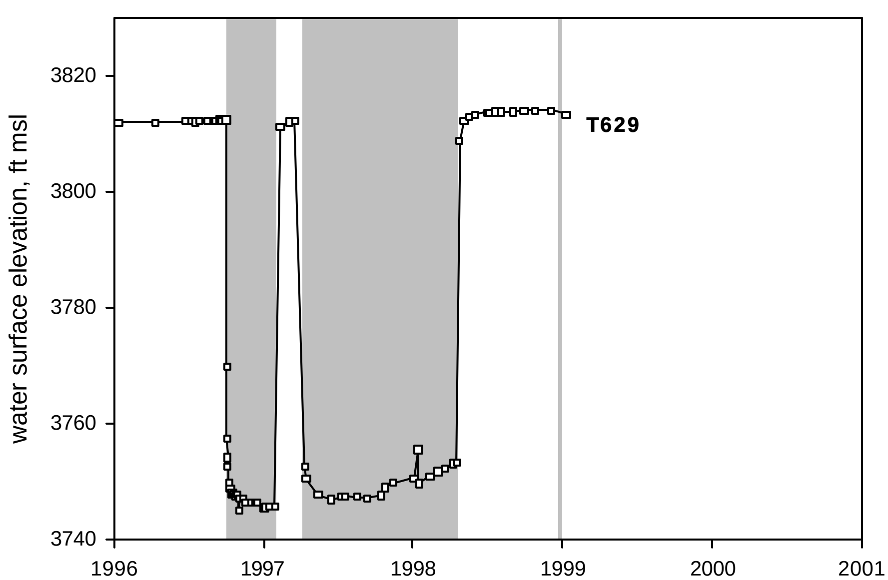

Figure 17. Deep well near 380W and 381W. Gray indicates when wells were on.

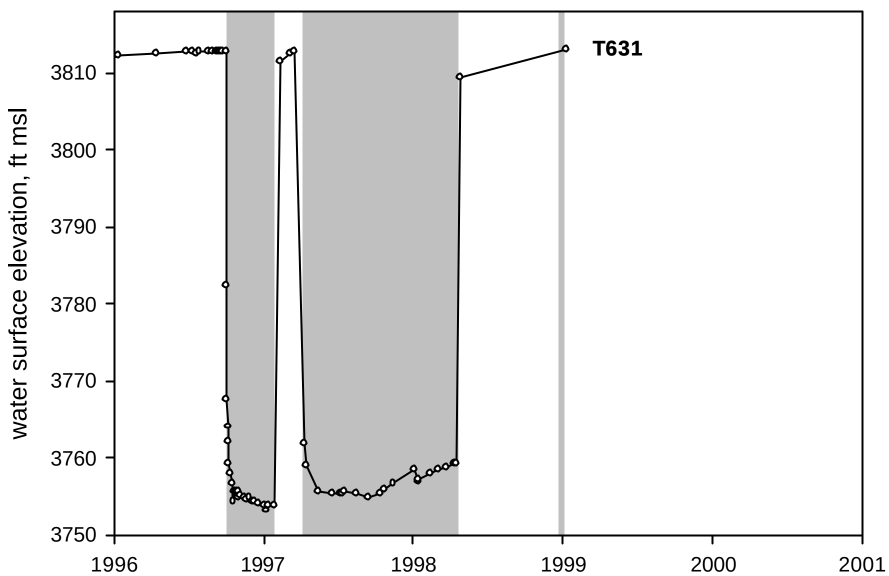

Figure 18. Deep well near 380W and 381W. Gray indicates when wells were on.

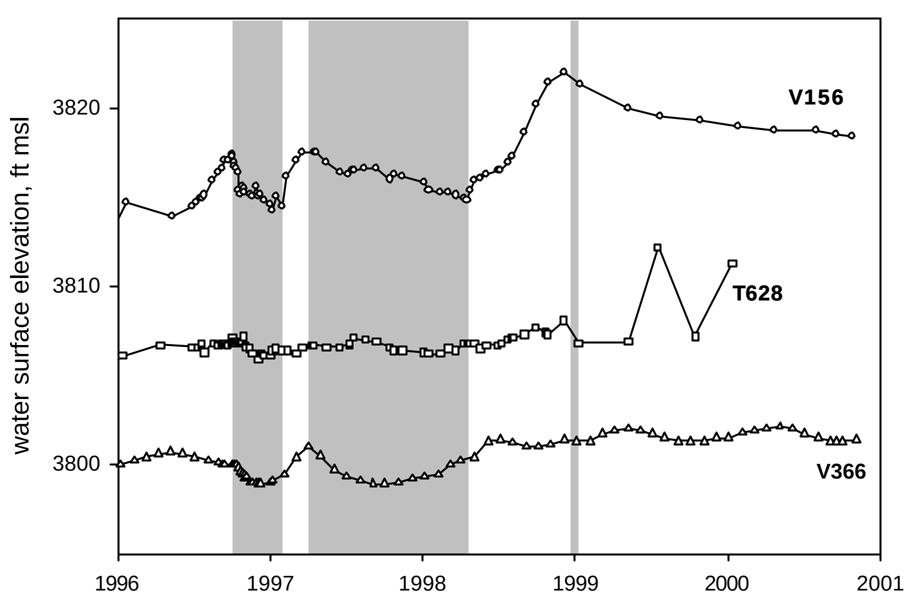

Figure 19. Deep wells near 380W and 381W. Gray indicates when wells were on.

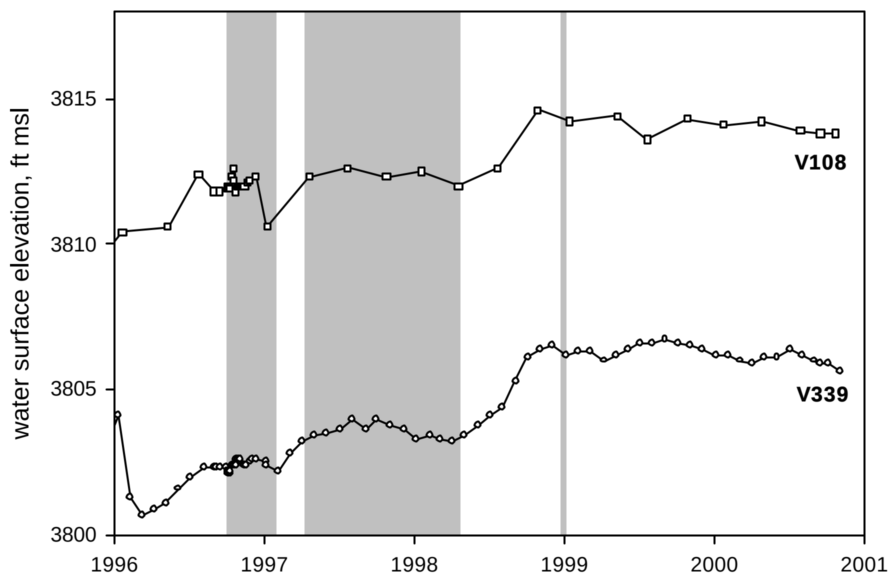

Figure 20. Deep wells near 380W and 381W. Gray indicates when wells were on.

