July 22, 2020 (Amended September 10, 2020)

Mr. Bob Slentz
Ms. Heather Justus, P.G.
Castle Rock Water
175 Kellogg Court
Castle Rock, CO 80109

VIA EMAIL TO: BSlentz@crgov.com and HJustus@crgov.com

RE: Pine Canyon Well Fields Interference Analysis

Dear Mr. Slentz and Ms. Justus,

LRE Water (LRE) is supporting Castle Rock Water (Town) with the evaluation of potential groundwater drawdown impacts from the development of the Pine Canyon Well Fields. LRE reviewed the Jehn Water report titled "*Water Supply Plan Report, Pine Canyon, Douglas County, Colorado*", dated April 22, 2020 (Jehn Report). We reviewed preliminary well field planning from the Jehn Report and performed an independent evaluation of potential impacts to Castle Rock's nearby wells.

Introduction

The Jehn Report includes an evaluation of future well interference from the development of the two well fields (**Figure 1**). Each well field includes wells planned to be completed in the Lower Dawson, Denver, and Arapahoe aquifers. The Jehn Report evaluates the impacts on one nearby well in each aquifer that is closest to the well fields. The Jehn Report does not describe the drawdown evaluation methodology or the aquifer property input data. The information provided does not allow for repeating or validating the reported drawdown estimates.

The sections below describe a well impact analysis LRE completed based on common methodology, publicly available data, and data provided by Castle Rock Water.

Interference Analysis

The Jehn Report presents the results of well interference estimates for a "worst-case" pumping scenario simulating pumping all of the available water in each aquifer over a

100-year period. The total pumping rate estimated was 709.9 AF/YR total pumping from the two well fields, for 100 years. The interference was estimated with both well fields pumping equal amounts:

- Lower Dawson aquifer - 158.9 AF/YR (98.5 GPM)
- Denver aquifer - 314 AF/YR (194.7 GPM)
- Arapahoe aquifer – 236.7 AF/YR (146.7 GPM)

No aquifer parameters were provided by the Jehn Report to compare well interference, however Castle Rock provided LRE storage and transmissivity parameters of local wells. The average parameters for each aquifer considered are provided in **Table 1.**

To estimate drawdown in each aquifer, LRE used a Theis drawdown solution provided in Rockworks (Rockware, Inc., 2020) that allows for multiple pumping wells. We made the following assumptions:

1) Pumping is simulated from a single fully penetrating well in the center of each proposed well field within a given aquifer;
2) No wells other than the proposed Pine Canyon wells pump during this simulation; and,
3) Wells pump for 100 years (36,500 days) at a constant rate.

Initially, we analyzed a similar scenario as described in the Jehn Report by pumping a single well field at the full appropriation for the given aquifer. The closest wells to that well field in each aquifer were assessed for drawdown interference. **Table 2** shows the drawdown calculated from a Theis solution using the parameters in **Table 1** compared to the same wells referenced in the Jehn Report. **Table 2** shows the drawdown impacts from pumping only one well in an attempt to most closely match the suspected methods used by Jehn Water. The drawdown referenced in the Jehn report underestimates drawdown compared to LRE's calculation of drawdown.

Colorado State University (CSU) analyzed multiple pumping datasets within the Arapahoe and Denver and Dawson aquifers within the Castle Rock area (Lewis, 2014). A novel approach was used to calibrate aquifer storage from multiple pumping wells interfering within one another. CSU reported that aquifer storage parameters in the range of 2.0×10^{-4} to 9.4×10^{-4} best represent each of these Denver Basin aquifers. The storage parameters in **Table 1** used by LRE to represent the lower Dawson, Denver, and Arapahoe aquifers are within the range of storage found by CSU.

Figures 2, 3 and 4 show the regional aquifer response for the lower Dawson, Denver, and Arapahoe aquifers based on the parameters in **Table 1**. **Figures 2-4** show a pumping scenario where the full appropriation is split between the two proposed well fields (Well Fields 1 and 2) for a given aquifer, pumping constantly for 100 years. These figures show that many wells are affected by greater than 40 feet of drawdown which extends over a mile from the proposed Pine Canyon Well fields.

Pumping Cost Impact Analysis

LRE Water computed the approximate increase in the yearly operational pumping costs after 100 years based on the computed 100-year drawdown spatial distributions from the Pine Canyon pumping. These calculations were assumed to incorporate two cost components (use and instantaneous demand) and based on a continuous, 100-year pumping stress. The additional drawdown predicted at the Town's wells closest to Well Fields 1 and 2 were assumed to represent the change in total dynamic head (TDH) after 100 years.

