Water Adequacy and Constant Rate Pumping Tests of

ICR 1 on January 28-29, 2015 and ICR 2 on May 20-21, 2016

Prepared for

ICR WATER USERS ASSOCIATION

By

William Meyer

Executive Summary

Water for Inscription Canyon Ranch, Whispering Canyon, and Preserve at the Ranch subdivisions is provided by the Inscription Canyon Ranch Water Users Association (ICRWUA) from the ICR well field consisting of two wells, referred to as ICR 1 and ICR 2. The yield of both wells is essentially the same, varying from about 370 to 390 gallons per minute (gpm) and averaging about 375 gpm.

Prior to offering lots for sale in the three subdivisions, the developer of each subdivision was required to obtain a Water Adequacy Report from the Arizona Department of Water Resources (ADWR) indicating that the proposed development has a sufficient water supply to meet the projected demand of the development for 100 years. Once demonstrated to ADWR's satisfaction, and upon issuance of a Notice of Intent to Serve by ICRWUA, ADWR issued Water Adequacy Reports for each of the developments. The Water Adequacy Reports were issued for all three subdivisions based on an analysis of the 100-year capacity of ICR 1 following its construction in 1994 and estimates of the annual rate of water movement into and through the aquifer tapped by the ICR well field. ICR 2, constructed in 2002, is about 47 feet from ICR 1. Its capacity was never tested.

Given that more than 21 years have passed since testing of ICR 1 and the lack of testing at ICR 2, the Board of Directors of ICRWUA decided to run tests on both wells in order to re-evaluate the well field's long-term capacity.

The wells were individually tested with a 24 hour constant rate pump test being conducted at ICR 1 from January 28-29, 2015 and a 26 hour test conducted at ICR 2 from May 20-21, 2016. The rate of pumpage and the decline in water levels through time were measured in the pumped well as well as the decline in water level in the non-pumped well in each test. Among other things the tests were designed to allow determination of the hydraulic properties of the aquifer that the well field is located in.

Based on present usage, the annual well field demand at full build-out of the subdivisions to 794 homes is estimated at 73,000,000 gallons, or an average demand of about 200,100 gallons per day (gpd) and an average daily demand of about 139 gallons per minute (gpm) at the well field. Using this demand and aquifer properties determined from the 2015 and 2016 tests in the Theis Equation indicates that either ICR 1 or ICR 2 is more than capable of meeting this demand. The predicted 100-year depth to water below land surface would be about 75 feet compared to a well depth of 220 feet.

Water Adequacy and Constant Rate Pumping Tests of

ICR 1, January 28-29, 2015
ICR 2, May 20-21, 2016

Purpose of the Tests

Water for the Inscription Canyon Ranch, Whispering Canyons, and Preserve at the Ranch Subdivisions is provided by the Inscription Canyon Ranch Water Users Association (ICRWUA) from water derived from the ICR well field consisting of two wells, referred to as ICR 1 and ICR 2 (registration numbers 55-542062 and 55-590550 respectively). ICR 1 serves as the primary well with ICR 2, located about 47 feet from ICR 1, serving as a back-up well. The yield of both wells is essentially the same varying from about 370 to 390 gallons per minute (gpm) depending on the pumping water level.

A test of the capacity of ICR 1 was conducted in 1994 immediately following its construction, while ICR 2 was never tested. Given that more than 21 years have passed since testing of ICR 1 and that the lack of testing at ICR 2, the Board of Directors of ICRWUA decided to conduct a test of each well in order to evaluate its long-term capacity. The wells were individually tested with a 24 hour constant rate pump test being conducted at ICR 1 from January 28-29, 2015 and a 26 hour test conducted at ICR 2 from May 20-21, 2016.

The well field currently (May 2016) serves about 307 residential customers and also provides a relatively small amount of water for irrigation of plants on commonly owned property, commercial purposes, and construction of new homes.

Average annual demand for all purposes over the last eight years (2008-2015) has averaged about 26,500,000 gallons (table 1) corresponding to an average daily demand at the well field of about 50 gallons per minute (gpm) and an average daily demand per residence of approximately 252 gallons per day (gpd). Based on present usage, the annual well field demand at full build-out of the subdivisions to 794 homes is estimated at 73,000,000 gallons, or an average demand of about 200,100 gpd and an average daily well demand of about 139 gpm. The well tests were specifically designed to evaluate the ability of the ICR well field to meet this demand.

Table 1 Annual ICR Well Field Demand, 2008 – 2015, in gallons

2008	2009	2010	2011	2012	2013	2014	2015
25,934,023	29,988,500	24,476,500	25,125,980	27,012,000	26,375,000	27,500,000	25,669,000

Water Adequacy Reports

Each of the three subdivisions has a Water Adequacy Report issued by the Arizona Department of Water Resources (ADWR). This report certifies that the developer has demonstrated to the satisfaction of ADWR that the subdivision has a water supply capable of meeting the projected demand of the development for 100 years. The source of water identified to ADWR was based on the yield of ICR 1 and the recharge rate of the aquifer in which the well is located. ICRWUA is identified as the water provider. ADWR's issuance of a Water Adequacy Report therefor required a Notice of Intent to Serve from ICRWUA.

Among other things, the proof of a 100 year water supply normally requires a hydrologic report discussing the water demand of the proposed development and the ability of the aquifer to meet that demand. The ability of an aquifer to provide a long-term water supply is based on an estimate of the volume of water passing through a known section of the aquifer over the year referred to as the Darcy Flux or on the long-term average recharge to the aquifer.

In addition to evaluating the ability of the aquifer to meet the requirement for a long-term water supply for the three subdivisions, ICRWUA also must evaluate the long-term ability of the ICR well field to meet this demand, particularly ICR 1. This requires comparing the projected water level decline occurring in ICR 1 as a result of continuously withdrawing 139 gpm for 100 years to the available drawdown in the well. The Theis Equation is one of the methods commonly used to accomplish this while in more complicated cases a digital model of the groundwater system is used. Both methods require knowledge of the construction details of the well and the transmissivity and specific yield of the aquifer. Transmissivity measures the ease that water can move through an aquifer while specific yield quantifies the amount of water released by the aquifer per unit decline in water level.

Construction of ICR 1 began on June 24, 1994 and was completed on August 5, 1994. Total depth of the well is 260 feet. The well is screened from a depth of 40 feet below land surface to 200 feet with a surrounding gravel pack. Depth to water at the completion of its construction was 19.35 feet below land surface.

Following construction of ICR 1, Manera Inc. (1994) conducted a three-day constant rate pump test on the well from August 24-27, 1994 for Williamson Valley Investors, Ltd. This consisted of pumping the well at a constant rate for three days and observing the decline of the water level in the well and in another well located 147 feet from ICR 1. Based on the test results Manera Inc. calculated the transmissivity of the aquifer, assumed a value for the specific yield, and based on an analysis utilizing the Theis Equation, concluded that the long-term yield of the well exceeded 450 gpm (726 acre-feet per year (af/y)). Manera, Inc. also concluded that the decline in water level after continuously pumping the well at 462 gpm for 100 years would be less than

53.86 feet. In addition to calculating the 100 year drawdown at ICR 1, Manera Inc. calculated an average recharge to the aquifer in the vicinity ICR 1 equal to 3,430 af/y.

The above conclusions were submitted to ADWR in support of a Water Availability Report for a proposed development (Inscription Canyon Ranch) of 1,000 dwellings located over 4,100 acres with a water demand of 343 acre-feet per year (equivalent to an average daily pumping rate of 213 gpm). The Water Availability Report was issued November 21, 1994. A Water Availability Report was initially used by developers and ADWR as a means to speed the process for a Water Adequacy Report.

Access to ICR 1 is provided by a Water Purchase Agreement between ICRWUA and Pierce Properties, LTD. (subsequently Aqua Meadows, LLC.) dated August 1, 1995 wherein Pierce Properties, LTD. agreed to sell and ICRWUA agreed to purchase a wholesale water supply from ICR 1 not to exceed 100,000,000 million gallons per year (gpy) (307 af/y, or 190 gpm at the well), or such lesser amount as the well may produce, for existing and future customers in ICRWUA's certified service area. Under this agreement, ICRWUA could deliver water only to the proposed developments of Inscription Canyon Ranch and Preserve at the Ranch Subdivisions.

The Water Availability Report was followed by a Water Adequacy Report dated November 15, 1995 based on the Manera Inc. report for Phase 1 of the Inscription Canyon Ranch Subdivision consisting of 323 residential lots with a water demand of 110.65 af/y or approximately an average daily demand of 70 gpm at the well. This demand, of course, is significantly below the estimated yield of ICR 1 and the average recharge rate to the aquifer calculated by Manera Inc., thereby allowing ADWR to issue the Water Adequacy Report.

The developer of the Inscription Canyon Ranch Subdivision subsequently increased the planned number of residential units at the Inscription Canyon Ranch Subdivision from 323 to 369 (Unit 5), an addition of 46 single-family units), and submitted a hydrologic report by Southwest Ground-water Consultants, Inc. (SWGC) dated July 6, 2001 to ADWR in support of a Water Adequacy Report for the expansion. The Water Adequacy Report was granted September 14, 2001. Water demand for Unit 5 was 10.3 af/y and ICR 1 remained the source of water supply. This report brought the total water demand for ICR 1 to 120.95 af/y (39,408,993 gpy or 75 gpm at the well).

Amendment Number One to the Water Purchase Agreement dated July 24, 2001 added Whispering Canyon to the area ICRWUA could deliver water to from ICR 1 and allowed ICRWUA to pump an additional 64,518,498 gpy for a total of 164,518,498 gpy (504.92 af/y or 313 gpm at the well).

On August 14, 2001 SWGC submitted a hydrologic report to ADWR in support of an application for a Water Adequacy Report on behalf of the Developer of Whispering Canyon Subdivision. In their report dated July 16, 2001, SWGC projected the water demand of the subdivision at 89.8 af/y and ICR 1 was identified as the source of water supply. SWGC re-evaluated the 1994 test at ICR 1 to determine a different value for transmissivity of the aquifer from that of Manera Inc. and increased recharge to the aquifer from the Manera Inc. value of 3,340 af/y to 8,207 af/y. ADWR issued a Water Adequacy Report for the development on March 7, 2002. This brought ICRWUA's total committed water demand from ICR 1 to 210.75 af/y (68,668,420 gpy or 131 gpm).

The Water Adequacy Report was dependent on inclusion of Whispering Canyon into ICRWUA's service area, a requirement that was granted by the Arizona Corporation Commission on March 25, 2002. Following this, ADWR issued a Revised Water Adequacy Report for Whispering Canyon dated August 27, 2002.

As part of their decision to allow ICRWUA to extend its service area to include Whispering Canyon, the Arizona Corporation Commission required that ICRWUA have ownership of its own well in recognition of the fact that ICRWUA did not actually own ICR 1. In an effort to partially meet this requirement ICR 2 was drilled with the intent to use the well solely as a back-up well.

Constructing of ICR 2 began on March 30, 2002 and was completed April 10, 2002. Total depth of the well is 300 feet based on the well log and 260 based on the as-built diagram. The well is screened from 40 feet below land surface to 200 feet with a surrounding gravel pack from 35 feet below land surface to 260 feet. No tests were conducted at the well.