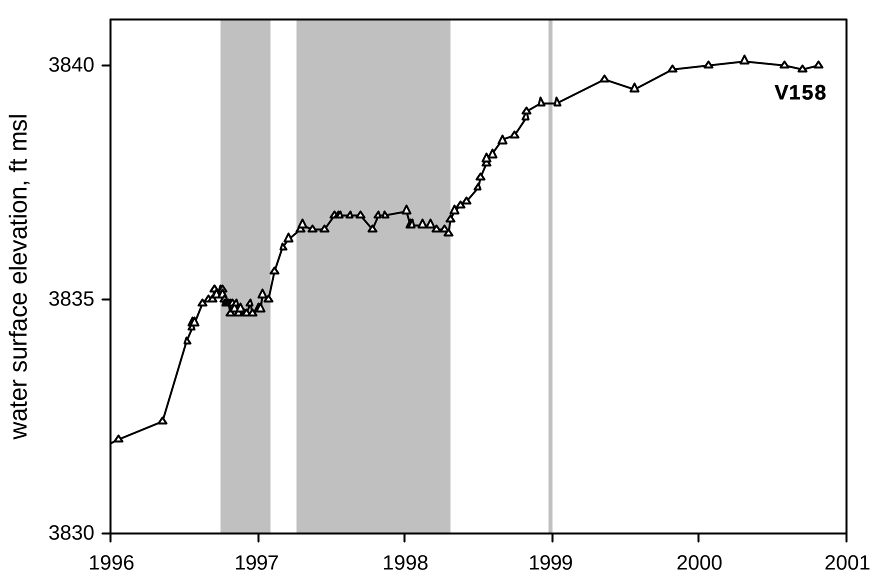

Figure 21. Deep well near 380W and 381W. Gray indicates when wells were on.

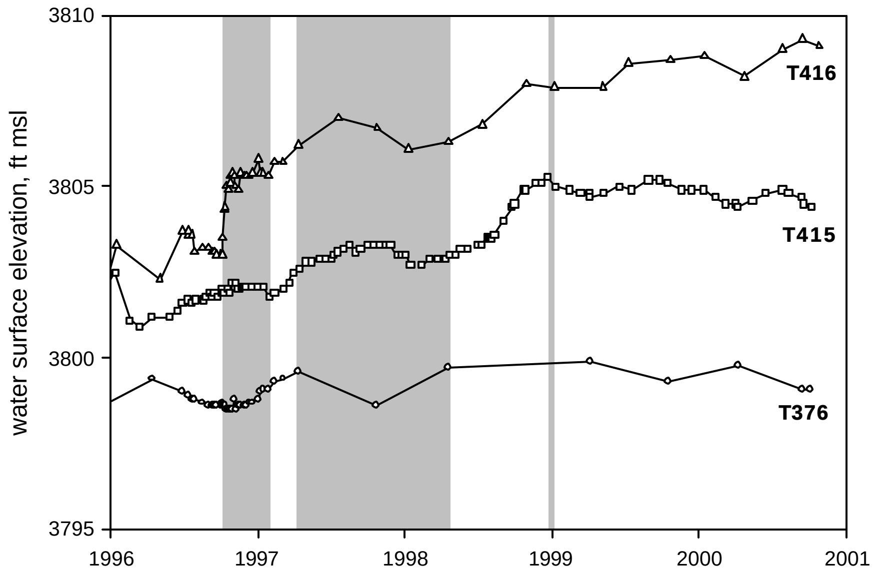

Figure 22. Shallow wells near 380W and 381W. Gray indicates when wells were on.

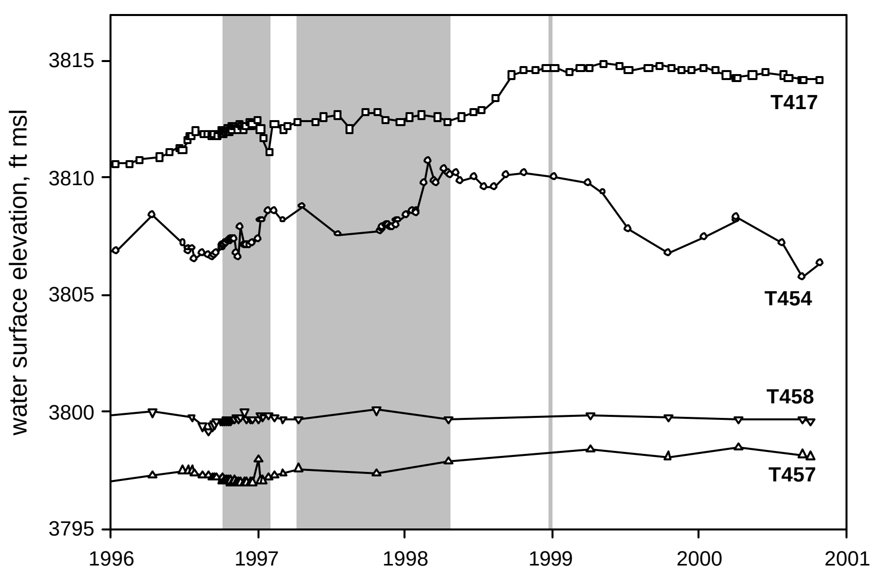

Figure 23. Shallow wells near 380W and 381W. Gray indicates when wells were on.