We assumed motor efficiency of 70% and that the wells would be pumped at the permit reported design capacity. The increase in annual use cost after 100 years was approximated with the change in TDH at each location and an estimated 2020 cost per kilowatt-hour ($0.05/kWh). The increase in annual instantaneous demand cost after 100 years was approximated from the change in TDH at each location and an estimated 2020 cost per kilowatt of $17.25/kW (billed monthly). The approximate cost per kWh ($0.05/kWh) and cost per kW ($17.25/kW, billed monthly) was estimated from historical data provided by the Town. The increase in annual use and instantaneous demand costs after 100-years of pumping associated with each well are detailed in **Table 3**.

Based on the six (6) selected wells owned by the Town (2 per aquifer, closest well to each Well Field 1 and 2), the total increase in annual use and instantaneous demand costs after 100 years of Pine Canyon pumping was estimated to be $14,650 per year in 2020 dollars, and $22,850 per year in predicted 2120 dollars for all six (6) wells included in this analysis. The 2120 currency was estimated by assuming a linear increase in industrial energy costs based on historical data from 1990-2020 from United States Energy Information Agency. It is important to note that the Town owns at least 6 wells completed in the Lower Dawson Aquifer, 18 wells completed in the Denver Aquifer, and 16 wells completed in the Arapahoe Aquifer that are within the 40 foot drawdown contour after 100 years of pumping of the proposed Pine Canyon wells from Well Fields 1 and 2. The increased pumping costs calculated only represent the six (6) wells discussed above, and the Town's total increased pumping costs would be higher.

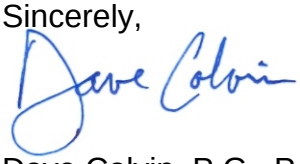
This type of analysis, although a good starting point to understand future cost impacts, has limitations. In reality, the cost for energy use and instantaneous demand with operating the well field are likely to increase due to increases in cost over time. It is important to note that over time, however, as the water level in the aquifer decreases, the wells will produce less water with the same energy input. At a certain point in time the production of the wells will be reduced to the point of necessitating new, additional wells to compensate for the reduction in yield assuming the same energy input. This additional cost is not considered in our analyses here, but is recommended in future analyses.

Conclusions

LRE Water concludes the following based on our analysis and review of the Jehn Report:

- The Jehn Report does not describe the drawdown evaluation methodology or the aquifer property input data and does not allow for repeating or validating the reported drawdown estimates.
- LRE's estimated drawdown in the Town's wells due to 100 years of Pine Canyon well field pumping is over 56 feet in the Arapahoe aquifer, 69 feet in the Denver aquifer, and 82 feet in the Dawson aquifer.
- The Jehn Report underestimates the interference impacts of Pine Canyon well field pumping and reports 8.5 to 10.5 feet of drawdown in Town wells within the three aquifers.
- There are at least 6 Town wells completed in the Lower Dawson Aquifer, 18 wells completed in the Denver Aquifer, and 16 wells completed in the Arapahoe Aquifer that are within the 40 foot drawdown contour after 100 years of pumping of the proposed Pine Canyon wells from Well Fields 1 and 2.
- The increase of operational costs for the closest Town of Castle Rock well to both Well Fields 1 and 2 (including use and instantaneous demand charges) will be approximately $14,650 per year in 2020 dollars, and $22,850 per year in predicted 2120 dollars for the six (6) wells included in this analysis.
- The increase in annual operational costs of the Town's well fields (use and instantaneous demand) is likely much higher after 100 years of the proposed Pine Canyon pumping as the Town owns more production wells in the Lower Dawson, Arapahoe, and Denver aquifers than were analyzed in this analysis.

Sincerely,



Dave Colvin, P.G., P.M.P.
Groundwater Team Leader
LRE WATER

DCC/dcc

September 10, 2020 Amendment

LRE reviewed Jehn Water's "*Response to Douglas County's Initial Review Letter Concerning the Water Supply for Pine Canyon*", dated July 7, 2020. In their analysis of well interference, Jehn Water used a specific yield value which represents unconfined aquifers in the well interference calculation. We believe the aquifers evaluated are better represented as semi-confined, based on the layering of the sandstone and siltstones. In our analysis of well interference, LRE Water used a specific storage value that represents semi-confined aquifer conditions. We feel that it is more appropriate to use a specific storage value rather than a specific yield value as it better represents observed drawdowns in Castle Rock Water wells. The specific storage values are also similar to those values used by CSU (Lewis, 2014) and the USGS (Paschke, 2011).

