Evaluation of Castle Pines North Metropolitan District Water Level and Well Production Data Technical Memorandum

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1.0 Introduction

Declining water levels in the aquifers that supply the Castle Pines North Metropolitan District (District) have led to decreases in production of the District's supply wells. The Integrated Water Supply Plan prepared for the District (CDM 2006) examined trends in water levels and well production using information that was available for the 2005 summer pumping season. The results of that analysis were used to estimate declines in District supply and to establish a timetable for securing additional supplies.

The current evaluation examines more recent water level and well production data, using information collected by the District in 2006 and 2007, and further analyzes the relationship between declining water levels and well production. In addition, this memorandum presents the District's water level data collected through September 2007.

This evaluation was undertaken by Camp Dresser & McKee Inc (CDM) at the request of the District and was performed as Task Order No. 3 under the existing contract between the District and CDM for on-call professional services. This memorandum summarizes the work performed by CDM, including the methods of analysis, technical findings, and recommendations to the District.

Data analysis methods developed by CDM for the District's Integrated Water Resources Plan (CDM, 2006) were used for this evaluation. The methods included a compilation of data from different files and formats (electronic, hard copy) into electronic spreadsheets, graphical presentation of the data, and regression analyses to project trends in water levels and pumping. Descriptions of the analysis steps, key findings, and recommendations are provided below.

2.0 Compilation and Processing of Data

Data received from the District included both hard files and electronic spreadsheets. The hard files consisted of daily well production summaries from June of 2005 through October of 2006. The information included on these daily summaries was found to be inaccurate due to the data reporting system, and was not used in the well production analyses. Instead, data for this period was sent electronically from District staff for all of 2005 through late May 2008. The District also has several ledger books of well operating data which included hand recorded flow meter and pumping water level data, but the data were recorded too infrequently to be of much use. The hard-copy files utilized in this analysis also included daily water level data from April through August of 2007. These data were considered reliable and so were used in the final evaluation.

The electronic water level and well production data received from the District was utilized for the assessment and came from several sources. Daily water production data provided by the District was compiled into a master spreadsheet using monthly summaries from 2003 through May 2008. Well production data was collected manually using a cumulative flow meter. Daily production numbers had to be calculated by subtracting the daily production meter reading for a given day from the previous day's reading. Daily well production data was available from August 2003 until late October of 2007. The daily data was organized into monthly worksheets that were combined into a single spreadsheet for each well for analysis purposes.

Daily water level data records were available for each of the wells, but had data gaps throughout the reporting period. Data was also collected in a variety of different ways. Some years had hourly records, some twice per day, and some monthly. Table 1 summarizes the different collection frequency and significant gaps in the records for each well. Hard-copy files of the daily water level data were available from the District from April through August of 2007. These were manually transferred to a spreadsheet to fill in the missing electronic data for the period corresponding to high pumping in 2007. Overall, the water level data contains significant gaps due to inconsistent measurements prior to November 2006 for most wells, which limits the current analysis.

The water level data were collected using two different methods to record the raw readings (water pressure and depth to water). Several meetings were held during spring and summer 2008 with District staff to review the water level data and confirm the time periods in which each method of data recording was implemented. Table 2 provides a summary of data recording units used for the water level readings; this documents the method for future evaluations. In all cases the raw readings were converted to water level elevations prior to analysis and graphing. Water level elevations were computed by translating the water pressure readings to equivalent depth to water readings, and then subtracting these from land surface elevations. Land surface elevations at each District well were obtained from a September 2006 well survey report provided by the District for this analysis.

3.0 Analysis of Water Level and Production Trends

Analysis of the Districts water level and production data began with characterizing water level trends. This was accomplished by extending previous water level hydrographs for each of the District's ten supply wells with data that had been compiled through September 2007 and checked. Trends in water levels are discussed in Section 2.1.

Well production data were analyzed for Arapahoe wells of A-1, A-2, A-3 and A-4C. These wells were selected because they contain constant-speed pumps, which allows for an unbiased assessment of declines in pumping with declines in groundwater levels. A comparison of water level declines and changes in pumping rates during the peak pumping season was attempted but was not successful due to problems with reporting the pumping run times. Well production analysis results are presented in Section 2.2.

3.1 Water Level Analyses

The water level data for each of the District's supply wells are shown in a series of graphs, presented in Appendix A. The water level elevations are plotted on separate graphs for each well. The time axis on each graph varies, and extends from the first date of water level measurement through the last measurement, generally in autumn 2007. Also shown on each graph, for references purposes, are the top and bottom elevations of the aquifer in which the well is completed. The water level data for all wells is presented on Figure 1, along with the aquifer tops and bottoms superimposed.

