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Appendices

3.1 NO ACTION ALTERNATIVE DEFINITION

Water supply planning and permitting per federal regulations require owners to compare multiple action alternatives to one another as well as the no action alternative. The No Action Alternative assumes that no additional water source will be delivered to rural Douglas County groundwater users before the year 2050, and users will continue to rely on Denver Basin groundwater to fulfill household water supply demand. By predicting the changes in the groundwater levels in the Denver Basin aquifers, the cost and general feasibility of this scenario can be compared to an Action Alternative, discussed in Section 4, which would implement a reuse water supply system. This Feasibility Study will compare this No Action Scenario with one potential action alternative, namely the DC Watersmart Rural Water System further described in Section 4.

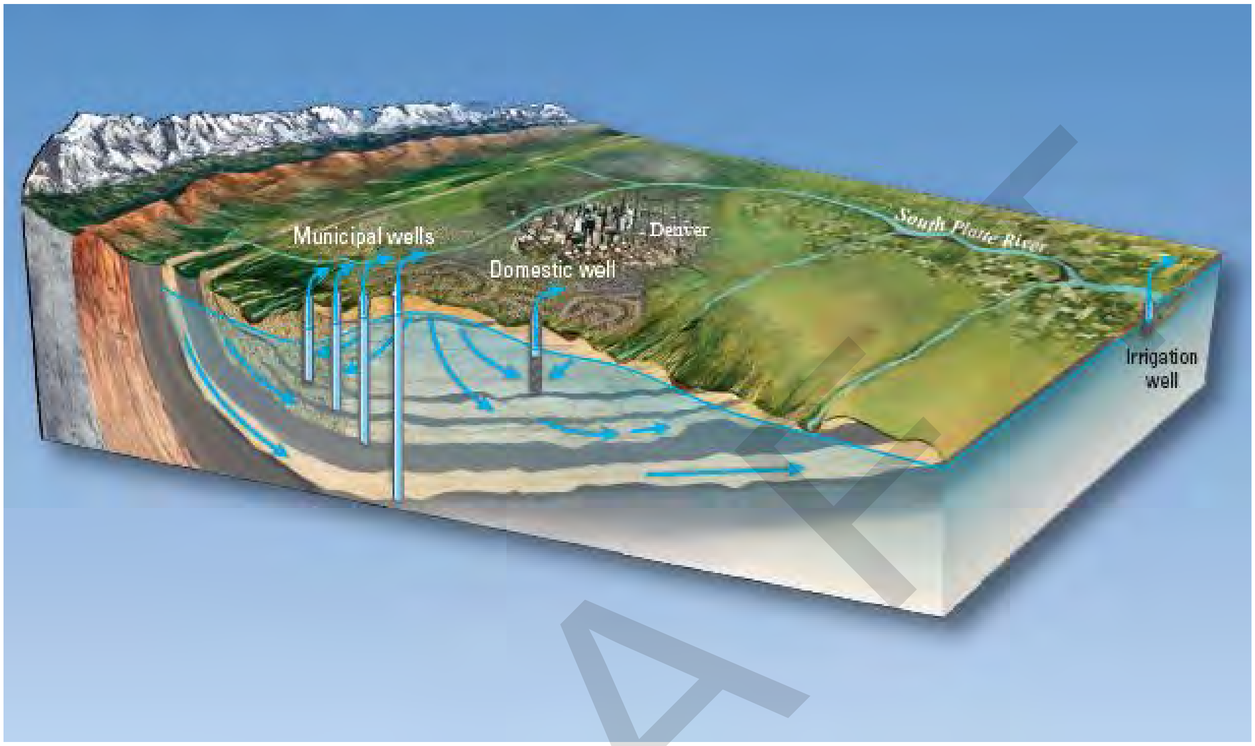
As the population in the unincorporated areas of Douglas County increases, so does water demand. The majority of rural residents obtain their drinking water from groundwater wells completed (screened) in one of the Denver Basin aquifers. The potential changes to groundwater levels with increased pumping are generally negative. The water levels in the regional aquifers are declining each year due to long term groundwater pumping and the removal of groundwater from storage (USGS 2011). When groundwater pumping rates from an aquifer exceed the estimated recharge from precipitation and other water supply sources to the aquifer, water levels in wells are lowered as the groundwater is “mined” from the aquifer. This has been documented in a number of studies over the years; such pumping has lowered the potentiometric heads in the Denver Basin bedrock aquifers. Regional water level declines are reportedly less in the alluvial aquifer, due to the connection between the alluvial aquifers and overlying stream systems. The hydraulic conductivity of the alluvial aquifer material results in greater recharge rates as compared to the bedrock aquifers. This Feasibility Study focuses on rural groundwater users that rely on bedrock aquifers and are potentially at risk of severe water shortages.