On July 6, 2004 ICRWUA signed a Notice of Intent to Serve Talking Rock Ranch Phase 26 (Preserve at the Ranch Subdivision) consisting of 38 residential lots with an estimated water demand of 2,760,130 gpy (8.47 af/y). On September 28, 2004, ADWR issued a Water Adequacy Report for phase 26. Although the Water Adequacy Report was based on the ADWR letter of December 2001 stating that 347 af/y of groundwater will be physically available for the Talking Rock Ranch Subdivision and therefore not directly related to the ICR well field, the water demand of Phase 26 was added to the demand from ICR 1 bringing the total demand on the well to 71,428,550 gpy (219.22 af/y or 136 gpm).

As discussed above, based on present usage, the water demand at the ICR well field for full build-out of the ICR, Whispering Canyons, and Preserve at the Ranch Subdivisions to 794 residential homes is projected at 73,000,000 gpy (224 af/y.) that, in turn, equates to an average daily pumping demand at ICR 1 of 139 gpm compared to the present average daily demand of about 50 gpm and the present pumping capacity of ICR wells 1 and 2 of about 375 gpm each. A summary of the Water Adequacy Reports issued for the three subdivisions is provided in table 2.

Table 2 Residential Units, Water Demand, and Water Adequacy Reports – ICR Well Field

Subdivision	**Residential Units**	**Water demand (af/y)**	**Average Daily Demand (gpm)**	**Water Adequacy Report**
Inscription Canyon Ranch, Phase 1	323	110.65	70	November 15, 1995
Inscription Canyon Ranch, Phase 5	46	10.3	5	September 14, 2001
Whispering Canyon	400	89.8	56	March 7, 2002 August 27, 2002
Preserve at the Ranch	38	8.47	5	September 28, 2004[1]
Totals	807[2]	219.22	136	

[1] Water Adequacy Report not directly related to ICR well field.

[2] Only 356 residential units were actually platted in the Inscription Canyon Ranch Subdivision, 13 less than indicated in Water Adequacy Reports.

Geologic Setting of the ICR Well Field

The well field is located in Section 17, Township 16 North, Range 3 West. It is situated in the Mint Wash floodplain about one-half mile west of Williamson Valley road where the road crosses the wash.

The aquifer tapped by the wells consists of a mixture of unconsolidated sediments consisting predominately of a mixture of sandy clay and gravel to a depth of 118 followed by a layer of hard cemented sand and gravel to a depth of 145 feet; sandy clay and gravel to 158 feet that is, in turn, underlain by a moderately cemented conglomerate consisting of coarse gravel to cobble size fragments of granitic origin to the bottom of the hole at 220 feet. The base of the aquifer is formed by granitic and metamorphic rocks occurring at depth of about 253 ft. at ICR 1 and about 220 ft. at ICR 2. The latter rocks rise to the surface about 600-800 feet east of the well filed thereby terminating the aquifer in that direction. The initial water level on completion of drilling of ICR 1 was 19.35 feet below land surface.

Water Levels

There is a long-term decline in the water level of a pumped well until water in an amount equal to the rate the well is being pumped is diverted to the well from the aquifer's discharge area. Once this occurs, the long-term decline ceases. For the two ICR wells, this diversion would be expected to take decades if not longer to occur. If water levels fall too far before stabilizing, the wells will cease to be viable. It is important therefore to measure water levels through time in order to monitor the well field's status. As a result, water levels and pumpage are measured at the well field on a daily basis. There is also a short term, but significant, decline in the water level at a well that is being pumped intermittently, such as those at the ICR well field. Water levels fall while the well is being pumped and subsequently rise to an altitude equal to or near that existent before pumping.

As discussed above, the ICR well field has been pumped at an average annual rate of only 50 gpm or less since the initiation of pumpage to the present time. In response, the non-pumping water level at the well had fallen to about 50 feet below land surface by October 2004 and to about 58 feet in July 2014. Given an initial water level of 19.35 feet below land surface, the July 2014 water level represented a maximum decline of about 39 feet since the initiation of pumping. As shown in figure 1, however, non-pumping depth to water has varied considerably, with non-pumping depths decreasing for long periods of time following periods of flow in Mint Creek.

Non-pumping water levels below land surface have been about 51 feet for the first four months of 2016; figure 1. This depth represents a decline of about 32 feet since the initiation of pumpage. The decline in the non-pumping water level since the well's construction is a combination of the effect of pumpage from the well field, pumpage from other relatively nearby wells including those in the TRR well field, and the ongoing 17 year drought. Since its construction in 2002 water levels at ICR 2 have, as would be expected, mimicked those at ICR 1.

A line approximately depicting the average non-pumping depth to water at ICR 1 since 1994 (figure 1) suggest that the rate of decline has significantly slowed for the existing rate of withdrawal from the well field. The pattern of the non-pumping depth to water for 2014 - 2015 (figure 2) shows water levels in 2015 about 5 feet greater than 2014 further suggesting this. Increased rates of withdrawal as demand at the subdivisions increases and continuation of the drought would be expected to cause additional decline however.

Figure 1

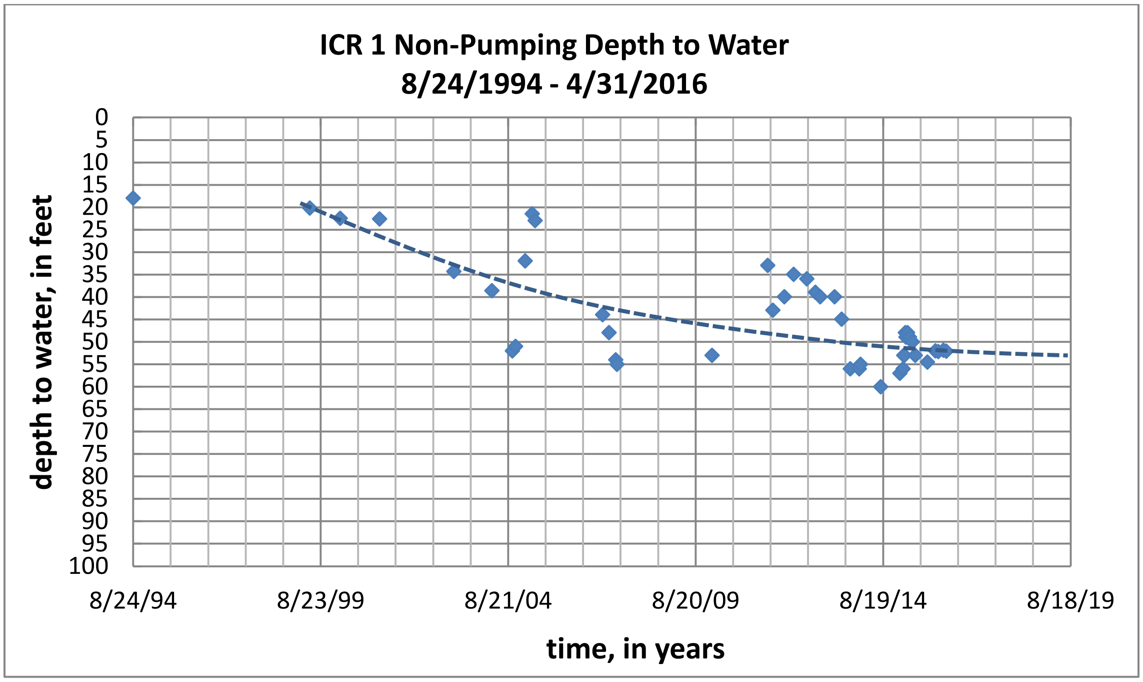
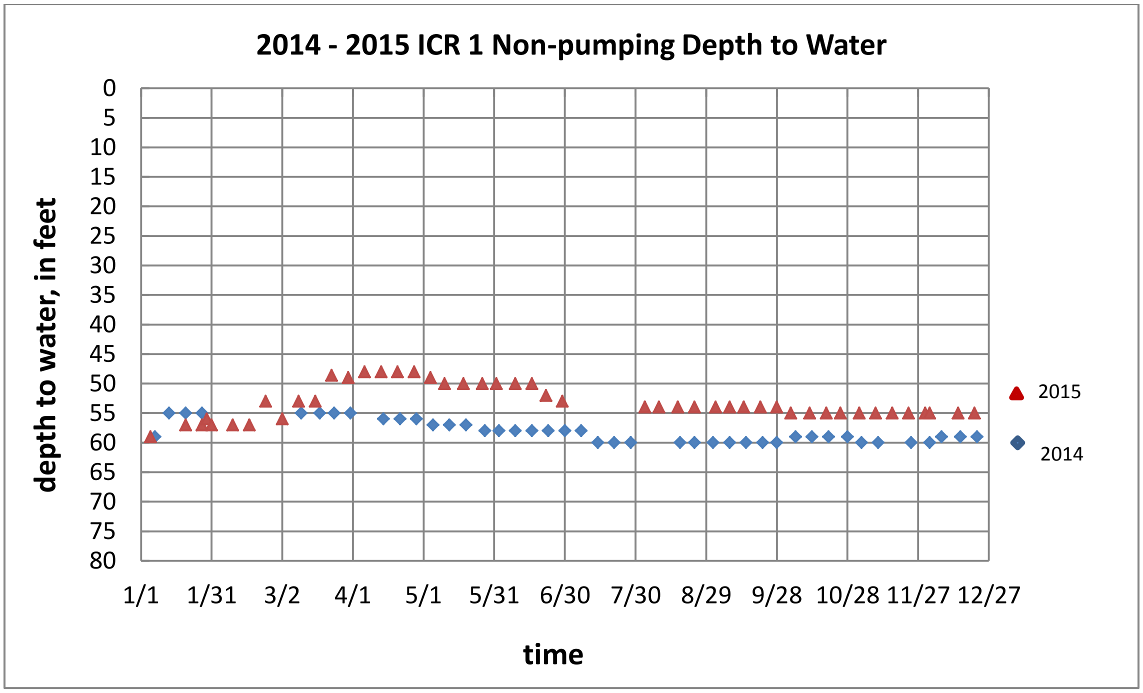