The District's Arapahoe wells A-1, A-2 and A-4C have seen water levels drop below the top of the Arapahoe Aquifer during portions of the summer months since 2001 or 2002. Although the water level data are limited in recent years, it appears that water levels have remained below the top of the aquifer over most of the past 3 years for these wells. Well A-3 water levels have dropped below the top of the aquifer only briefly prior to 2007, but appear to remain below the aquifer since spring of 2007. Water levels in the District's other Arapahoe wells (A-6 and A-7) have been below the top of the aquifer since their monitoring periods began in 2003 and 2001, respectively. Water levels have also remained below the top of their respective aquifers for the District's Denver wells DE-6 and DE-7 and the Lower Dawson wells LDA-1 and LDA-2.

A general trend observed in these production wells is that water levels appear to have a greater rate of decline in the wells whose water levels were above the top of their respective aquifers (wells A-1 through A-4C) compared to the other wells, whose water levels have been within their respective aquifers. This was investigated by computing the decline in water levels through the period of record for each well, and for the period since the last measurement collected in 2002. The average decline in water levels for both of these periods for each well is shown in Figure 2. The exact periods of record for both water level measurements and well production differ somewhat for each well so in some cases the measurements may be from different times of the year at the start and end of each period. Accordingly, the values shown should be viewed in relative terms only. Several wells had data collection starting after 2002 (wells A-6, DE-6, and LDA-2) so the long-term and shorter-term values are identical for these wells. Despite this course-scale analysis approach, the results shown in Figure 1 and Appendix A provide insight into water level trends in the following ways:

- Declines in Arapahoe wells that began under fully confined aquifer conditions (wells A1 through A-4C) are slightly less than declines in Arapahoe wells whose water levels have remained within the aquifer;
- The rate of water level decline in the District's Arapahoe wells have increased in the past 5 years compared to the full period of record for each well; the increase in rate ranges from about 12 percent (well A-7) to almost 70 percent (well A-1);
- Since about 2002, water level declines range from approximately 35 to 65 feet per year in the District's Arapahoe wells, and from approximately 5 to 17 feet per year in its Denver and Lower Dawson wells.

The rate of water level declines shows a large range in the Districts wells, as shown on Figure 2. Reasons for the range in declines were investigated further. It is logical to conclude that the rate of decline in water levels is proportional to the production from each well. This was evaluated by summing the well production since 2002 and computing an average production rate for each well, in acre-feet per year (AF/yr). The results are shown in Figure 3, with the average well production posted above the bar chart showing the average rate of water level decline for each well, also since 2002. The bar chart in this figure is identical to one of the bars shown in Figure 2.

As shown in Figure 3, there appears to be little correlation between average pumping rates and average rates of water level decline. For example, well A-1 has amongst the highest average rate of water level decline but the lowest average production rate of the Arapahoe wells. The relationship between production and water level decline is shown on Figure 3 as a line graph, which represents the ratio of the average production to average water level decline, in AF/ft. The larger the ratio number the better is the output of a given well per foot of drawdown. All other factors being equal, a well with a larger ratio is more efficient than a well with a smaller ratio. Based on the trends shown in Figure 3, the following conclusions are offered:

- It appears that the District's Denver and Lower Dawson wells are more efficient than the Arapahoe wells since they show a higher ratio of production to water level decline. Note that limited production from well LDA-2 biases its ratio to be unrealistically low;
- Amongst the District's Arapahoe wells, wells A-6 and A-7 appear to be slightly more efficient than wells A-1 through A-4C even though their average production rates are higher;
- Although the rate of water level decline in wells A-1 through A-4C is slightly lower than the other Arapahoe wells (red bars shown on Figure 3), their pumping is also somewhat less efficient.

This analysis is based on multi-year averages that include slightly different time periods for the water level and production data within each well and between wells. A more refined analysis using fixed time periods amongst datasets may yield somewhat different results and is recommended for future work.

3.2 Well Production Analyses

Wells A-1 through A-4 underwent further analysis of changes in well production. The purpose of this analysis is to identify if a relationship exists between declines in water levels with declines in well production. If such a relationship exists it could be beneficial for predicting longer-term declines in well production and assist the District in its planning for additional wells.

Trends in water levels and well production were evaluated by plotting these data on a single graph for each well and visually examining trends. Since the water production during the higher production months of May through September was of the most interest, this period was selected for the data analysis. Water level data were sufficient only in 2007 to enable a comparison of both water level and well production trends. An example of the relationship between well production and water levels is shown for well A-4C in Figure 4. The data trends shown on this figure suggest that with declining water levels there is a decline in the well production.