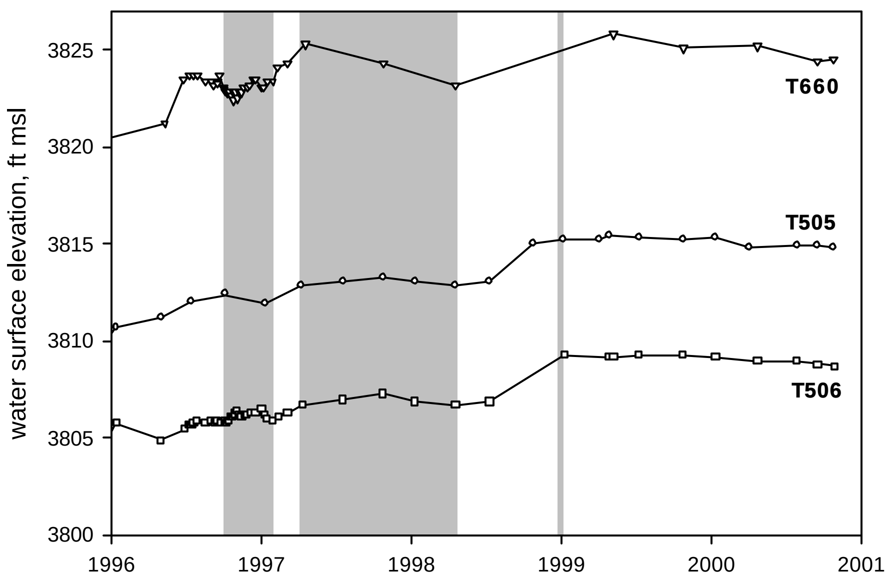

Figure 24. Shallow wells near 380W and 381W. Gray indicates when wells were on.

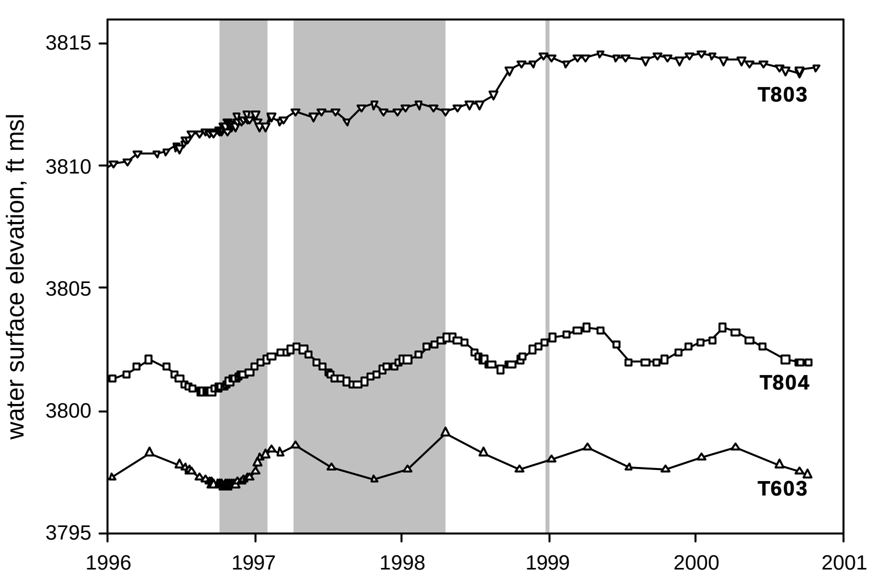

Figure 25. Shallow wells near 380W and 381W. Gray indicates when wells were on.

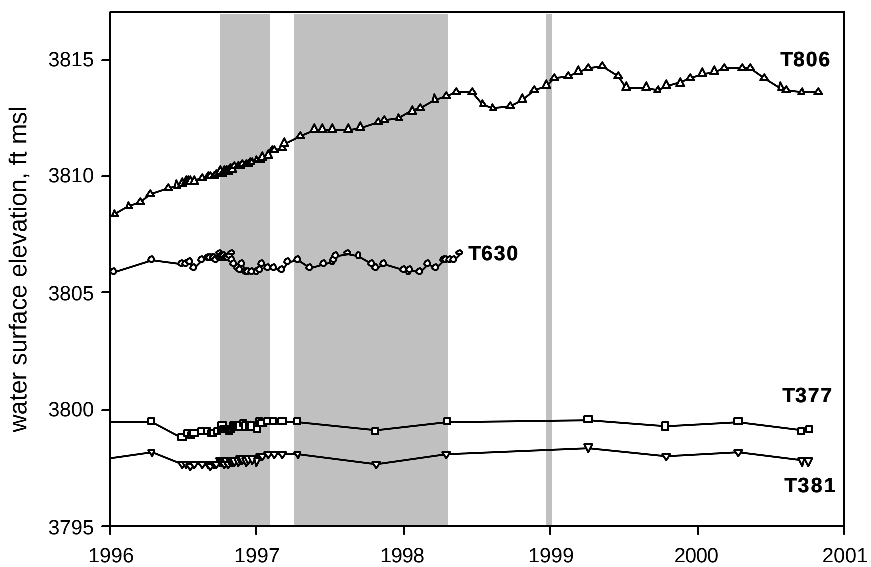

Figure 26. Shallow wells near 380W and 381W. Gray indicates when wells were on.

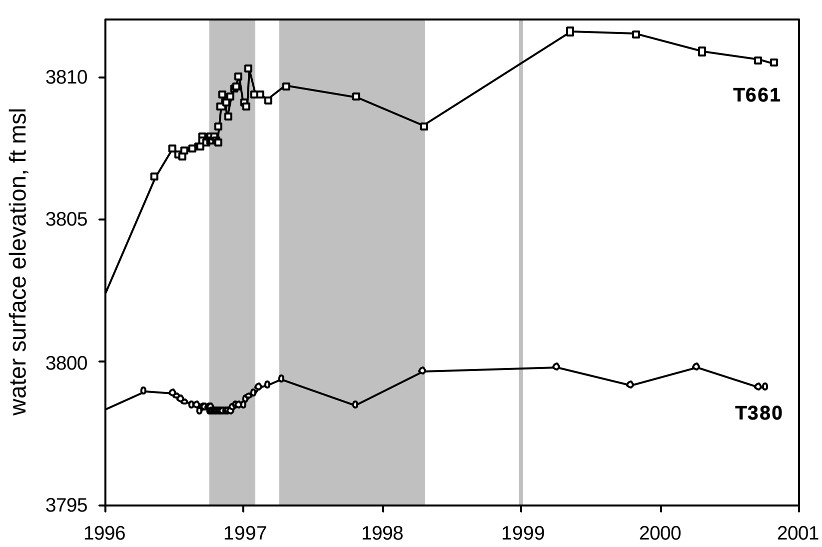

Figure 27. Shallow wells near 380W and 381W. Gray indicates when wells were on.