References

Lewis, Allan. 2014. A METHOD USING DRAWDOWN DERIVATIVES TO ESTIMATE AQUIFER PROPERTIES NEAR ACTIVE GROUNDWATER PRODUCTION WELL FIELDS. Department of Geosciences Colorado State University. Fort Collins, Colorado

Paschke, S.S. ed., 2011, Groundwater availability of the Denver Basin aquifer system, Colorado: U.S. Geological Survey Professional Paper 1770, 274 p.. https://pubs.usgs.gov/pp/1770/

Robson et al. 1987. Bedrock Aquifers in the Denver Basin, Colorado A Quantitative Water-Resources Appraisal. https://pubs.usgs.gov/pp/1257/report.pdf

Rockware, Inc., 2020. Rockworks, https://www.rockware.com/product/rockworks/

United States Energy Information Agency. 2020. https://www.eia.gov/outlooks/steo/data/browser/#/?v=8

Tables

Table 1: Averaged aquifer parameters from local Castle Rock wells used in Theis Drawdown analysis.

Aquifer	Well Field	Transmissivity (gpd/ft)	Storage (-)	Pump Rate (gpm)
Arapahoe	**1**	2707.8	2.54E-04	146.7
	2	3275.4	2.07E-04	146.7
Denver	**1**	3237.6	3.53E-04	194.7
	2	2909.1	2.25E-04	194.7
Lower Dawson	**1**	1226.3	3.93E-04	98.5
	2	1226.3	3.93E-04	98.5

Table 2: Drawdown comparison from Jehn Report and LRE Theis analysis.

Aquifer	Well Field Pumping	Well Permit No.	Jehn Report Estimated Drawdown (100 years pumping, feet)	LRE Estimated Drawdown (100 years pumping of one Pine Canyon well, feet)
Arapahoe	**1**	68742-F	9.9	56.4
	2	66696-F	8.5	46.6
Denver	**1**	68741-F	22	69.6
	2	67253-F-R[a]	24.8	69.6
	2	66697-F	-	58.5
Lower Dawson	**1**	26267-F[a]	9	76.1
	1	55976-F	-	56.5
	2	24620-[a]	10.5	82.7
	2	51753-F	-	69