Figure 2



January 28-30, 2015 ICR 1 Constant Rate Test

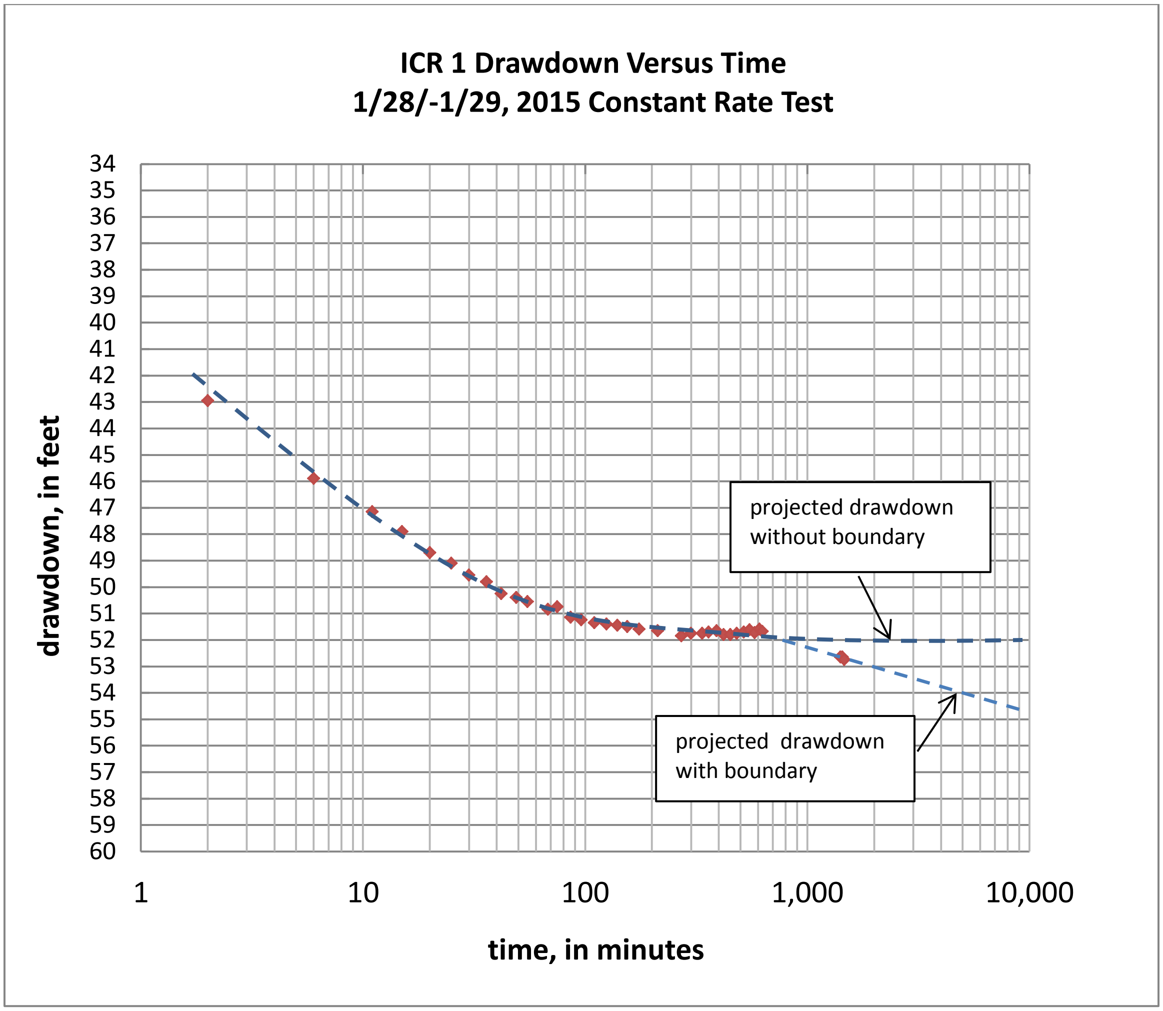
A constant rate pumping test was conducted at ICR 1 from 7:30 a.m. January 28, 2015 through 7:59 a.m. January 29, 2015. Water Levels versus time were measured at both ICR 1 and ICR 2 for the entire period of pumping and for an additional twenty four and one-half hours after cessation of pumping. Both wells had been off for 5 days prior to the test. Pre-pumping depth to water at ICR 1 and 2 were 56.5 and 59.08 feet respectively. The measuring point for ICR 1 is 1.8 feet above land surface and 1.4 feet above land surface at well 2. Data from the test for ICR 1 and ICR 2 are provided in Appendix C.

Discharge at ICR 1 was 385 gpm at the early part of the test and 365/370 gpm at the end of the test. Average discharge was 376 gpm.

Test Results

As discussed above, pumpage at the ICR well field was stopped for five days prior to the initiation of the test in order to allow water levels to stabilize. The water level at ICR 1 declined from 56.5 feet at the initiation of the test to 109.29 feet at the end, Appendix C. Total drawdown at the well at the end of the test therefore was 52.79 feet, figure 3, Appendix C. The depth to the pump intake at the well is 172 feet below land surface leaving approximately 64 feet of water above the intakes at the end of the test. Water levels increased rapidly following cessation of pumping being only 0.9 feet below the pre-pumping water level by 8:00 am on January 30th (not shown on figure 3).

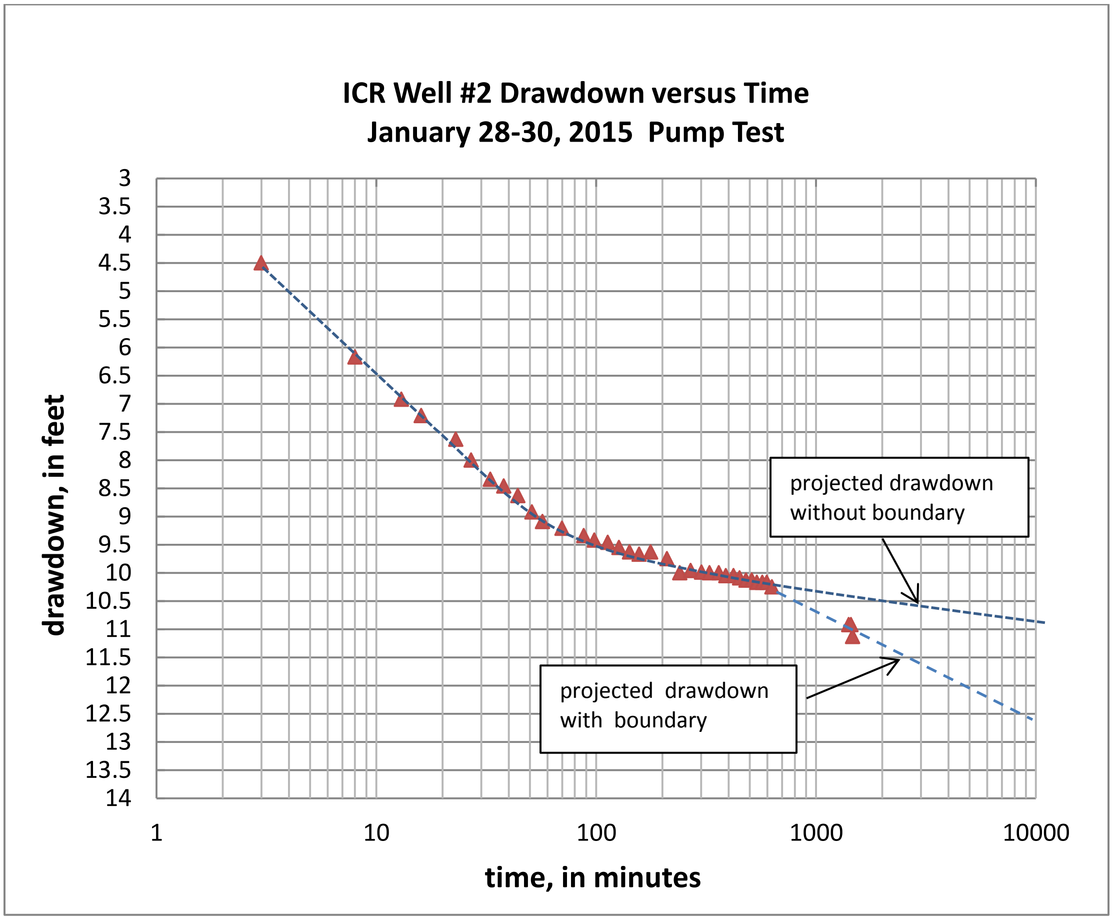
Figure 3


ICR 1 Drawdown Versus Time
1/28/-1/29, 2015 Constant Rate Test
drawdown, in feet
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
1
10
100
1,000
10,000
time, in minutes
projected drawdown without boundary
projected drawdown with boundary

Water Level Decline at ICR 2

Pumpage at ICR 1 caused the water level at ICR 2 to decline from a pre-test depth of 59.08 feet to 70.21 at the end of the test for a total drawdown of 11.13 feet, figure 4. Water Levels were not measured at the well following cessation of pumping.

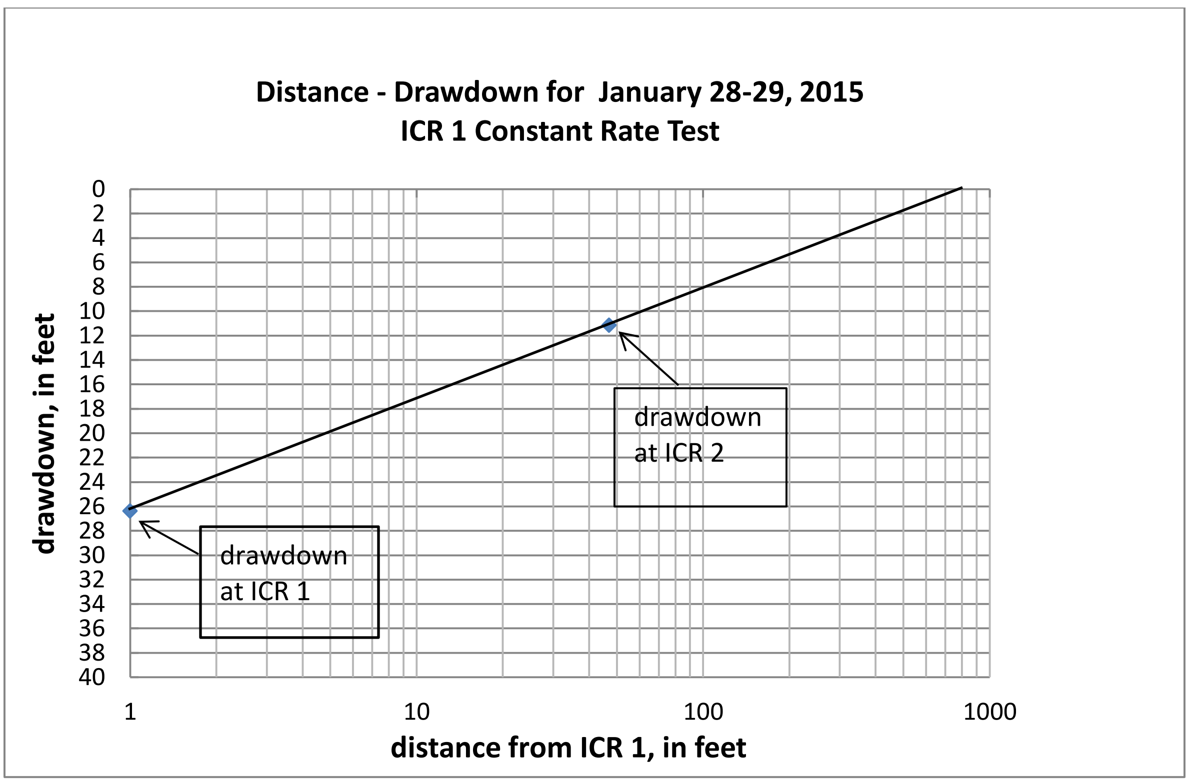
Figure 4



Extension of the Cone of Depression

The drawdown, or decline in water level (cone of depression) due to pumping ICR 1 spread in all directions away from the well, with water levels at a given location deepening as pumping continued and time increased. Figure 5 shows the extent of the cone of depression outward from ICR 1 immediately prior to termination of pumping. The measured drawdown at ICR 1 was corrected to reflect that in the aquifer alone based on the efficiency of the well (Appendix D). As can be seen, the cone of depression extended outward from the well to a distance of about 800 feet. At this extent it would be expected to have reached the eastern boundary of the aquifer discussed above. Once reached, the rate of drawdown would increase at a given location once the effect of the termination of the aquifer reached that location. This effect is reflected in the time-drawdown graphs for both wells and best seen in the graph for ICR 2 (figure 4), wherein the rate of drawdown approximately doubles after about 600 minutes of pumping. The decline rate following interception of the aquifer boundary is about 2.0 feet per log cycle.