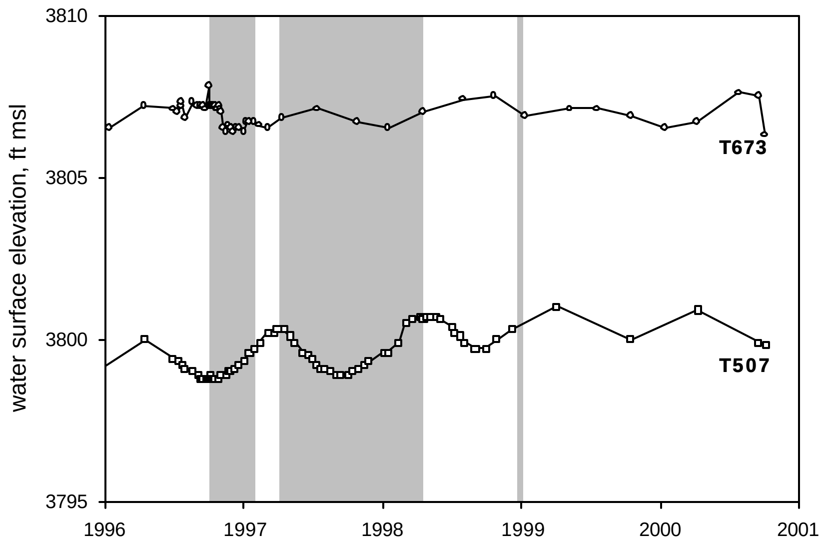

Figure 28. Shallow wells near 380W and 381W. Gray indicates when wells were on.

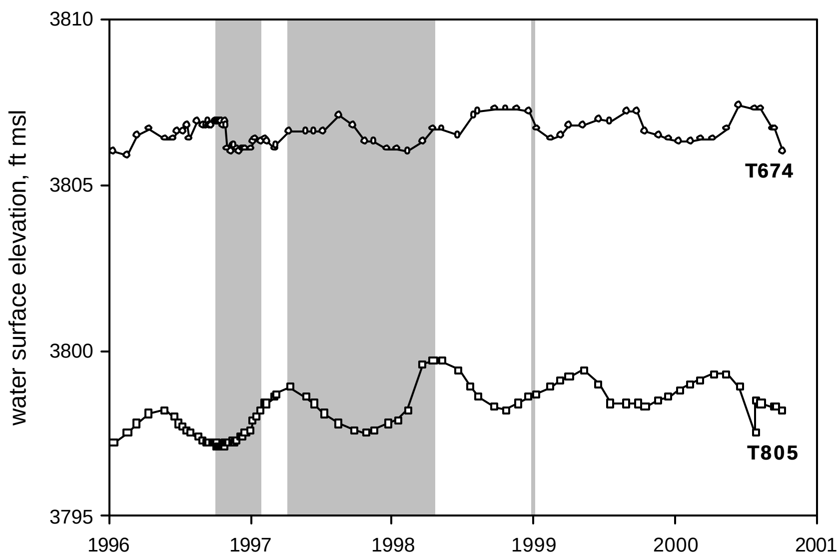

Figure 29. Shallow wells near 380W and 381W. Gray indicates when wells were on.

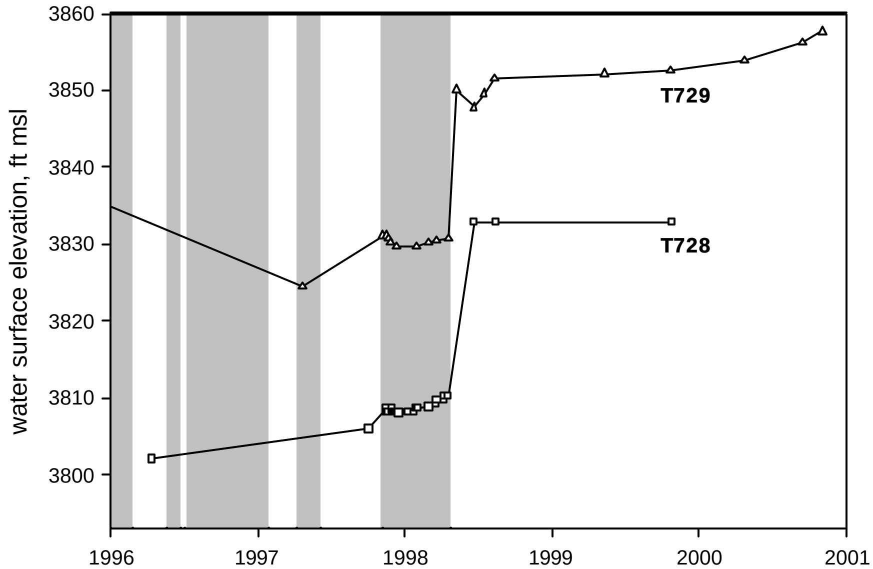

Figure 30. Deep wells near 382W. Gray indicates when 382W was on.

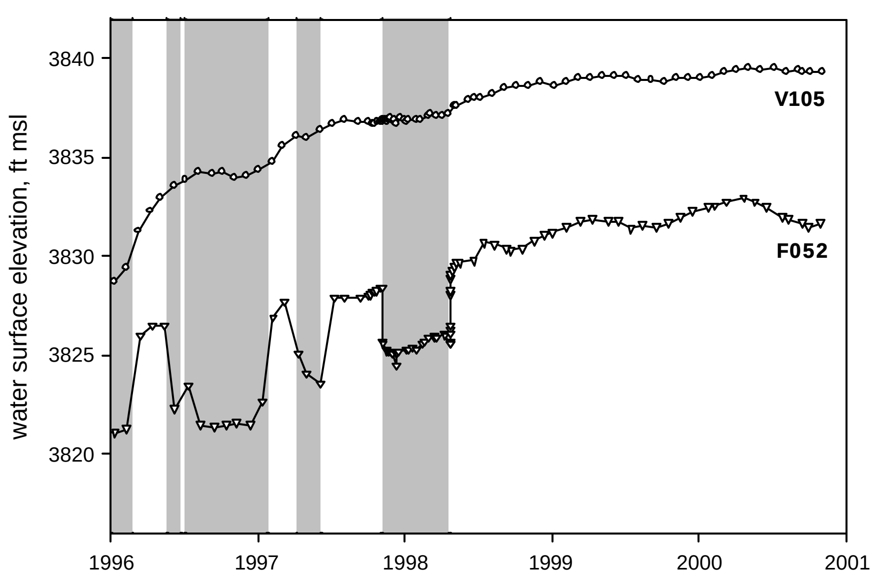

Figure 31. Deep wells near 382W. Gray indicates when 382W was on.