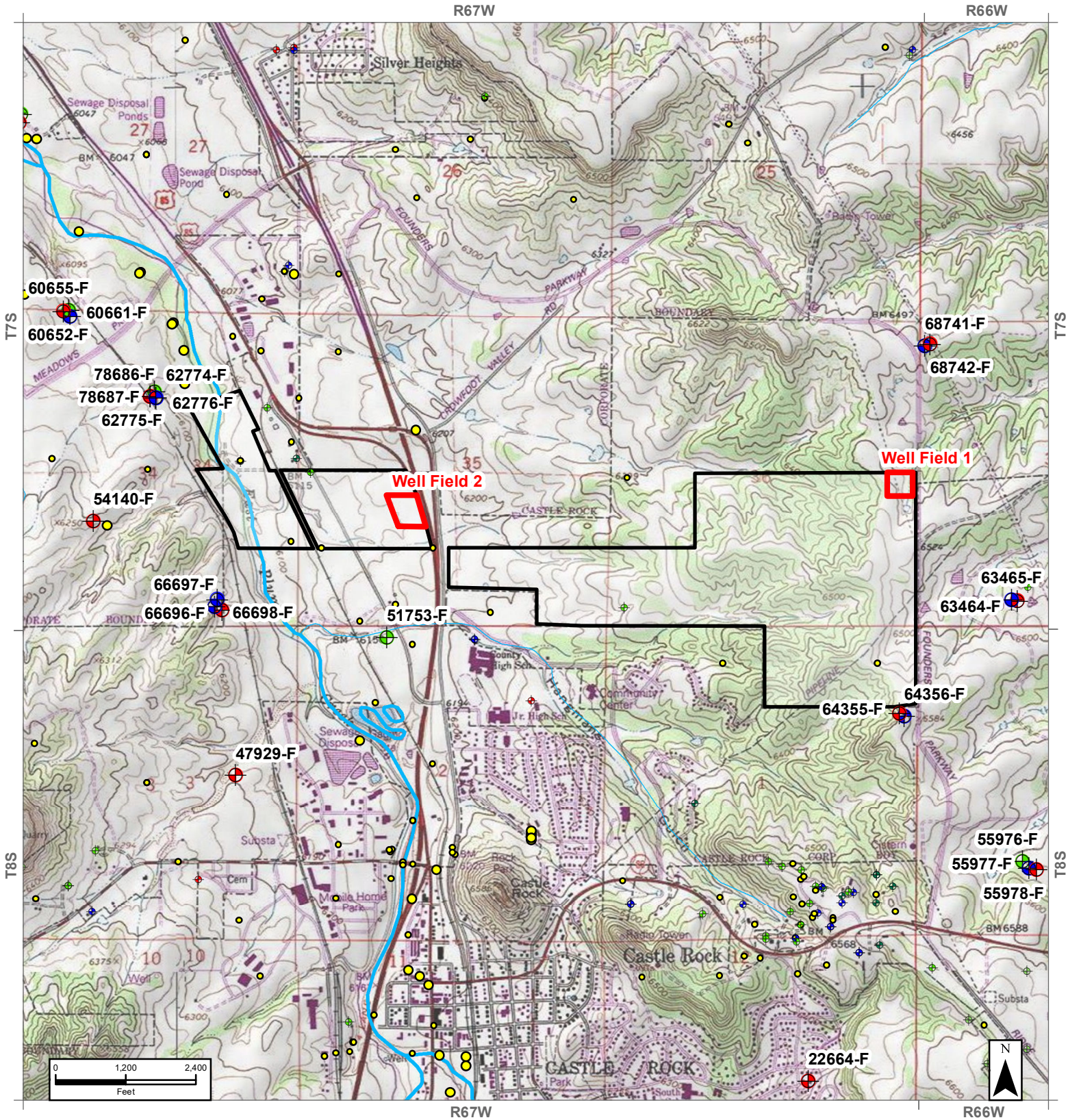
[a]Wells that Jehn Water analyzed, but are not owned by Town of Castle Rock

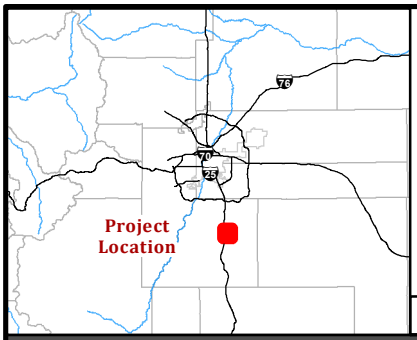
LRE WATER
CONNECTING WATER TO LIFE

Table 3: Estimated Well Pumping Cost Increase Due to Interference from Pine Canyon Well Fields

Well Field No.	Well ID	Owner	Design Q (GPM)	Assumed Constant Operational Q (GPM)	Aquifer	Approximate Change in TDH after 100 years of pumping from Pine Canyon Interference (feet)	Increase in Instantaneous Demand after 100 years w/70% Pump Efficiency[b] & $0.05/kWh[a] (kW)	Increase in Use Cost after 100 years w/70% Pump[b] Efficiency & $0.05/kWh[a] ($/Day)	Annual Use Cost Increase @ 100 years ($/Year)	Annual Use Cost Increase @100 Years **in 2120 Dollars**[d] ($/Year)	Increase in Demand Cost after 100 years $17.25/kW[a] ($, Billed Monthly)	Annual Demand Cost Increase @ 100 years ($ for 12 months)	Annual Demand Cost Increase @ 100 years **in 2120 Dollars**[d] ($ for 12 months)	Total Annual Cost Increase @ 100 years[g] ($/Year)	Total Annual Cost Increase @ 100 years **in 2120 Dollars**[d,g] ($/Year)