Figure 5

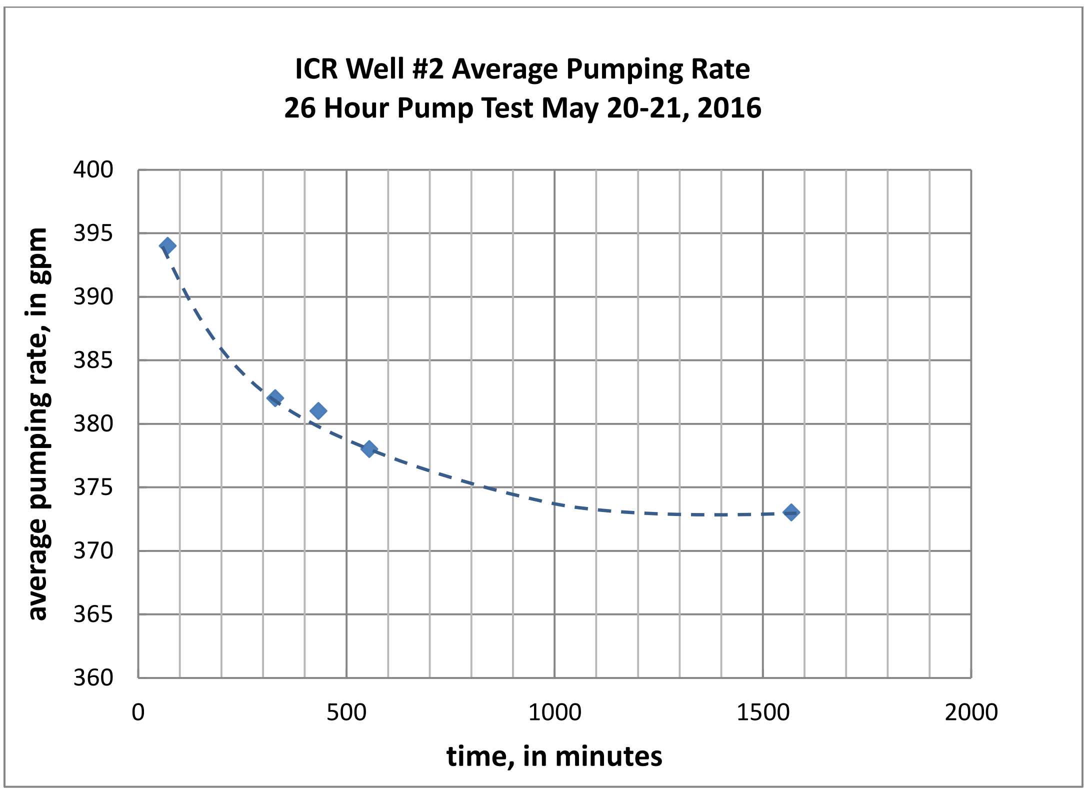


May 20 – 21, 2016 ICR 2 Constant Rate Test

A constant rate pumping test was conducted at ICR 2 from 7:45 a.m. May 20 through 9:54 a.m. May 21, 2016. Water Levels versus time were measured at both ICR 1 and ICR 2 for the entire period of pumping. Water levels were also measured at both wells the next morning following cessation of pumpage. Both wells had been off for 4 days prior to the test in order to allow water levels to stabilize. Pre-pumping or static depth to water at wells 1 and 2 were 55.67 and 54.25 feet respectively. The measuring point for ICR 1 is 1.8 feet above land surface and 1.4 feet above land surface at ICR 2. Data from the test for the wells are provided in Appendix C.

Discharge at ICR 2 was 392 gpm at the early part of the test and 368 gpm at the end of the test. Average discharge was 373 gpm, figure 6.

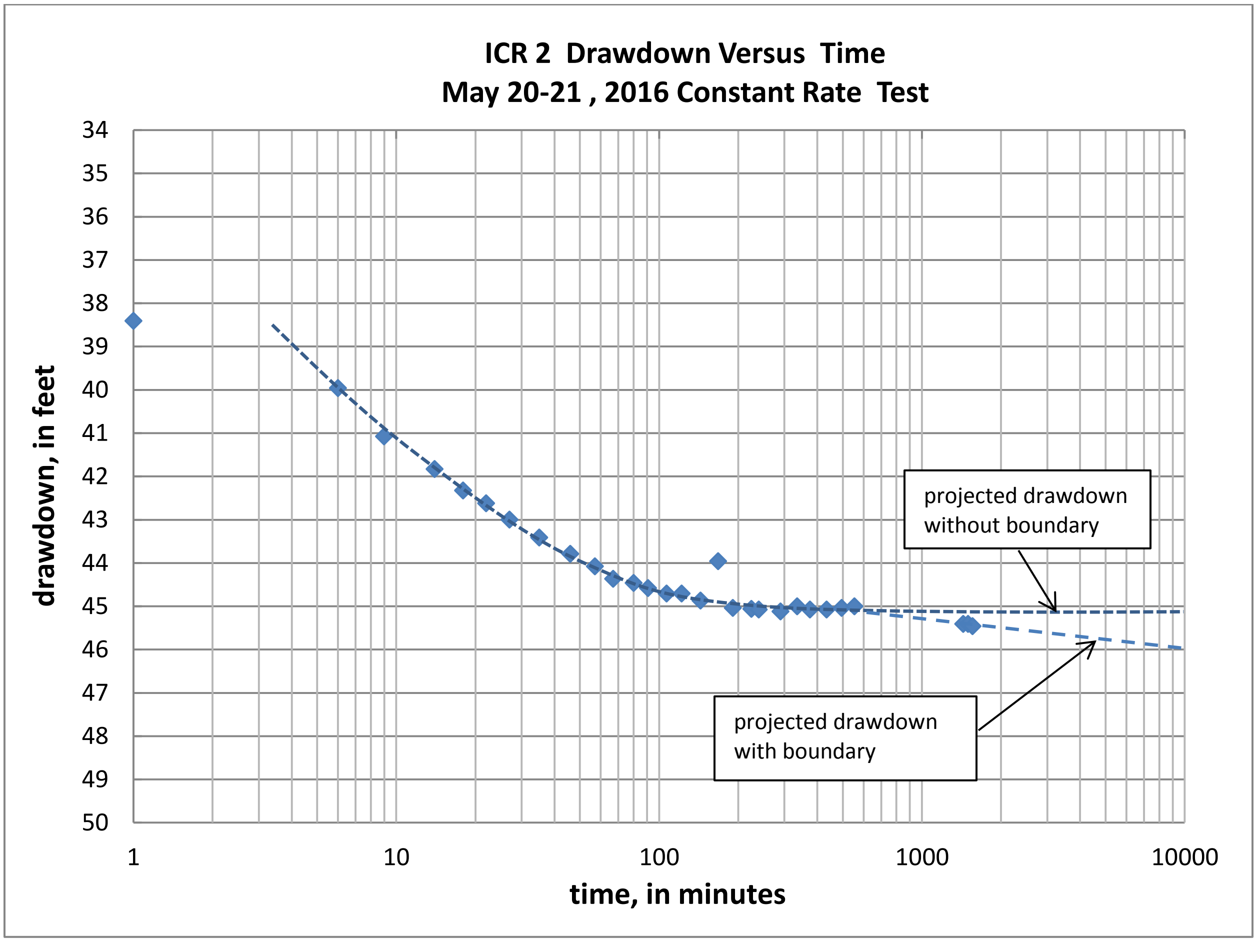
Figure 6



Test Results

Depth to water at ICR 2 declined from 55.67 feet at the initiation of the test to 101.13 feet at the end (Appendix C). Total drawdown at the well at the end of the test therefor was 45.46 feet (figure 7, Appendix C). The depth to the pump intake at the well is 160 feet below land surface leaving approximately 60 feet of water above the intakes at the end of the test. Depth to water in the well was 55.63 by 6:15 am on May 23 being only 0.04 feet below the pre-pumping depth (not shown on figure 7).

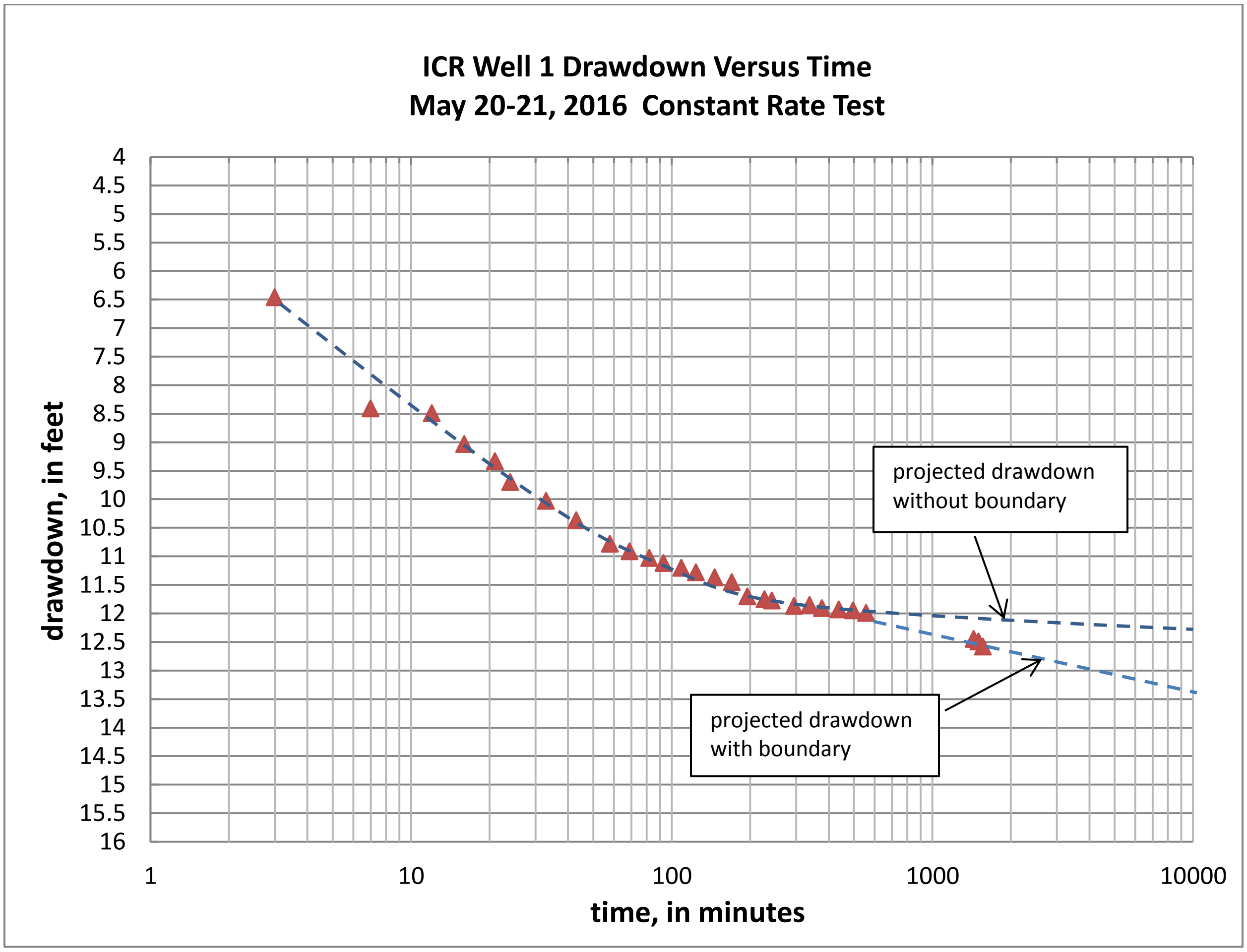
Figure 7



Water Level Decline at ICR 1

The water level at ICR 1 declined from a pre-test depth of 54.25 feet to 66.88 at the end of the test for a total drawdown of 12.63 feet, figure 8.