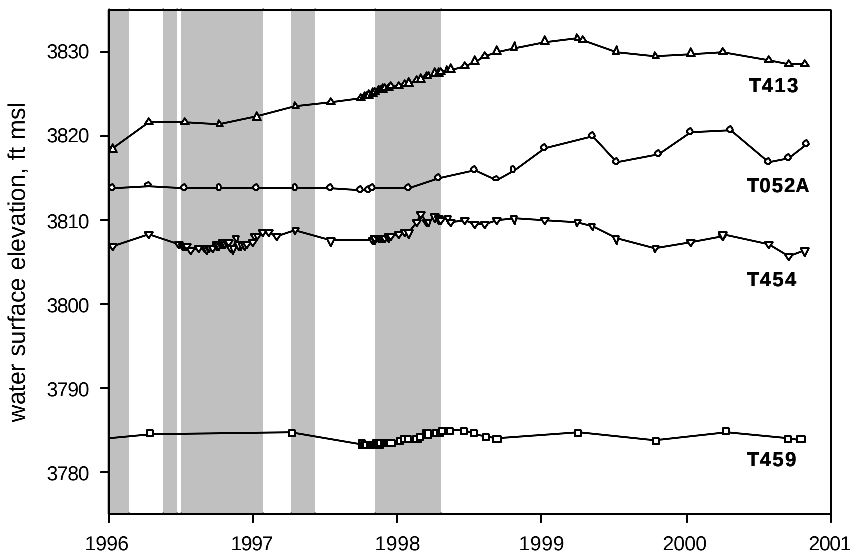

Figure 32. Shallow wells near 382W. Gray indicates when 382W was on.

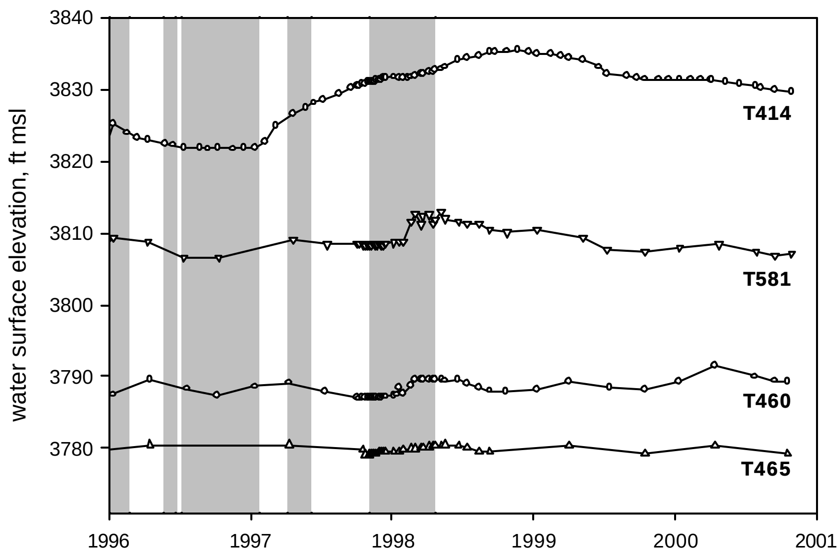

Figure 33. Shallow wells near 382W. Gray indicates when 382W was on.

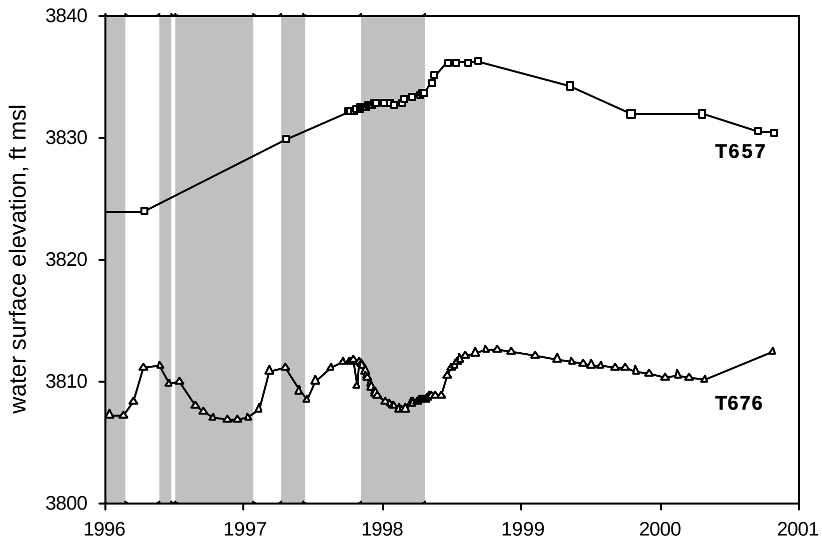

Figure 34. Shallow wells near 382W. Gray indicates when 382W was on.

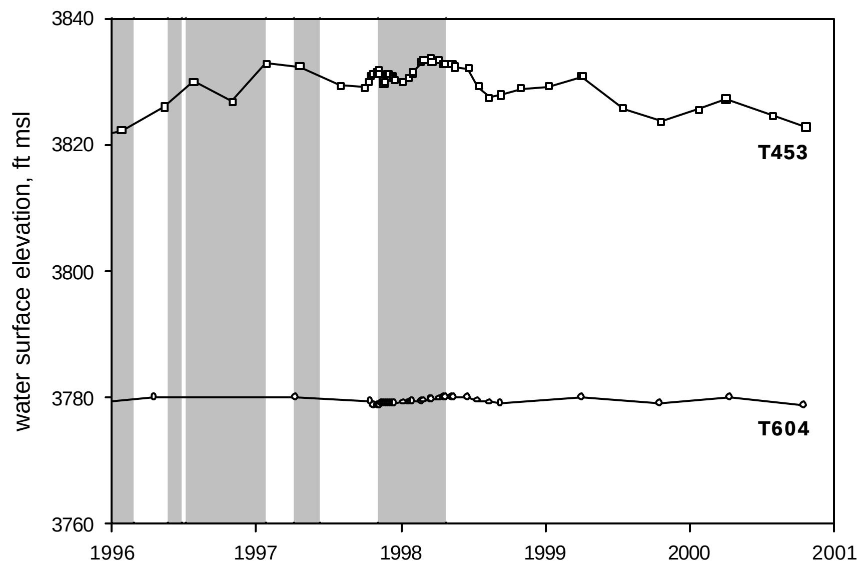

Figure 35. Shallow wells near 382W. Gray indicates when 382W was on.