1	68742-F	Town of Castle Rock	400	400	Arapahoe	56.4	6.1	7.3	2,662.7	4,153.8	104.7	1,256.8	1,960.5	14,647.3	22,849.8
2	66696-F	Town of Castle Rock	650	650	Arapahoe	46.6	8.2	9.8	3,572.1	5,572.5	140.6	1,687.4	2,632.3		
1	68741-F	Town of Castle Rock	200	200	Denver	69.6	3.7	4.5	1,643.6	2,564.1	64.6	775.4	1,209.7		
2	67253-F-R[e]	Douglas County School District	230	230	Denver	69.6	4.3	5.2	1,888.3	2,945.8	74.3	891.8	1,391.2		
2	66697-F	Town of Castle Rock	250	250	Denver	58.5	3.9	4.7	1,724.0	2,689.4	67.9	814.7	1,271.0		
1	26267-F[e]	Castle Oaks Corporation	155[c]	155	Lower Dawson	76.1	3.2	3.8	1,391.6	2,170.9	54.8	657.1	1,025.1		
2	24620-[e]	Centennial Properties Inc.	7	7	Lower Dawson	82.7	0.2	0.2	69.4	108.3	2.7	32.3	50.3		
1	55976-F	Town of Castle Rock	30[f]	30	Lower Dawson	56.5	0.5	0.6	200.9	313.4	7.9	94.4	147.3		
2	51753-F	Town of Castle Rock	18	18	Lower Dawson	69	0.3	0.4	146.1	227.9	5.8	69.2	107.9		