Declines in water levels and declines in well production during the summer 2007 pumping period were estimated and average daily declines were computed for wells A-2 through A-4. A ratio of the average daily decline in production to average daily decline in water level was determined from these analyses. The results differ from well to well, ranging from 700 to almost 6000 gal/day/ft (gpd/ft) decline. This variation is likely due to site-specific factors for each well such as site hydrogeology and well construction. Data were available for well A-3 in summer 2005 to conduct a similar evaluation. This ratio was 2290 gpd/ft decline in 2005 and increased to 5730 gpd/ft decline in 2007. Based on this limited comparison, the production is leading to over twice as much water level decline in well A-3 over this 2-year period. A comparable analysis is subsequent years would be out the value of this analysis.

An additional analysis on well production was undertaken by evaluating the change in well production over time. Daily pumping data, available since 2004, were available for this analysis. The results are summarized as follows:

Change in Production During Peak Summer Pumping Season

Year	Total Decline (MGD)	Avg Daily Decline (Kgal/day)
2004	0.7	42
2005	1.2	26
2006	0.7	24
2007	0.8	28
Average	0.8	30

Trends in peak production during the summer pumping season were identified for each well and each year (see Figure 4 for an example). The trends were tabulated and summarized as the average daily decline in production, and as the percent decline in production during the period evaluated. The percent decline in well production for wells A-1 through A-4 for the summer pumping periods 2004 through 2007 is provided in Figure 5. No clear trends exist, either by well or by year, for the percent decline in well production for this time period. However, with 2 exceptions, well production is shown to decline by 14 to 58 percent in these wells in a given summer pumping season. This is a significant decline, as indicated in the table presented above.

4.0 Summary and Conclusions

The District has implemented an important step in managing its water resources by equipping its supply wells to collect both water level and production data on a daily basis. This information allows for a more detailed characterization to be made of the existing well yields and provides the District with the tools to make informed decisions regarding it future well supplies. The current analysis makes use of the available data to characterize water levels and to establish trends in both water level and production declines. Electronic files of water levels and well production have been compiled from hardcopy and electronic sources, and have been checked for consistency and for accuracy of internal computations. These files are being provided to the District under separate cover to document system operations and for the District's ongoing analyses.

Daily data have been available for both sets of data only since spring 2004 and there have been some gaps in the record since that time as equipment issues were sorted out. Unfortunately, run times for the pumping wells were not available due to equipment malfunctions so it was not possible to evaluate changes in pumping rates. Instead, daily production numbers were used and it was assumed that the duration of pumping was the same for each day. This is not likely to be the case, so there are unknown variations in production rates that could distort some of the trends in the production data. In addition, the analyses of water level and production trends have been somewhat limited by the short amount of time that both sets of data have been available. Despite these issues several important trends appeared in the data. These can be summarized as follows:

- The District's Arapahoe Aquifer wells all appear to have water levels that are below the top of the aquifer.

- Since about 2002, water level declines range from approximately 35 to 65 feet per year in the District's Arapahoe wells, and from approximately 5 to 17 feet per year in its Denver and Lower Dawson wells.

- The rate of water level decline in the District's Arapahoe wells have increased in the past 5 years compared to the full period of record for each well; the increase in rate ranges from about 12 percent (well A-7) to almost 70 percent (well A-1).

- The District's Denver and Lower Dawson wells may be more efficient than its Arapahoe wells, as defined by the average change in well production to the average change in water level.

- Well production has declined in Arapahoe Wells A-1 through A-4 by an average of 0.8 MGD through the peak pumping season for 2004 to 2007, corresponding to an average daily decline of approximately 30,000 gallons/day in production from these wells.

- There is a weak correlation between water level declines and well production declines. The lack of clear trends amongst wells over time may be related to variations in local aquifer properties, well completion and well operations.

5.0 Recommendations

Based on the data compilation and analyses undertaken, the following recommendations are offered:

5.1 Recommendations for data collection

- For computerized data collection on daily well production, make sure that computers are recording accurate:
  - Runtimes (hrs)
  - Flow (gpm)
  - Daily flow (Mgal)
  - Flow Totals, including for that day, the previous day, that month, and the previous month
- For manually collected data on daily well meters, make sure that the numbers are accurately entered.
- Daily water level data should be collected each day that includes:
  - Date
  - Depth to Water
  - Water Elevation
  - Flow Rate
- Each employee involved with operations should know how to identify each of these data collection techniques, especially the daily production data collection.
- The District should continue to collect daily data. These data should be downloaded and reviewed on a monthly basis to verify that the equipment is operating correctly.

5.2 Recommendations for data analysis

- The District should undertake an analysis of the well production and water level data comparable to what is presented in this memorandum once per year, after the peak summer pumping period. More frequent analyses may be warranted to verify the correct operation of the data collection equipment.

6.0 References

Camp Dresser & McKee Inc, 2006. Integrated Water Resources Plan. Prepared for the Castle Pines North Metropolitan District. November.