Analysis. The timing of changes in water levels in observation wells monitored during the operational tests was compared to changes in hydrologic variables such as canal and aqueduct operation, river flows, and test pumping to get a qualitative sense of what variables influenced each observation well. By looking for contemporaneous changes in water level and external variables, the relative importance of various hydrological stresses was assessed. In a few cases (e.g., 631T, Figure 18), the effect due to test pumping is of far greater magnitude than other effects. In most cases, any effect of pumping is overprinted on background fluctuations of greater magnitude than the effect of pumping.

There are two general strategies for assessing background effects during aquifer tests. One is based on the assumption of spatially uniform background trends, the other based on temporally uniform background trends (Kruseman and de Ridder, 2000). If an observation well is distant enough from the pumped well that it is unaffected by the pumping, it can be used to define the background trend for wells closer to the pumped well. This requires that the well used to define the background trend be influenced by the same hydrologic variables as the pumping-affected wells nearer to the production well. In other words, the background trend must be spatially uniform, or at least is a simple function of location. Because of the extended period of time that the pumping wells were run during these tests, a large area encompassing a variety of local sources and sinks was potentially influenced by the test pumping; therefore, the assumption of a spatially uniform background trend is not met in these tests. An alternative is to observe trends in wells before and after the pump test and to interpolate the background trend through the period of the pump test. In this case, it is assumed that the background trend at each well is temporally uniform. Background trends observed during these tests were variable between wells, consisting of linear and nonlinear trends, periodic signals driven by seasonally varying recharge and discharge, step changes caused by stage changes in surface water conveyances, or combinations of these patterns. The complex form and uncertain cause of these background patterns renders all but a few of the records unsuitable for aquifer parameter estimation and no attempt was made here to estimate parameters. If one was to attempt to estimate parameters from these data, using the hydrograph before and after the test would be the more tenable way of discriminating pumping effects from background effects.

Results

375W test deep wells. Deep wells in the Big Pine area showed three distinct patterns. Wells 203V, 204V, and 212V (Figure 6) showed smooth annual periodic fluctuations with maxima in the late fall and minima in the late spring. Wells 216V, 221V, 224V, 228V, 229V, and 233V (Figures 6, 7, 8, and 9) showed an abrupt increase in spring of 1998 during the operational test. Wells V014GA and V016GA (Figure 6) increased steadily except for a clear effect due to the test pumping. The first two patterns appear to be related to operation of the Big Pine Canal (cf. Figure 4). Wells that penetrate volcanic rocks responded with abrupt increases when the canal flows increased in the spring of 1998 (Figure 4); however, it is not clear why the rise in water levels in 1998 was larger than during previous or subsequent years. 1998 was a heavy runoff year, and spreading operations west of Highway 395 may have contributed to the rise in water levels, but no records exist to confirm this. Conversely, wells 203V, 204V, and 212V responded gradually to the increase in canal stage although they are immediately adjacent to the canal. These three wells do not penetrate volcanic rocks. Wells V014GA and V016GA (Figure 6) were not affected by fluctuations in the Big Pine Canal. Aquifer parameters could be derived from the hydrographs for these two wells. Well 834V (Figure 7), at Steward Ranch, does not follow a pattern similar to any of the three described above, presumably because its fluctuations are largely governed by pumping for irrigation on the ranch and its source of recharge is primarily from the Wacoubi Embayment rather than from the Sierran range front.

375W test shallow wells. Patterns in shallow wells in the Big Pine area are more varied than patterns in deep wells. Wells 427T, 468T, 568T, 687T, V014GC, and V014GB (Figures 10, 11, and 14) began declining prior to the start of the test and recovered subsequent to the test, making it impossible to assess how much, if any, of the drawdown observed in these wells was attributable to test pumping. The declines prior to the start of the test were probably due either to reductions in Big Pine Canal or Owens River flows (Figure 1) or cessation of irrigation in the Steward Lane area in the early fall of 1997. Many wells (567T, 568T, 569T, 571T, and 685T; Figures 11, 12, and 13) show an annual cycle that peaks in the fall. Precipitation, irrigation, canal operations, pumpage, ET, stream flow, water spreading, and other natural and man-caused factors also exhibit quasiperiodic annual cycles, thus the relative importance of these sources of the annual fluctuations in these wells is difficult to identify and probably is influenced by multiple factors. It is likely that operation of the Big Pine Canal, stage of the Owens River, and irrigation influenced these hydrographs. For example, the abrupt rise in 687T (Figure 11) appears attributable to increased flow in the Big Pine Canal. Wells 427T, 799T, V014GC, and V014GB (Figures 12, 13, and 14) show less well-defined annual cycles, but are seasonally variable. The patterns in these four wells during the test are similar, but the amplitude of fluctuations in 427T is greater, probably in response to changes in stage of the Owens River (Figure 1). Wells 425T, 426T, 680T, 681T, 719T, V005G, and V016GB (Figures 11, 14, 15, and 16) have smoothly increasing trends with possibly a few inches of drawdown during the test superimposed upon the trend.

Pumping-induced drawdown from 375W. Deep wells V014GA and V016GA show clear responses to test pumping of 375W (Figure 6). Other deep wells may have been affected by test pumping, but the effect was not detectable because of fluctuations due to changes in recharge conditions. Shallow wells with smooth hydrographs show a slight deflection in the slope of the hydrograph during the test (425T, 426T, 719T, V005G, and V016GB). These wells are in the east and south part of the test area. Even with the relatively smooth background trends in these wells it is difficult to quantify the exact amount of pumping-induced drawdown in these shallow wells, because the effect of pumping appears to amount to at most a few inches of drawdown. However, the possibility of pumping induced drawdown of the shallow aquifer cannot be ruled out based on the results of these tests. Other shallow wells may have had similar or greater amounts of pumping induced drawdown than those identified above; however, the few inches of drawdown attributable to the test pumping may not have been discernable against the larger background fluctuations that were prevalent in the western and northern part of the test area. Wells 680T and 681T also show slight changes in slope during the test, but it is not clear whether this is part of a seasonal cycle or due to test pumping. It cannot be determined whether or not wells with large seasonal fluctuations or changes due to river stage were affected by test pumping.