[a]Estimated from Pump Use Only of Castle Rock Well Pumping Operations
[b]Assumed pump efficiency
[c]Calculated from Annual Appropriation
[d]Calculated Increase of Energy Costs of 156% in 2120 based on USEIA historical data assuming linearty
[e]Wells analyzed by Jehn Water that are not owned by the Town of Castle Rock
[f]Pump Rate determined from 4-hour conducted pump test
[g]Total Cost Increase from Closest Wells Owned By Town of Castle Rock Impacted from Pine Canyon Wells
Note: All calculations based on the assumption that TDH changes by the Additional Drawdown Due to Pine Canyon Wells. There are additional Town of Castle Rock Wells that will be impacted by Pine Canyon Pumping, this analysis only incoporates the closest wells to Well Fields 1 and 2





Alluvial
Dawson
Upper Dawson
Lower Dawson
Denver
Arapahoe

Pine Canyon Well Fields
Pine Canyon Development
Major Streams
Streams

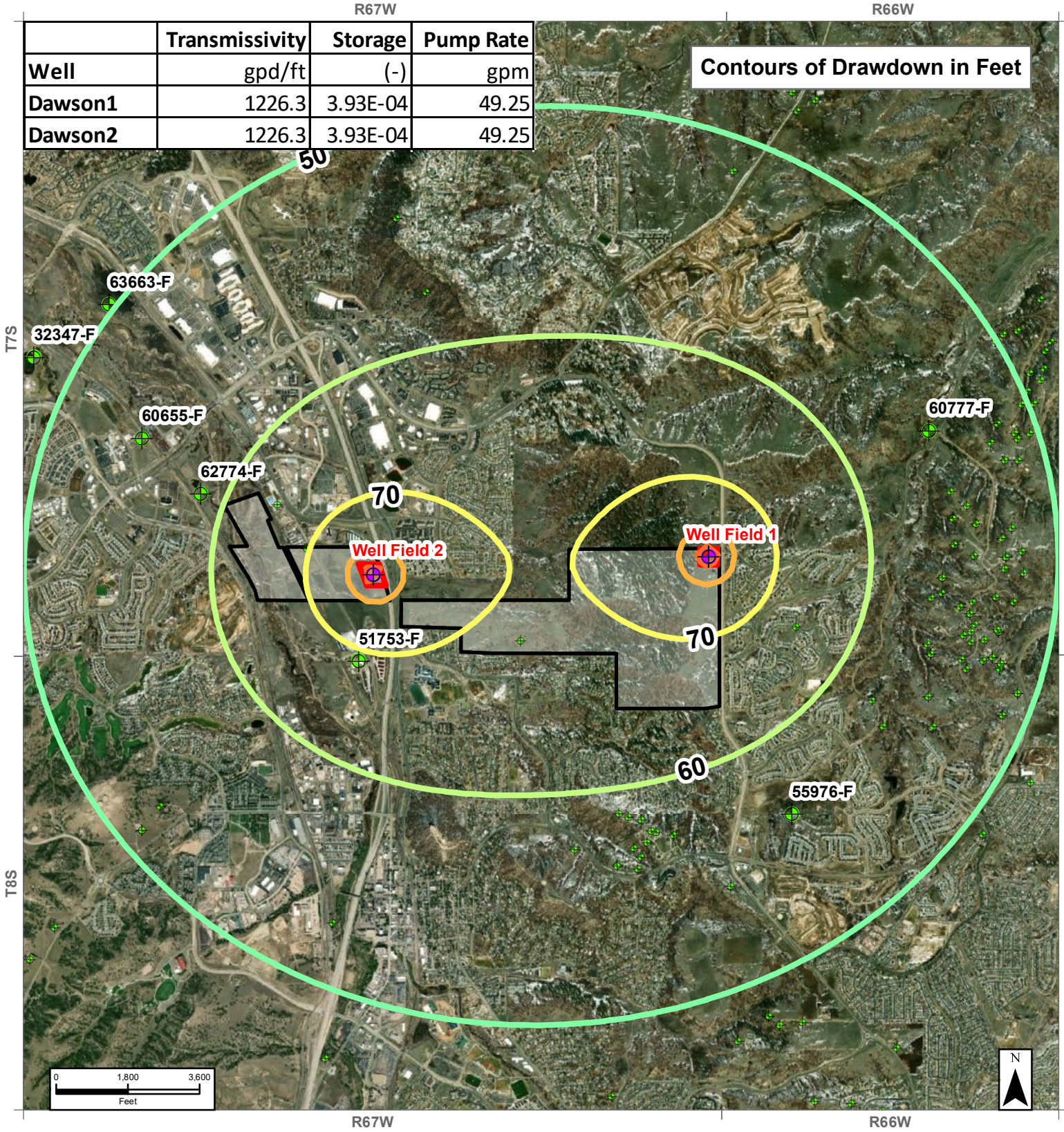
Non-Castle Rock owned wells are smaller and not labeled