Figure 8



Extension of the Cone of Depression for the May 20-21, 2016 Test

As indicated by the drawdown patterns for ICR 2 and ICR 1, and best seen in drawdown pattern for the latter well, the cone of depression resulting from pumping ICR 2 extended to the eastern boundary of the aquifer. This result was to be expected given the same occurrence during the constant rate test of ICR 1. Once reached, as in the case of the January 28-29, 2015 constant rate test of ICR 1, the rate of drawdown would approximately double.

<u>100 - Year Capacity of the ICR Well Field</u>

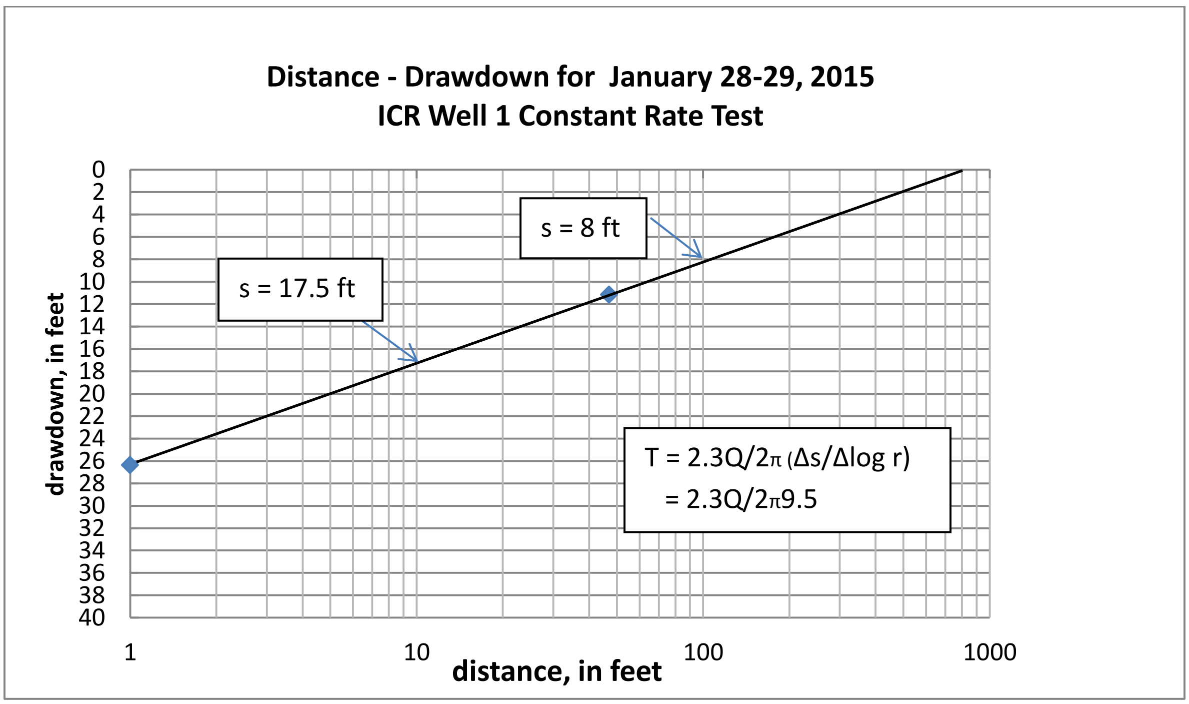
The ability of the ICR well field to meet the average daily demand of the three subdivisions at full build-out was evaluated by first, calculating a value for the drawdown at ICR 1 as a result of continuously withdrawing an average 139 gpm for 100 years, and comparing this value to the available drawdown in the well.

Drawdown in the well was calculated using the Theis Equation (Equation 2, Appendix B). The analysis included the decline in water level at the well resulting from the termination of the aquifer about 800 feet east of the well field and the decline in water level at the well induced by pumpage at the TRR well field. Based on these considerations the drawdown at the well as a result of withdrawing an average 139 gpm for 100 years would be 35 feet (Appendix B). Previous testing at ICR 1 indicates that well loss would introduce an additional decline in the pumping level in the well of about 20 feet from the above value. Given these considerations the predicted drawdown as a result of withdrawing an average 139 gpm for 100 years is approximately 55 feet. Given an initial non-pumping water level of 19.35 feet, total depth to water after 100 years would be about 75 feet compared to the well's screened depth of 200 feet thereby leaving 125 feet of saturated aquifer that is more than adequate to meet the 100 year pumping requirement.

In addition to the rate of pumping, the Theis Equation requires transmissivity and specific yield values of the aquifer. As discussed in Appendix A, the value for transmissivity determined by Manera Inc. in 1994 was technically flawed negating the use of this value. Two methods were used to establish both transmissivity and specific yield based on the results of the January 2015 constant rate test at ICR 1. First, because the aquifer predominately consists of a mixture of sandy clay and gravel underlain by a moderately cemented conglomerate, the release of water from these sediments would not be able to keep up with the decline in water level induced by pumpage as the Theis Equation assumes. In order to account for this, the Boulton delayed yield curves (see Lohman, 1972) were used to calculate both aquifer transmissivity and specific yield. This analysis indicated a value for transmissivity of 2,880 ft^2/d and an early value for specific yield of about 0.001. The latter value is at the lower end of an unconfined aquifer and reflects the slow release of water from the fine grained mixture of clay and gravel and from the cemented conglomerate.

The second method used the slope of the water table defined by the drawdown at ICR 1 and ICR 2 immediately prior to the termination of pumping, (figures 5 and 9) to calculate a value for the transmissivity of the aquifer equal to 2,789 ft^2/d, (figure 9, equation 1). This technique is based on the fact that the slope of the water table near the well is directly proportional to the quantity of water being pumped and inversely proportional to the transmissivity of the aquifer. The transmissivity value determined from equation 1 is virtually identical to that obtained from the Boulton analysis. The drawdown value for ICR 1 in figure 9 (the drawdown at one-foot) represents the drawdown value measured during the test corrected for well loss. Following calculation of a value for transmissivity, a specific yield value of 0.01 was calculated from the Theis equation given knowledge of the transmissivity, rate of pumpage and the drawdown at both, ICR 1 and 2. This value is one order of magnitude higher than that obtained from the Boulton analysis and reflects the use of drawdown at the end of the test to calculate specific storage. The values derived for transmissivity and specific storage from the second method were used in the Theis Equation calculations discussed above and in Appendix B.

Figure 9



$T = 2.3\ Q / (2\pi 9.5) = 2{,}789\ ft^2/d$ **(1)**

for:

T = transmissivity

Q = to the pumping rate in ft^3 per day = 72,385 ft^3/day, and

$\Delta s/\Delta \log r$ = to the slope of drawdown in figure 9 over a log cycle = 9.5

In comparison, SWGC (1999) reported a value for transmissivity of the aquifer equal to 2,886 ft^2/d that is essentially equal to the two values obtained from the January 2015 test. Neither Manera nor Southwest Ground-water Consultants undertook an analytic estimated for specific yield.

APPENDIX A

<u>Comparison of Conclusions from the 2015 ICR 1 and 2016 ICR 2 Constant Rate Tests to the August 25-28, 1994 Constant Rate Test at ICR 1</u>

As discussed above the constant rate tests at ICR 1 and 2 were for 24 and 26 hours respectively. As also discussed above, average discharge was at ICR 1 was 376 gpm. Average discharge at ICR 2 was 373 gpm. In contrast, the August, 1994 constant rate test at ICR 1 was conducted over three days. The average discharge was approximately 408 gpm.

Drawdown in response to pumpage is directly proportional to the discharge rate so that drawdown resulting from the 1994 test would be expected to be greater than that for the other two tests. This, however, is not the case; maximum drawdown at ICR 1 was 29.9 feet in the 1994 test and 52.79 feet in the 2015 test. Maximum drawdown at ICR 2 for the 2016 test was 45.46 feet.

Drawdown essentially ceased at ICR 1 in the 1994 test after only 100 minutes of pumping whereas it continued to decline in the 2015 test, figure 10. Drawdown also ceased after about 300 minutes in the observation well located 147 feet from ICR 1 during the 1994 test after which the water level increased, figure 11a. In contrast, drawdown continued at ICR 1 and ICR 2 throughout the entire tests of 2015 and 2016 (figures 3 and 4, 2015; figures 7 and 8, 2016 respectively). The drawdown at ICR 2 used as an observation well in the 2015 test is shown in figure 11b for comparison to figure 11a.

Given the location of ICR 1, drawdown would not cease or increase in a constant rate pump test without the introduction of water into the aquifer or a significant reduction in pumping from a nearby well(s) during the test, conditions that invalidate the use of the Theis Equation by Manera, Inc. to calculate the transmissivity of the aquifer and to conclude that ICR 1 is capable of continuously pumping 406 gpm for 100 years with less than 53.86 feet of drawdown.

Given the lack of significant nearby pumping during the 1994 test, the introduction of water into the aquifer is the most likely cause for the cessation of drawdown and a rise in water level. The source of the introduced water was in all probability the water being pumped at ICR 1 as a result of failing to physically remove it a sufficient distance from the location of the well.