380W/381W deep wells. Wells 629T and 631T (Figures 17 and 18), each within 100 ft of one of the pumping wells, showed clear responses to the test pumping of 380W and 381W. Several deep wells more distant from the pumping wells show more subdued, but clear, drawdown due to the test pumping (156V, V158, 339V, and 366V; Figures 19, 20, and 21). Other wells do not show a clear response to the test pumping (628T and 108V; Figures 19 and 20).

380W/381W shallow wells. Most shallow wells near wells 380W and 381W follow one of three patterns: (1) irregular hydrographs due to surface water fluctuations (415T, 416T, 417T, 454T, 460T, 630T, 661T, 673T, and 674T; Figures 22, 23, 26, 27, and 33); (2) smooth quasi-sinusoidal hydrographs with an annual period peaking in the springtime (376T, 377T, 380T, 381T, 457T, 458T, 507T, 603T, 804T, 805T, and 806T; Figures 22, 23, 25, 26, 27, 28, and 29), apparently due to the seasonality of plant transpiration; or (3) relatively smooth hydrographs (505T, 506T, and 803T; Figures 24 and 25). The shallow wells nearest the pumping wells fall into the first category, suggesting that water levels in the LA Aqueduct, the Blackrock Ditch, and the ponds at the Blackrock Fish Hatchery maintain the water table in this area. Wells displaying quasi-sinusoidal hydrographs lie east of the LA Aqueduct in areas of shallow groundwater, suggesting a linkage to climatological stresses.

Pumping-induced drawdown from 380W and 381W. Deep wells 629T and 631T near 380W and 381W showed about sixty feet of drawdown when the wells were operated. Deep wells more distant from the production wells also showed drawdown of up to a few feet of response (156V, 158V, 339V, and 366V). Pumping effects could not be detected in any shallow wells, either because effects were buffered by surface water, masked by other variations, or no pumping effects propagated to the shallow aquifer.

382W deep wells. Two deep wells within 200 ft of well 382W (728T and 729T; Figure 30) showed slight drawdown at the beginning of the test and abrupt recovery following the end of the test. These two wells were artesian before the test began and resumed flowing after 382W was shut off. No pressure data are available to quantify the head in these wells prior to the start of the test, but the cessation of flow was clearly related to operation of 382W. Well 052F (Figure 31) showed a clear response to pumping. Well 105V (Figure 31) possibly showed some drawdown due to test pumping of 382W, but the deflection of its hydrograph began before test pumping of 382W started. Interpretation of this hydrograph is complicated by effects due to pumping of 103W and 104W in late-1995 and test pumping from 380W and 381W. 105V is approximately equidistant from 382W and wells 380W and 381W.

382 shallow wells. Well 676T (Figure 34), about 50 ft from 382W, clearly showed drawdown due to operation of the well, but it is unclear whether this was due to leakage through the well seal, leakage through the aquitard, or cessation of artesian flow in nearby artesian wells. During the period of test pumping, abundant runoff and water spreading affected several shallow wells near 382W (453T, 454T, 460T, and 581T; Figures 32, 33, and 35). Wells 414T and 657T (Figures 33 and 34) showed slight deflections in their hydrographs that may be related to the test pumping. Wells 459T, 465T, and 604T (Figures 32, 33, and 35) showed smoothly varying hydrographs, apparently unaffected by test pumping or surface water spreading.

Pumping-induced drawdown from 382W. Artesian flow ceased in wells 728T and 729T when 382W was turned on and resumed when it was turned off. Well 052F showed a clear response to pumping and may be suitable for parameter estimation. 676T showed a clear response to operation of 382W, but as discussed above, the pathway by which this effect propagated to the shallow aquifer is unclear.

Conclusions and Recommendations

Operational tests. The two main conclusions to be drawn from these tests are: (1) that the problem of separating the effects of test pumping from effects of other factors severely hampers observation of pumping affects in the shallow aquifer, and (2) that operational testing as conducted in these tests to assess the effects of these wells is unlikely to provide a useful assessment of the long-term operation of these wells. In all but a few wells monitored during these tests, the assessment of pumping effects was inconclusive because of the large amount of external noise in the hydrographs compared to the modest signal due to pumping. Danskin (1998) states that, though confining pumping to the deep aquifer may reduce impacts to the shallow aquifer, sustained pumping of such wells will eventually affect groundwater dependent vegetation by propagation of drawdown around the margins of confining clay layers. Were this to occur, impacts would be far progressed before they were detectable in the shallow aquifer. Regarding the original goal of the tests, they were successful in showing that the hydraulic linkage between the production wells and their associated monitoring sites is not a reliable management strategy. In cases where effects of test pumping were qualitatively detectable, in most cases the background effects appeared sufficiently complex that any attempt at parameter derivation by standard aquifer test analysis techniques would be subject to large errors. Furthermore, conducting operational tests by operating these wells and monitoring for drawdown, even for longer than a year as done for 380W and 381W, does not provide a clear assessment of the long-term effects of operation of these wells. A more viable strategy would be to design and conduct aquifer tests so that they support a modeling effort directed at assessing pumping impacts, thereby accounting for the many factors contributing to each hydrograph and providing the capability to simulate long periods of well operation.

In the area of 375W, these tests suggested that drawdown may be propagating through or around confining layers east and south of 375W. Further work should be aimed at confirming or refuting this hypothesis by quantifying the aquifer confinement in the area. The linkage between the stage of surface water conveyances and hydraulic head in aquifer systems should be determined, because this linkage appeared to control many of the hydrographs during the test. Further, the linkage between various local hydrostratigraphic units should be determined, in particular, the linkage between volcanic rocks related to Crater Mountain and the fluviolacustrine deposits of the valley floor appeared to control the response to recharge from the Big Pine Canal. Any further operational testing should be aimed at establishing hydraulic parameters, extent of confinement, and hydrostratigraphic and structural relationships to support a numerical model of the Big Pine area.