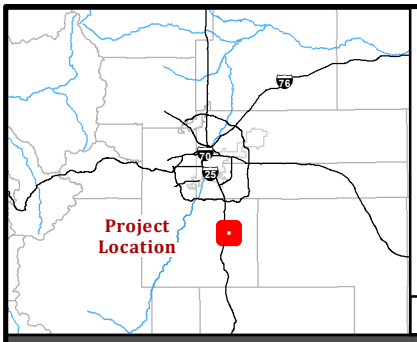
PROPOSED PINE CANYON WELL FIELDS WITH CASTLE ROCK WELLS

LRE WATER
CONNECTING WATER TO LIFE

1423CRK18
June 2020

	Transmissivity	Storage	Pump Rate
Well	gpd/ft	(-)	gpm
Dawson1	1226.3	3.93E-04	49.25
Dawson2	1226.3	3.93E-04	49.25





Proposed Pine Canyon Dawson Well

Constructed Lower Dawson Well

Pine Canyon Well Fields

Pine Canyon Development

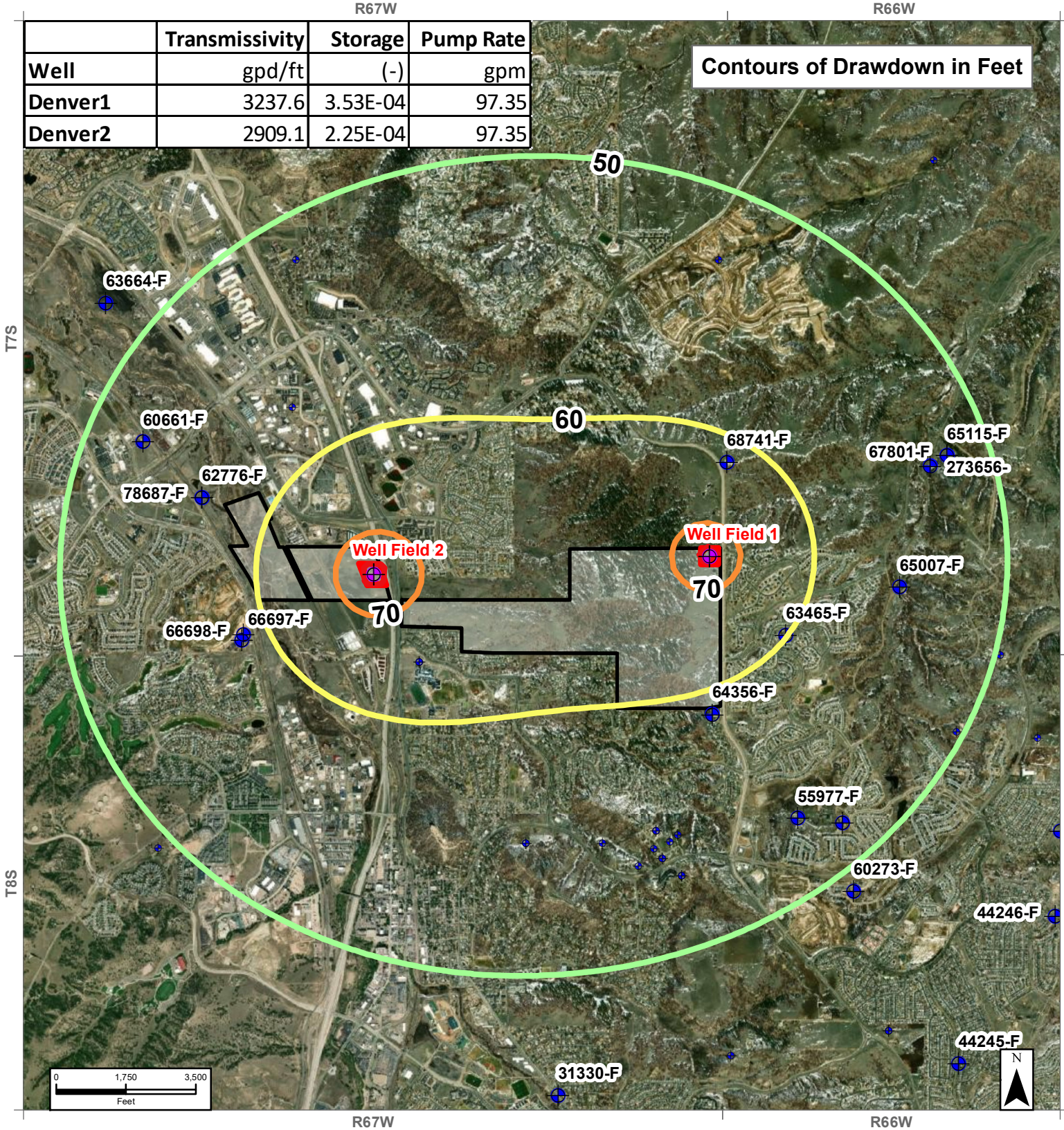
Non-Castle Rock owned wells are smaller and not labeled

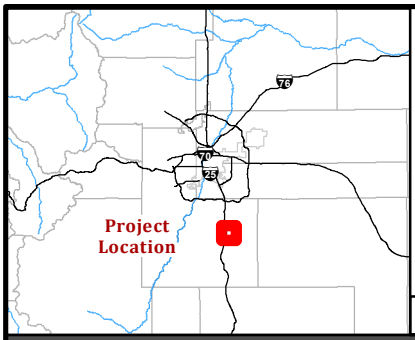
CUMULATIVE DRAWDOWN FROM PINE CANYON WELLS IN LOWER DAWSON AQUIFER AFTER 100 YEARS OF PUMPING

LRE WATER
CONNECTING WATER TO LIFE

1423CRK18
June 2020

	Transmissivity	Storage	Pump Rate
Well	gpd/ft	(-)	gpm
Denver1	3237.6	3.53E-04	97.35
Denver2	2909.1	2.25E-04	97.35