Figure 10

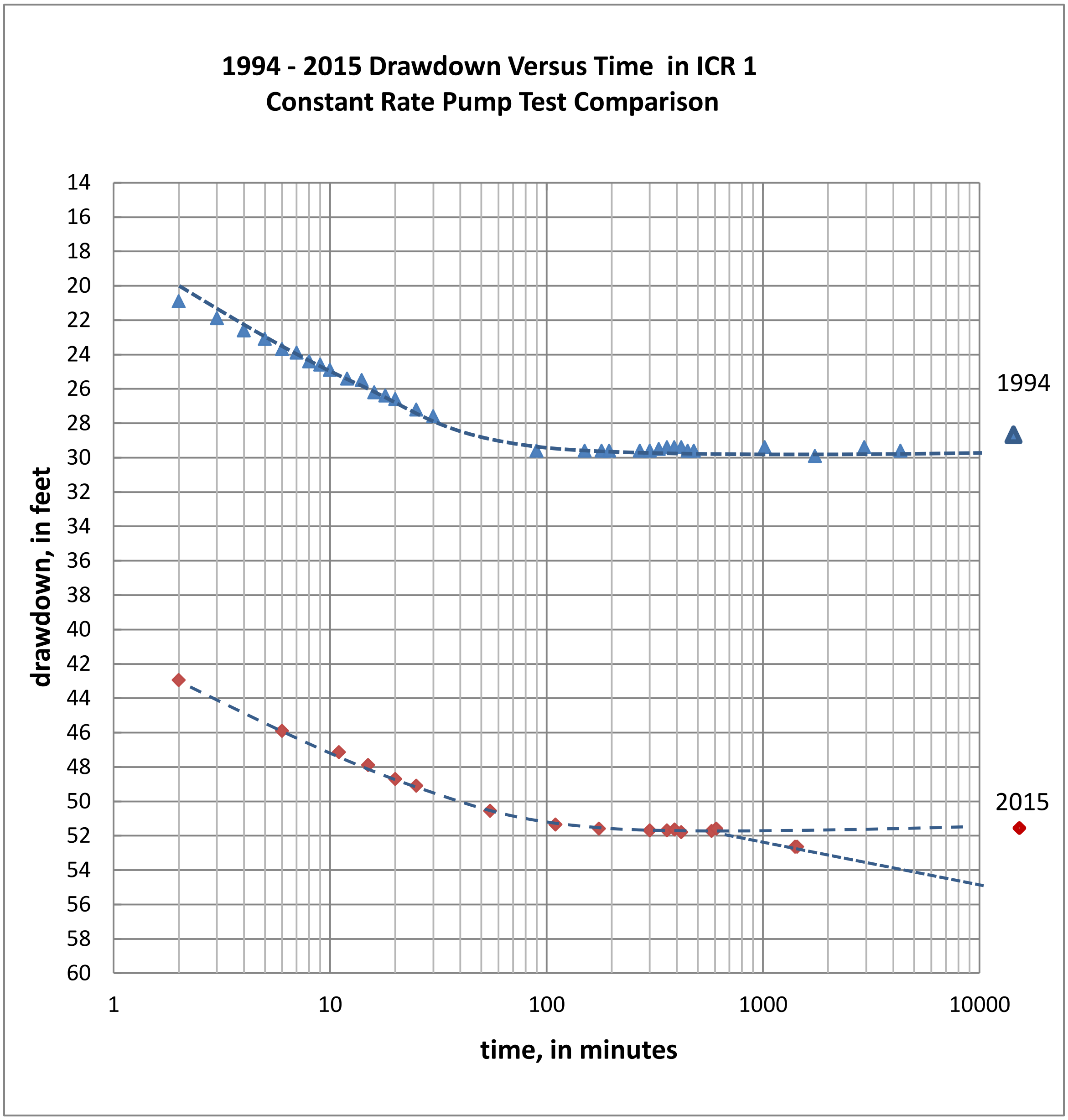

1994 - 2015 Drawdown Versus Time in ICR 1
Constant Rate Pump Test Comparison
drawdown, in feet
time, in minutes
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
1
10
100
1000
10000
1994
2015

Figure 11 a

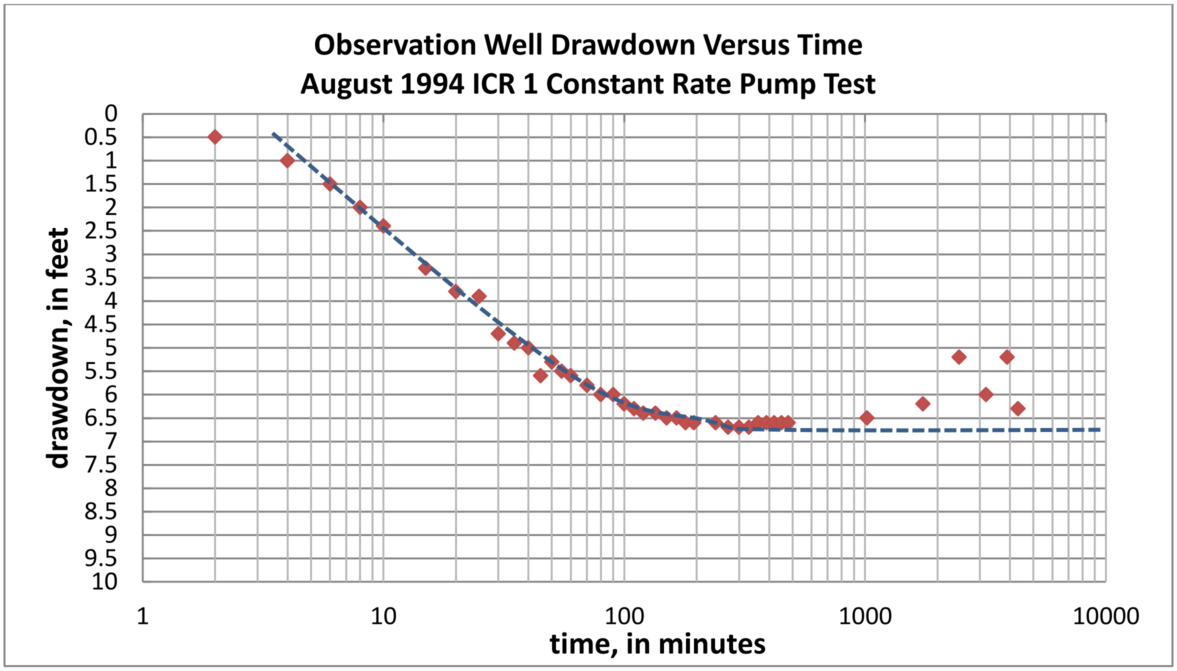
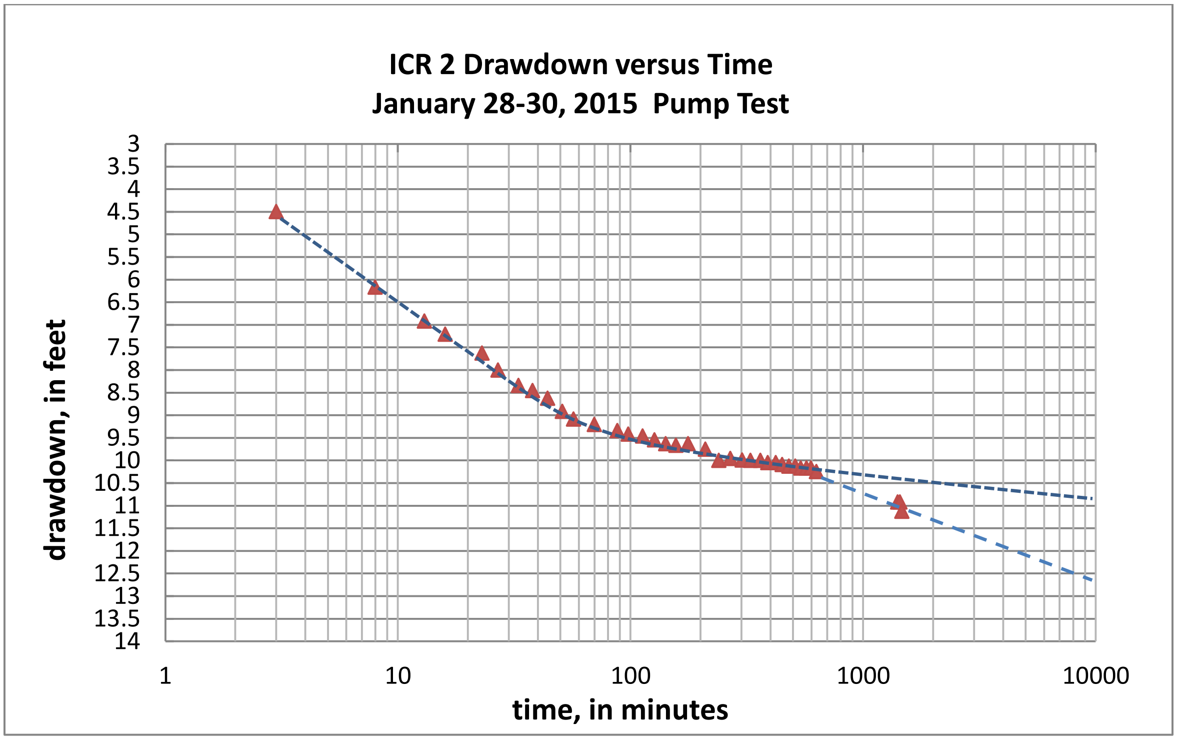


Figure 11 b



The water withdrawn during the 2015 and 2016 tests was discharged into the existing infrastructure transmitting water from the well field to the Magner storage tank located several miles from the well field. This precluded the movement of water back into the aquifer in the vicinity of the tests as apparently occurred during 1994 test. As a result the assumptions allowing the use of the Theis Equation were satisfied during the 2015 and 2016 tests whereas, as discussed immediately above, they were violated during the 1994 test.

APPENDIX B

Theis Equation Calculations

$s = (Q/4\pi T) * W(u)$ **(2)**

for:
s = drawdown in feet; Q = pumping rate in cubic feet per day; π = 3.1417; T = transmissivity in cubic feet per day per foot; W(u) = function of u and:

$u=r^2S/4Tt$ **(3)**

for:
r = distance from pumped well in feet; S = specific storage, dimensionless; T = transmissivity, t = time of pumping in days

Calculation of Drawdown at ICR Well 1 for 100 Year Adequacy ; Q = 139 gpm for:

S = 0.01 T = 2789 ft 2/d Q = 139 gpm=26,759 ft^3/

$s = (Q/4\pi T)* W(u)$ s = 0.7635W(u)

Values of u for r=1 $u=r^2S/4Tt$ = 1*1 (.01)/(4*2789*t) = 8.964*10-7/t

t	u	W(u)	s(well)	boundary	TRR	final s
1	8.964*10-7	13.34	10	0.0	0.0	**10**
10	8.964*10-8	15.64	12	0.8	0.9	**14**
100	8.964*10-9	17.95	14	2.4	3.1	**19**
1000	8.964*10-10	20.25	15	4.2	5.6	**25**
10000	8.964*10-11	22.55	17	5.9	8.2	**31**
36500	2.46*10-11	23.85	18	6.9	9.6	**35**

Drawdown values at ICR 1 resulting from Aquifer Termination 800 feet of the ICR Well Field

r = 1600 ft u = 1600*1600 (.01)/4Tt = 2.295/t

t	u	W(u)	s
1	2.295	0.033	0.0
10	2.295*10-1	1.07	0.8
100	2.295*10-2	3.17	2.4
1000	2.295*10-3	5.46	4.2
10000	2.295*10-4	7.76	5.9
36500	6.29*10-5	9.1	6.9

Drawdown values at ICR 1 for pumpage at TRR Well Field = 203 gpm

values for r=2000 u = 2000*2000 (0.01)/4Tt = 3.59/t

t	**u**	**W(u)**	**s**
1	3.59	0.006	0.0
10	3.59*10-1	0.77	0.9
100	3.59*10-2	2.78	3.1
1000	3.59*10-3	5.05	5.6
10000	3.59*10-4	7.35	8.2
36500	9.8*10-5	8.65	9.6

APPENDIX C

Time – Drawdown – Discharge Data
For 2015 Test at ICR 1 and for 2016 Test at ICR 2.