In the 380W/381W area, testing suggested that surface water buffered pumping effects near the wells, but effects propagated long distances from the wells. Surface water buffering southeast of wells 380W and 381W will probably increase in the future as the Blackrock Waterfowl Management Area is intermittently inundated as part of the Lower Owens River Project. Drawdown was observed in deep wells near the alluvial fans west of 380W/381W, indicating that the mechanism identified by Danskin is probably active in this area. Further operational testing of 380W/381W is unlikely to yield any additional information unless aimed at supporting a modeling effort, e.g., aquifer testing to determine confining layer characteristics. An observation well was drilled in 2000 into the confining layer near wells 380W and 381W for the purpose of evaluating confining layer properties. An aquifer test should be designed and conducted using this well as part of the confining layer cooperative study.

During the 382W test, drawdown related to the test was observed in shallow well 676T near the pumping well. It remains unclear how drawdown propagated from the deep aquifer to 676T. Possible pathways by which drawdown in the deep aquifer might have been communicated to the shallow aquifer are propagation through the confining layer by Darcian flow, flow through natural breaches in the confining layer such as faults or fractures, propagation around confining layers where they pinch out or grade into more permeable material, propagation through abandoned wells that are completed in both the deep and shallow zones, leakage past the seal in the pumping well, or propagation through artesian wells. The role played by the artesian flows in maintaining the water table could be investigated by temporarily sealing the artesian wells and observing the response of well 676T, however, it is not necessary to answer this question before a monitoring program could be developed. Well 382W differs from 375W, 380W, and 381W in that there are clearly identifiable groundwater dependent resources near the well. Extensive spring and seep areas and areas of phreatophytic vegetation in the Thibaut Springs area are within 0.5 miles of 382W (Ecosystems Sciences, 2000), as well as rare plant populations east of the LA Aqueduct. Monitoring should be installed to observe any affects of 382W on these areas.

Future management of wells sealed to deep aquifers. Wells 375W, 380W, 381W, and 382W withdraw water only from the deep aquifer, and as a consequence the cones of depression of these wells affects a greater area than would be affected if an equivalent amount of water was withdrawn from both the deep and shallow aquifers. When wells extract water directly from the shallow aquifer, it can be expected that the impact on water levels in the shallow aquifer will be a function of distance from the pumping well; however, when extraction is limited to the deep confined zone, impacts to the shallow aquifer will depend on the properties and extent of the confining layer.

Of particular concern is the possible impact of these wells on spring, seep, wetland, or riparian resources that occur where groundwater emerges due to structural or stratigraphic controls on groundwater flow (e.g., faults that allow upward flow through confining layers, or facies changes that terminate confining layers). Existing knowledge of the characteristics of the confining layers is insufficient to predict when and where effects will reach the shallow aquifer system; therefore, it is recommended that management for these wells be focused on identification of areas within the radius of influence of these wells that might be impacted and developing monitoring for those areas. Section I.V.3 of the Green Book (City of Los Angeles and Inyo County, 1990) notes that Type D vegetation is more sensitive to water deficits than Types A, B, or C, and specifies that the effectiveness of existing management methods will be evaluated and appropriate monitoring and management methods developed. It should further be recognized that the delineation of Type D as defined by the management maps appended to the Agreement may be insufficient to fully identify all the riparian and marshland areas within the radius of influence of these wells. For example, the Thibaut Springs area near well 382W is identified by Ecosystem Science (2000) as spring area (DWP 11), but is designated as Type C on the Agreement management maps.

A study is identified in Section V.B.8 of the Green Book (City of Los Angeles and Inyo County, 1990) aimed at developing effective monitoring for riparian and marshland vegetation. LADWP is currently developing this study. It is recommended that monitoring for spring, seep, and riparian areas within the radius of influence of wells sealed to the deep aquifer be incorporated into this study.

LADWP and Inyo County are currently engaged in two other cooperative studies that should prove useful in designing management for these wells. One cooperative study is aimed at evaluating the hydraulic properties of confining layers; the other is aimed at improving hydrological modeling tools. Together, these studies should provide tools for assessing the radius of influence of these wells, and provide information about the timing and location of drawdown propagating from the deep to the shallow zones. It is recommended that development of alternative management of these wells be addressed within the scope of these studies, and that data from the tests be incorporated into these studies. If in the course of these studies data gaps are identified, LADWP and Inyo County should seek joint funding for research to address them.

The following steps are a suggested outline for the development of a management program for these wells:

1. *Identify the radius of influence of these wells.* This task consists of developing and using groundwater models to delineate the area within which groundwater dependent resources might be impacted due to pumping from the wells.

2. *Identify groundwater dependent resources within the radius of influence of these wells.* Likely areas to be impacted are spring and seep areas, where groundwater

emerges along faults or through artesian wells, or areas where confining layers are inferred to grade into more permeable material (for example, at the toe of an alluvial fan). It should also be recognized that Type B and C vegetation may be impacted if drawdown propagates to the shallow aquifer.

3. *Identify the allowable fluctuation in measurable hydrological variables at the identified resources.* Ecosystem water requirements should be estimated and the water source identified for the resources identified in the second step.

4. *Identify a monitoring program for the identified resources.* Management should be based on monitoring of hydrologic conditions (surface water and groundwater levels, hydraulic gradients, and flow rates) rather than vegetation or soil water conditions, because once a measurable decline in vegetation has been observed, impacts may be irreversible or expensive and difficult to mitigate. Monitoring and management based on hydrologic conditions will identify pumping-induced changes earlier than either vegetation or soil water monitoring. In addition, once water level or flow measurement devices are installed, hydrological monitoring is easier and more certain than vegetation or soil water measurements. This monitoring program should be designed to identify baseline hydrologic and biologic conditions, provide data to verify modeling results, monitor conditions during well operation, provide management triggers to govern well operation, and monitor recovery in the event that triggers are exceeded. Monitoring may be at the identified resource, or at trigger locations between the production well and the resource. Hydrological monitoring may consist of surface water levels; spring discharge; groundwater levels in spring, seep, or phreatophyte areas; groundwater levels at intervening trigger locations; and/or vertical gradients in hydraulic head. Trigger locations intermediate between the production well and the resource may be preferable if the resource is so sensitive that no fluctuation is allowable, or if measurement at the resource is impractical. The monitoring program should also identify a sampling schedule and schedule for reporting to the Technical Group. This program should recognize that spring, seep,

and wetland vegetation is more immediately sensitive to water deficits than groundwater dependent scrub and alkali meadow communities.

5. *Define operational rules for a well management program based on the monitoring program.* Required components of this program are definitions of monitoring components and trigger points that direct changes in well management, actions that occur when trigger points are exceeded, means of determining when resources or triggers have recovered, and decision-making mechanisms that implement management of well operations.

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