Proposed Pine Canyon Denver Well

Constructed Denver Well

Pine Canyon Well Fields

Pine Canyon Development

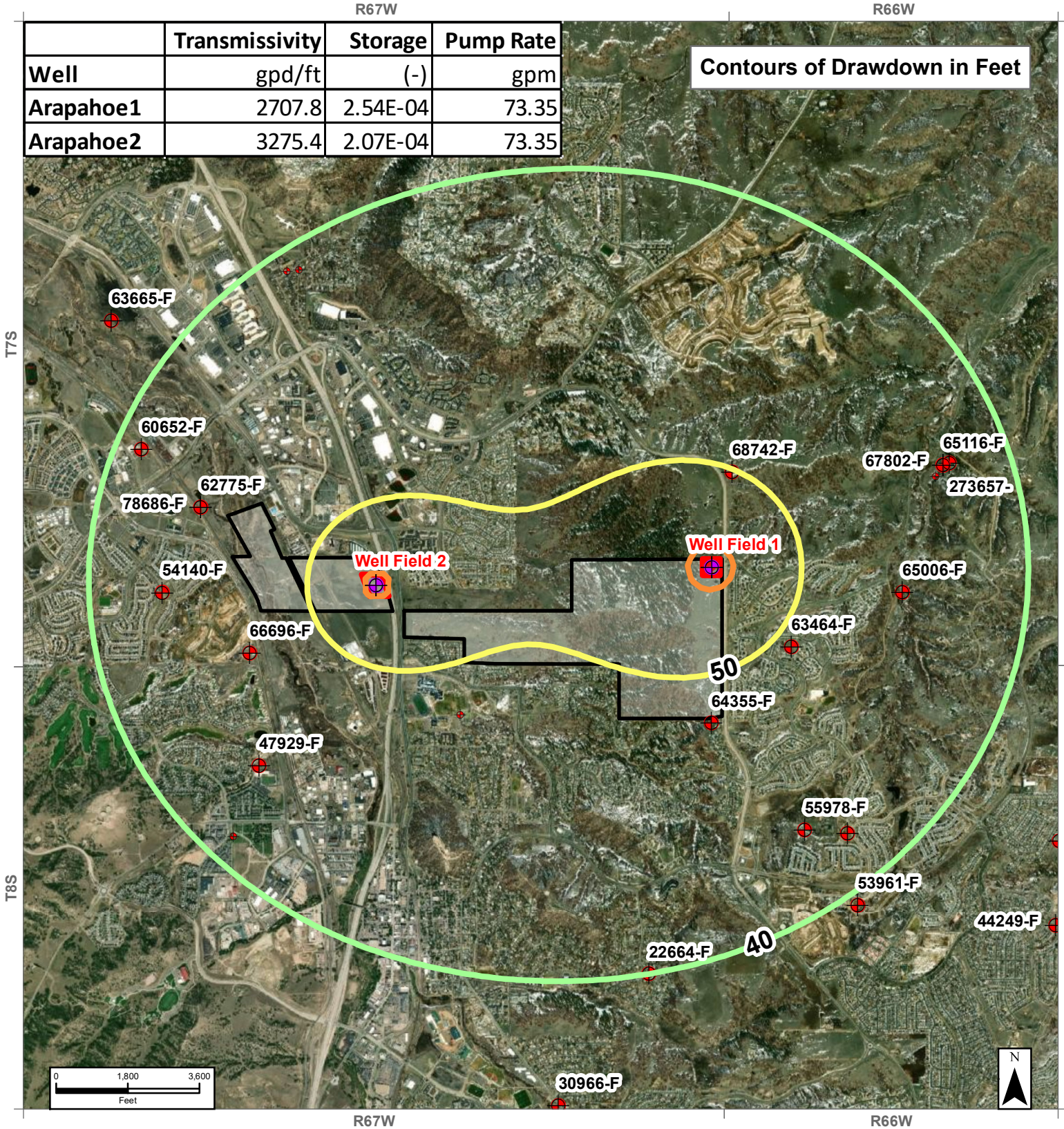
Non-Castle Rock owned wells are smaller and not labeled

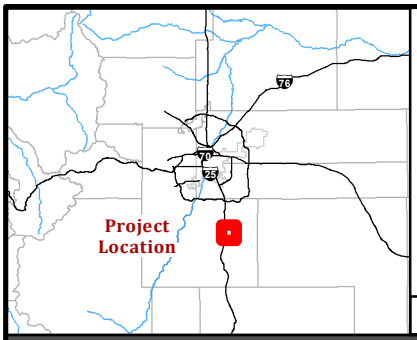
CUMULATIVE DRAWDOWN FROM PINE CANYON WELLS IN DENVER AQUIFER AFTER 100 YEARS OF PUMPING

LRE WATER
CONNECTING WATER TO LIFE

1423CRK18
June 2020

	Transmissivity	Storage	Pump Rate
Well	gpd/ft	(-)	gpm
Arapahoe1	2707.8	2.54E-04	73.35
Arapahoe2	3275.4	2.07E-04	73.35





Proposed Pine Canyon Arapahoe Well

Constructed Arapahoe Well

Pine Canyon Well Fields

Pine Canyon Development

Non-Castle Rock owned wells are smaller and not labeled

CUMULATIVE DRAWDOWN FROM PINE CANYON WELLS IN ARAPAHOE AQUIFER AFTER 100 YEARS OF PUMPING

LRE WATER
CONNECTING WATER TO LIFE

1423CRK18
June 2020