ICR 1 Drawdown versus Time
Constant Rate Test at ICR 1, January 28-30, 2015
Measuring point 1.8 feet above land surface

Date	Time	Time (min)	Q	Depth to Water (ft)	Drawdown	Remarks
28-Jan	7:20		0	56.5		
	7:30		0	56.5	0	meter reading =29,249,000 gallons
	7:32	2	385	99.46	42.96	
	7:36	6	385	102.42	45.92	
	7:41	11	385	103.63	47.13	
	7:45	15	385	104.42	47.92	
	7:50	20	385	105.25	48.75	
	7:55	25	385	105.58	49.08	
	8:00	30	385	106.13	49.63	
	8:06	36	385	106.33	49.83	
	8:12	42	385	106.71	50.21	
	8:19	49	385	107	50.5	
	8:25	55	385	107.13	50.63	
	8:38	68	385	107.38	50.88	
	8:45	75	385	107.29	50.79	
	8:56	86	385	107.63	51.13	
	9:06	96	385	107.71	51.21	
	9:20	110	385	107.79	51.29	
	9:35	125	385	108	51.5	
	9:50	140	385	108.05	51.55	
	10:05	155	385	108.08	51.58	
	10:25	175	375	108.17	51.67	
	11:02	212	375	108.21	51.71	
	12:01	271	375	108.38	51.88	
	12:30	300	375	108.29	51.79	
	13:07	337	375	108.29	51.79	
	13:30	360	375	108.25	51.75	
	14:01	391	375	108.21	51.71	
	14:30	420	370	108.33	51.83	
	15:01	451	370	108.33	51.83	
	15:32	482	375	108.29	51.79	

	15:59	519	375	108.25	51.75	
	16:31	551	370	108.2	51.7	
	17:00	580	370	108.28	51.78	
	17:30	610	370	108.17	51.67	
	17:58	628	370	108.24	51.74	meter reading =29,486,000 gallons
29-Jan	7:01	1411	370	109.21	52.71	
	7:30	1440	370	109.21	52.71	
	7:59	1469	0	109.29	52.79	pump off :
	8:00	1470	0	71	14.5	meter reading =29,801,000 gallons
	8:02	1472	0	64	7.5	Average Pumpage = 376 gpm
	8:04	1474	0	62.58	6.08	

ICR 2 (observation well) Drawdown Versus Time
ICR 1 Constant Rate Test, January 28-30, 2015
Measuring point = 1.4 feet above land surface
r = 47 feet

Date	Time	Time (min)	Depth to water (ft)	Drawdown (ft)
28-Jan	7:19		59.08	
	7:30	0	59.08	
	7:33	3	63.58	4.5
	7:38	8	65.25	6.17
	7:43	13	66	6.92
	7:46	16	66.29	7.21
	7:53	23	66.71	7.63
	7:57	27	67.08	8
	8:03	33	67.42	8.34
	8:08	38	67.54	8.46
	8:14	44	67.71	8.63
	8:21	51	68	8.92
	8:27	57	68.17	9.09
	8:40	70	68.29	9.21
	8:58	88	68.42	9.34
	9:08	98	68.5	9.42
	9:23	113	68.54	9.46
	9:37	127	68.63	9.55
	9:52	142	68.71	9.63
	10:07	157	68.75	9.67
	10:27	177	68.71	9.63
	11:00	210	68.83	9.75

	11:30	240	69.08	10
	11:59	269	69.04	9.96
	12:32	302	69.07	9.99
	12:58	328	69.08	10
	1:32	362	69.08	10
	1:59	389	69.13	10.05
	2:32	422	69.13	10.05
	2:59	449	69.17	10.09
	3:30	480	69.21	10.13
	4:01	511	69.21	10.13
	4:29	539	69.25	10.17
	5:01	571	69.25	10.17
	5:28	598	69.25	10.17
	6:00	630	69.33	10.25
29-Jan	7:00	1410	70	10.92
	7:32	1442	70	10.92
	7:57	1469	70.21	11.13

ICR 2 Drawdown versus Time
Constant Rate Test at ICR 2, May 20 - 21, 2016
Measuring point 1.4 feet above land surface

Date	time	time (min)	pumping rate (gpm)	Depth to water (ft)	s (ft)
20-May	0745 AM	0	0	55.67	0
	746	1	392	94.08	38.41
	751	6	391	95.63	39.96
	754	9	388	96.75	41.08
	759	14	388	97.5	41.83
	803	18	385	98	42.33
	807	22	384	98.29	42.62
	812	27	385	98.67	43
	820	35	385	99.08	43.41
	831	46	385	99.46	43.79
	842	57	382	99.75	44.08
	852	67	381	100.04	44.37
	905	80	381	100.13	44.46
	916	91	380	100.25	44.58
	932	107	380	100.38	44.71
	947	122		100.38	44.71
	1009	144	380	100.54	44.87

	1033	168	379	99.63	43.96
	1056	191	380	100.71	45.04
	1130	225	379	100.73	45.06
	1145	240	380	100.75	45.08
	1235	290	383	100.79	45.12
	1321	336	378	100.67	45
	1400	375	377	100.75	45.08
	1500	435	377	100.75	45.08
	1600	495	375	100.71	45.04
	1700	555	373	100.67	45
21-May	745	1440	369	101.08	45.41
	845	1500	369	101.08	45.41
	945	1560		101.13	45.46

ICR 1 (observation well) Drawdown versus Time
Constant Rate Test at ICR 2, May 20 - 21, 2016
Measuring point 1.8 feet above land surface
R = 47 feet

Date	Time (min)	Depth to Water (ft)	s (ft)
20-May	0	54.25	
	3	60.71	6.46
	7	62.71	8.41
	12	62.79	8.49
	16	63.33	9.03
	21	63.63	9.33
	24	64	9.7
	33	64.33	10.03
	43	64.67	10.37
	58	65.08	10.78
	69	65.21	10.91
	82	65.33	11.03
	93	65.42	11.12
	109	65.5	11.2
	124	65.58	11.28
	146	65.67	11.37
	170	65.75	11.45
	195	66	11.7
	227	66.05	11.75
	242	66.075	11.775

	295	66.17	11.87
	338	66.15	11.85
	377	66.21	11.91
	437	66.23	11.93
	497	66.25	11.95
	557	66.29	11.99
21-May	1442	66.75	12.45
	1504	66.79	12.49
	1563	66.88	12.58

Appendix D

Rehabilitation of ICR Well 1, September 23-30, 2013

Report to the ICR Water Association Board of Directors

October 24, 2013

by

William Meyer

Rehabilitation of ICR Well 1, September 23-30, 2013

The yield from ICR well 1 decreased over time, from about 415 gallons per minute (gpm) when initially constructed in August 1994 to about 340 gpm in 2013. Drawdown in the well had increased from about 30 feet below land surface (bls) when initially constructed to as much as 82.5 feet in 2011 and 94 feet in 2012. More importantly, pumping depths to water had increased from about 50 feet bls to as much as 139 feet during the same time period. Part of the latter decline included a loss of about 35 feet in the static or non-pumping water level at the well field. The decline in the static water level is, in part, from the continuing drought that began in about 1999 and from the continued pumping since 1994 at the well field and other nearby wells. The total decline in the pumping level, however, has placed this level to within about 30 feet of the pump intake (set at 172 feet) and the continued nature of the decline suggested the possibility of potential pump failure from cavitation.

Given these facts the ICR Water Users Association Board of Directors decided to undertake rehabilitation of the well that occurred from September 23-30, 2013. After pulling the pump a video was ran. Video results included the following information; depth of the well is 242 feet, the well screen (wire wrapped) extends from 43 feet to 200 feet and was totally clogged by chemical deposition on the inside of the screen. The effort to rehabilitate the well consisted of first brushing the well to remove as much material from the well screen as possible and then baling the well to remove fines created by the brushing. This was followed by adding chemical (acid) to the well and continually surging the well over a 24 hour period. A test pump was then installed to remove the acid. Following acid treatment, a second video was obtained indicating an estimated 40 percent or less of the deposition had been removed. Continued efforts to rehabilitate the well would probably result in little improvement relative to the cost expended while pumping information obtained during removal of the acid had indicated that considerable rehabilitation had occurred. Given these facts, the decision was made to put the well back into service. Prior to activating the well, a two hour test was conducted to determine the extent to which the well had been rehabilitated. This test was conducted on October 7, 2013 following which the well was immediately put back on line. The static water level prior to conducting the test was 56.5 feet below land surface and the pumping level at the end of the test was 99.45 feet, a decrease of almost 40 feet in the pumping level.

Initial Well Efficiency of ICR Well 1

The results of the rehabilitation effort can best be examined by evaluating the efficiency of the well, past and present. There is a short term, but significant, decline in the water level in a well that is being pumped intermittently, such as those at the ICR well field. Water levels fall while the well is being pumped and subsequently rise to an altitude equal to or near that existent before pumping. The difference between the pre-pumping and pumping water levels is referred to as drawdown. For a given rate of pumping, Q, the total drawdown in a well, s_w, is composed of aquifer loss, BQ, and well loss CQ^2 for B and C equal to constants. The efficiency of a well is determined by dividing aquifer loss by the total drawdown.

The relationship between total drawdown, aquifer loss, and well loss is described by the equation:

$$s_w = BQ + CQ^2 \qquad (1)$$

Well loss occurs from two variables. One source of well loss results from the fact that the flow of ground water changes from laminar to turbulent flow as it nears the immediate vicinity of a pumping well. This change results in an increase in the pumping level or drawdown from that caused by the aquifer alone. Clogging of the well screen (partial or complete) or gravel pack immediately outside the screen will also increase the pumping level in a well above that caused by the aquifer.

Determination of aquifer loss and well loss requires identification of the constants B and C which is possible by dividing equation 1 by Q which yields:

$$s_w/Q = B + CQ \qquad (2)$$

Equation 2 is a straight line with B equal to intercept and C equal to the slope of the line. B and C are determined by plotting s_w/Q versus Q from values determined during a step-drawdown test. This test consists of pumping the well at a minimum of three different rates for a specified time period (at least one hour for each rate) and recording the drawdown at the end of each pumping cycle.