The following section will evaluate historical data regarding groundwater pumping, Denver Basin bedrock aquifer conditions, new USGS modeling results, and provide assumptions to allow predictions for anticipated annual groundwater level decline rates. These groundwater decline rate predictions will then be applied to existing groundwater well users within the area being proposed for the action alternative and the local resident’s ability to sustain the use of their respective wells through the planning horizon of 2050. While historic conditions cannot predict the future, a reasonable analysis of water availability and associated challenges can be developed to provide groundwater users the tools to decide if and when an action alternative may be necessary to provide an alternate sustainable water supply source.

3.2 GEOLOGIC CONCEPTUAL MODEL

Figure 3-1 is a block diagram for the southern portion of Denver Basin illustrating the shape of the geologic units located beneath the Project Area. In layman’s terms, the Denver Basin is shaped like a giant bowl, and the bottom of the bowl is more than 2 miles (over 13,000 feet) deep. As the center of the basin slowly sank over geologic millennia, the bowl was filled with a sequence of sand, silt, clay deposits that were compressed and heated with depth, and formed into sedimentary rocks. The west side of the bowl slopes steeply up against the uplifted Front Range, and the east side of the bowl slopes gently towards Nebraska and Kansas.

Figure 3-1
Block Diagram of Denver Basin aquifers (USGS 2011)



The uppermost sedimentary rock formations of the Denver Basin comprise the Denver Basin aquifer system. Table 3-1 lists the various geologic units and associated aquifers, and the confining layers (aquitards, which restrict groundwater flow, and are composed of fine-grained sediments, clay/shale) that separate the aquifer intervals. From youngest to oldest, the bedrock units comprising the Denver Basin aquifer system are:

- Upper and Lower Dawson Aquifers
- Denver Aquifer
- Upper and Lower Arapahoe Aquifers
- Laramie-Fox Hills Aquifer

The Pierre Shale underlies the Laramie-Fox Hills aquifer and serves as a regional aquitard. The Pierre Shale is a thick, low permeability unit, which defines the lower limit of groundwater development within the Denver Basin. Along stream channels in the larger drainage, alluvial sand, gravel, and clay deposits overlie the bedrock formations, and these materials form an unconfined alluvial aquifer where saturated (USGS 2011).

Table 3-1
Hydrogeologic Units of the Denver Basin Within Study Area (Modified from USGS 2012)

Hydrogeologic Unit	Stratigraphic Unit	Model Layer	Lithologic Description	Mean Thickness (feet)	Hydrogeologic Description
Alluvial aquifer where excavated	Alluvial, floodplain, terrace, colluvial sand, gravel, and clay deposits	1	Unconsolidated sand and gravel with clay lenses	0 to 175	Productive unconfined alluvial aquifer where saturated
Upper Dawson aquifer	Dawson Formation	2	Arkosic fluvial sandstone and conglomerate with interbedded claystone	54 to 183	Productive unconfined as to confined aquifer
Dawson confining unit	Dawson Formation	3	Claystone	76	Claystone confining unit in northern part of Dawson extent
Lower Dawson aquifer	Dawson Formation	4	Mixed arkosic and andesitic fluvial sandstone with interbedded claystone, lignite, and volcanics	180 to 242 where undiffer-entiated	Productive confined aquifer
Upper Denver confining unit	Denver Formation	5	Predominantly claystone with interbedded sandstone, lignite, and volcanics	49	Fine-grained confining unit in upper Denver Formation
Denver aquifer	Denver Formation	6	Mixed arkosic and andesitic fluvial sandstone	674 to 858	Confined to unconfined aquifer; lower hydraulic conductivity and less productive than Arapahoe aquifers
Lower Denver confining unit	Denver Formation	7	Predominantly claystone with andesitic fluvial sandstone	42	Fine-grained confining unit at base of Denver Formation
Upper Arapahoe aquifer[1]	Arapahoe Formation	8	Arkosic fluvial sandstone with interbedded claystone	221 to 259	Productive confined aquifer above Arapahoe confining unit in northern one-third of basin
Arapahoe confining unit[1]	Arapahoe Formation	9	Predominantly claystone	0.1	Claystone confining unit in northern one-third of basin, simulated as aquifer in Project Area
Lower Arapahoe aquifer[1]	Arapahoe Formation	10	Alluvial fan conglomerate and sandstone with interbedded claystone	221 to 259	Productive confined aquifer; greatest thickness and hydraulic conductivity in west-central part of basin
Laramie confining unit	Laramie Formation	11	Gray to black shale, coal, siltstone, and sandstone	398	Confining unit in upper part of Laramie Formation
Laramie-Fox Hills aquifer	Laramie Formation Fox Hills Sandstone	12	Poorly consolidated delta-front fluvial sandstone Yellow-brown marine delta-front and beach sandstone	268 to 331	Productive confined to unconfined aquifer composed of sandstones of lower Laramie Formation and Fox Hills Sandstone
Pierre Shale confining unit	Pierre Shale	Not simulated	Dark to light gray marine shale	5,200	Low-permeability base of Denver Basin aquifer system