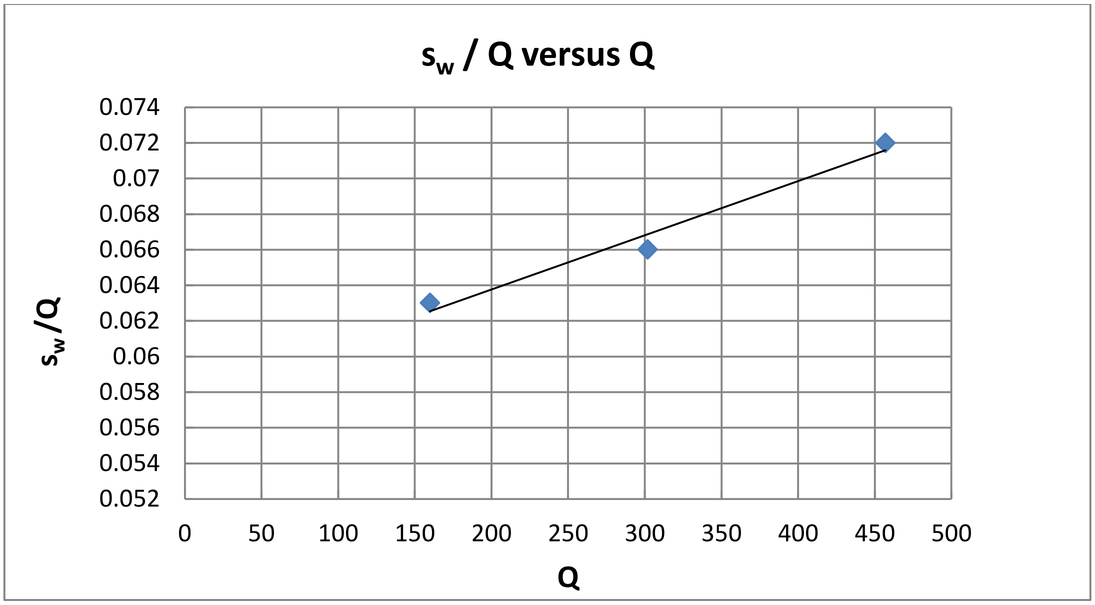
A step drawdown test was conducted at well 1 immediately following its construction, although the data were not used to calculate well efficiency at that time. Values of Q and s_w obtained from the test are shown in table 1 below as is the calculated value for s_w/Q.

Table 1

Q (gpm)	**S_w (feet)**	**S_w/Q**
160	10	0.063
302	20	0.066
457	32.8	0.072

Although well efficiency was not calculated 1n 1994, the data can still be used for that purpose. Plotting s_w versus Q yields the relationship shown in figure 1:

Figure 1



The value of B in the above graph is 0.0578 while that of C is 3.429 $*10^{-5}$. Substituting these vales into equation 1 yields:

s_w =(0.0578)Q + (3.429 *10 5)Q^2

Following the step drawdown exercise, the well was pumped for three days at a constant rate of about 415 gallons per minute (gpm). Drawdown, s_w , at the end of the test was about 30 feet. Substituting 415 gpm into the above equation yields:

$s_w = 0.0578(415) + 3.429 *10^{-5}(415)^2$

= 24 ft. + 6.2 ft. = 30.2 ft.

Thus, the aquifer caused 24 ft of the observed drawdown while well loss accounted for 6.2 ft. Well efficiency at the time of construction therefore was equal to

$BQ / (BQ + CQ^2) = 24 / 30.2 = 79$ percent.

Well 1 then was 79 percent efficient immediately following it construction. Stated differently, 79 percent of the drawdown in the well was due to the aquifer while 21 percent was from well loss. These values fall within the range of those considered generally acceptable. The aquifer constant B, will remain constant throughout time while the value of C can, and often does, increase, thereby decreasing well efficiency and increasing the pumping depth. In the case of well 1, well loss would be expected to increase due to chemical clogging of the screen or fine sand moving into the gravel pack around the well thereby increasing the resistance to water entering the well.

The results from the initial testing of the well can be compared with the two hour October 7, 2013 test. In this test the well was pumped for a two hour period at 390 gpm during which water level readings were made at selected times. These measurements and those made during the first two hours of the 1994 test (corrected for the difference in pumping rates) are shown in figure 2. As can be seen, the total drawdown for the 2013 test consistently exceeds that of 1994 by 15 to 16 feet, table 2.

Total drawdown at the end of the 2013 two hour test was 42.95 feet compared with the calculated value for the same rate of pumpage of 27.5 feet in 1994. Since the value of the coefficient B in aquifer loss will remain constant, the extra drawdown is related entirely to an increase in well loss. The efficiency of the well is therefore:

$$\text{Efficiency} = B(390) / 42.95 = 0.0578\ (390) / 42.95 = 22.54 / 42.95 = 0.52$$

The current efficiency of the well is now 52 percent, meaning that 52 percent of the drawdown is due to the aquifer while 48 percent is from well loss. Thus, well loss has increased from its initial value of 21 percent to its present value of 48 percent following rehabilitation of the well.

Figure 2

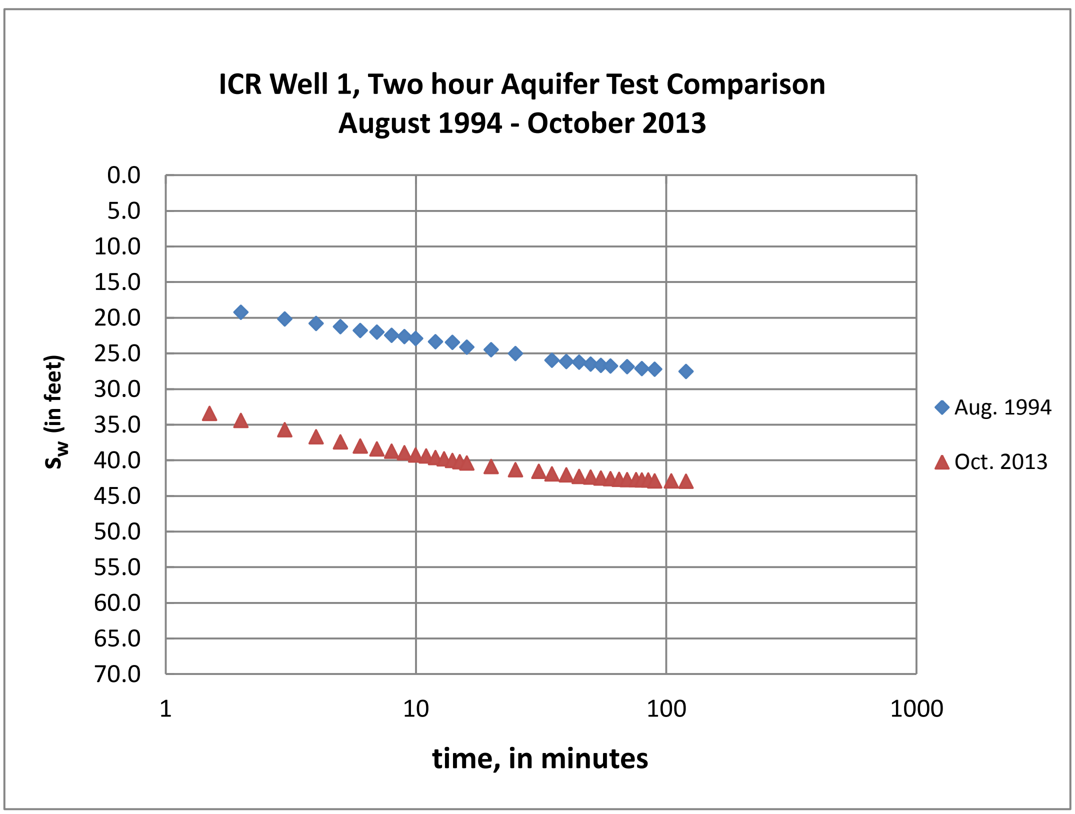


Table 3. August 1994 and October 2013 Drawdown versus Time for ICR Well 1 Aquifer Test

1	2	3	4
Time (minutes)	Aug. 1994 (s_w)	Oct. 2013 (s_w)	(2)-(3)
1.5		33.4	
2	19.2	34.4	-15.2
3	20.1	35.7	-15.6
4	20.8	36.7	-15.9
5	21.3	37.4	-16.1
6	21.8	38	-16.2
7	22.0	38.4	-16.4
8	22.4	38.7	-16.3
9	22.6	38.95	-16.3
10	22.9	39.25	-16.3
11		39.4	
12	23.4	39.6	-16.2
13		39.8	
14	23.5	40	-16.5
15		40.2	
16	24.1	40.35	-16.2
20	24.5	40.85	-16.4
25	25.0	41.3	-16.3
31		41.55	
35	25.9	41.9	-16.0
40	26.1	42.05	-15.9
45	26.2	42.25	-16.0
50	26.5	42.35	-15.9
55	26.7	42.5	-15.8
60	26.8	42.55	-15.8
65		42.65	
70	26.9	42.7	-15.8
76		42.7	
80	27.1	42.75	-15.6
85		42.75	
90	27.2	42.875	-15.6
105		42.875	
120	27.5	42.95	-15.4

History of Well Performance

The water level record for ICR well 1 seldom provides pumping water levels owing to the fact that, although used on a nearly daily basis, actual hours of pumping is only several hours for most days. Water level measurements are made weekly, but the well is seldom on at this time. Even so, available data on pumping levels indicates that the efficiency of the well had potentially declined as early as September 2006, table 3. It had significantly declined by May 2011 to a value that was equal to or less than 24 percent and by March 12, 2012 efficiency had fallen to 24 percent. More importantly, the August 14, 2011 pumping water level of 139 feet was within 33 feet of the pump intake, an unacceptable value assuming continued declines in water levels.

Table 3. Selected Measurements of Pumping Rates, Static and Pumping Water Levels, Drawdown, and Efficiency (Well 1), in ICR Wells, 1994-2013.

Date	Well	Q (gpm)	Static Water Level (ft.)	Pumping Water Level (ft.)	S_w (ft.)	Well Efficiency (percent)
8/25-27/1994	1	415	21.1	50.7	29.6	79
	2	NC	----	----	----	----
10/6/04	1	0	52.3	60.8	8.5	----
	2	400	53.9	86	32.1	----
9/24/2006	1	?		≥100		
	2	0	59.2	----	----	----
8/2/2007	1	369	54.5	----	----	----
	2	----	55.4	----	----	----
3/31/2009	1	0	48			
	2	0	49.8	----	----	----
5/24/2011	1	344		133	≥82.5	≤24
	2	0	50.5	----	----	----
6/20/2011	1	344		120		≤26
	2	0	----	42.7	----	----
6/25/2011	1	0	43			
	2	?	----	73	----	----
8/14/2011	1	341	----	139	≥90.4	≤22
	2	0	----	48.6		----
3/12/2012	1	345	34	128	94	21
	2	0	35	44	9	----
10/7/2013	1	390	56.5	99.45	42.95	52
	2	0	58.2	68.75	10.55	----

Rehabilitation has increased the efficiency of the well by about 2.5 times above the March 12, 2012 value. More importantly it has brought the pumping level to around 100 feet below land surface. This compares to the 139 foot pumping level measured on August 14, 2011 and 128 feet measured on March 12, 2012. The pump intake was reset at 172 feet below land surface following rehabilitation so that the current pumping level should be about 70 feet above the intakes. It will be important to continue to measure pumping and static water levels on a periodic basis however. Also, Pump Tech has recommended that the Board consider a program of treating all wells with acid at 5 year intervals.