[1]Where Arapahoe confining unit is absent (as in the study area), upper Arapahoe and lower Arapahoe aquifers are considered undifferentiated. A minimal layer thickness is required in the model where the confining unit is absent.

3.3 USGS GROUNDWATER FLOW MODEL

The United States Geological Survey (USGS) has recently published a report documenting construction of a computerized groundwater flow model for the Denver Basin aquifers (USGS 2011). The USGS model extends beneath the full extent of the Denver Basin aquifers, which includes the eastern portions of Douglas County (Figure 3-2). The model simulates the geologic and hydrologic conditions within the Denver Basin, and includes both domestic and municipal pumping wells completed in each aquifer.

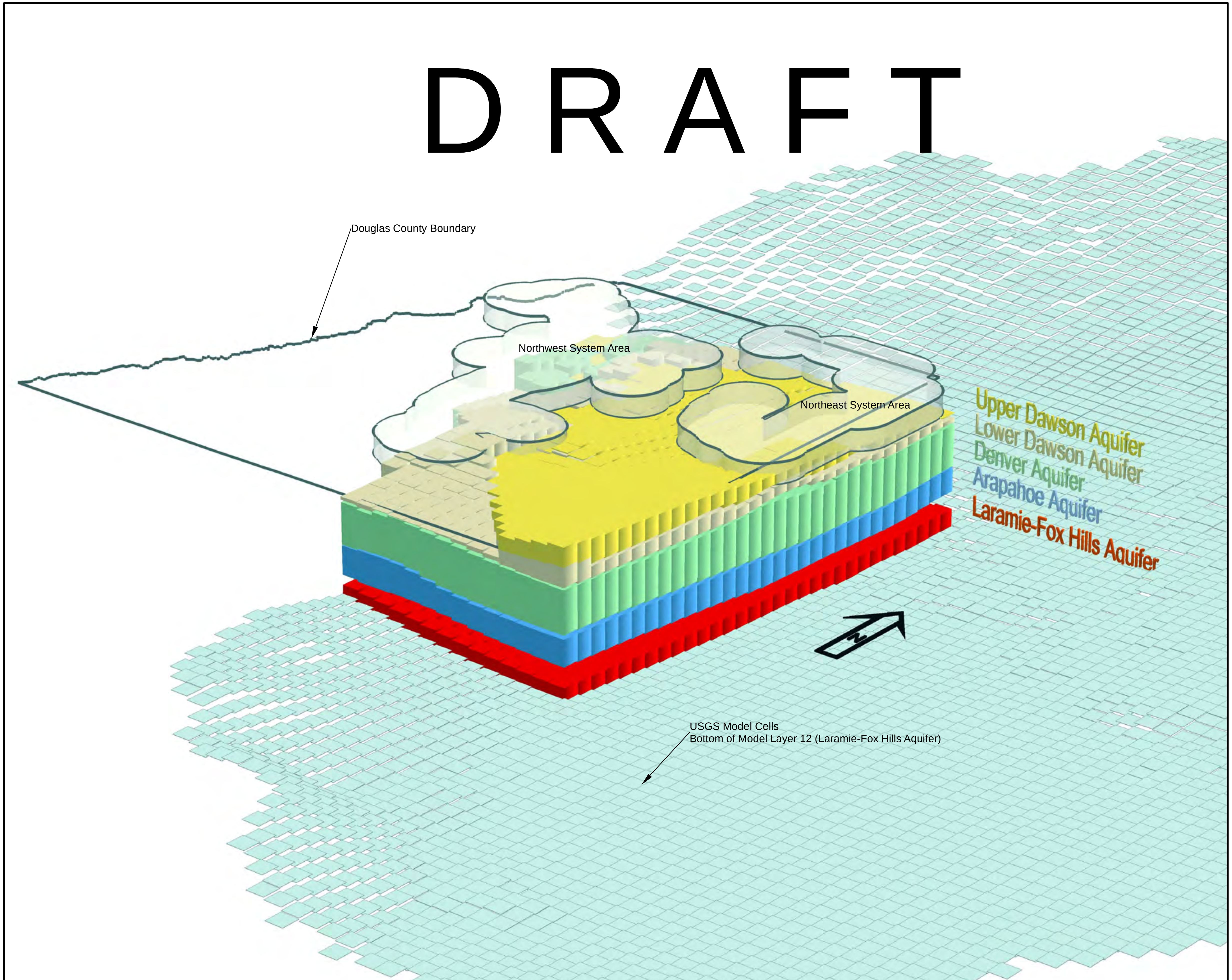
The model input and output files were obtained from the USGS website and utilized by URS in order to evaluate groundwater conditions in the study area. The model was not run as part of this project, however the model inputs were compared to water well permit information obtained from the Colorado State Engineers Office (SEO). The evaluation of the USGS model presented in this report is based upon the portion of the Project Area which overlies the Denver Basin aquifers. Water wells located in western Douglas County, which are drilled into metamorphic and granitic bedrock, are not producing water from the Denver Basin aquifers, and are therefore not simulated within the USGS numerical groundwater flow model, and are not included within this evaluation.

The USGS model simulates the horizontal extent of the portion of Douglas County beneath the Project Area and overlying the Denver Basin aquifers with 581 cells, each measuring one-square-mile in size. This represents a relatively small portion of the total model horizontal extent, which consists of 84 columns and 124 rows, or 10,416 square miles. There are 110 model cells simulating the region below the Northeast Service Area, the Northwest Service Area is simulated by 159 model cells, and the area of Douglas County outside of either service area but overlying the Denver Basin aquifers is simulated by 312 model cells.

The total region of the model in Douglas County includes 3,203 layer cells, comprising the 6 model layers comprising the aquifer units. Table 3-2 lists the number of model cells that simulate each aquifer or model layer. This table shows that the lateral extent of the Upper Dawson aquifer is more limited than for the underlying aquifers, as is reflected in the number of model cells that simulate each of the underlying aquifers or model layers.

Table 3-2
Summary of USGS Model Cells by Model Layer in Douglas County

Model Layer	Aquifer Simulated	Number of Model Cells in Layer
Layer 2	Upper Dawson	381 cells
Layer 4	Lower Dawson	530 cells
Layer 6	Denver	568 cells
Layer 8	Upper Arapahoe	570 cells
Layer 10	Lower Arapahoe	576 cells
Layer 12	Laramie-Fox Hills	578 cells



LEGEND

USGS Model Cells
in Douglas County

- Upper Dawson Aquifer (Model Layer 2)
- Lower Dawson Aquifer (Model Layer 4)
- Denver Aquifer (Model Layer 6)
- Arapahoe Aquifer (Model Layers 8 and 10)
- Laramie-Fox Hills Aquifer (Model Layer 12)
- Full Extent of USGS Model Cells for the Laramie-Fox Hills Aquifer (Model Layer 12)

DC WaterSmart System

Figure 3-2
Three-dimensional depiction of the USGS model layers simulating the Denver Basin aquifers

Sub-Regional Study Areas
- - - - - - - - - - - - - -
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3.3.1 Geologic and Hydrologic Properties in the USGS Model

The USGS model has a number of input parameters to simulate groundwater flow. The inputs include hydraulic conductivity (i.e. rock permeability with respect to fresh water), silt-plus-sand fraction, aquifer unit thickness, and aquifer storage (specific yield for unconfined units and specific storage for confined units). Recharge from numerous sources was simulated, including: precipitation, irrigation return flow, and infiltration from streams and reservoirs. Hydrologic stresses simulated by the USGS model include evaporation, transpiration by plants, pumping wells, and losses to streams and reservoirs.

URS reviewed the aquifer thickness and permeability properties assigned by the USGS to model cells within the Project Area, to evaluate the primary physical dimensions of the modeled aquifers and corresponding well completions, and potential variations in water yields that could be anticipated in this area. Aquifer thickness and permeability (hydraulic conductivity) are combined into one term, transmissivity, which is calculated by multiplying the hydraulic conductivity of a unit by its thickness. In the USGS model, the influence of the fraction of silt and sand in each unit also was considered in their transmissivity calculations, as described in the following sections.

3.3.2 Aquifer Thickness

The USGS numerical model is constructed of multiple layers to simulate aquifer units and confining layers. The modeled thicknesses of each aquifer and confining unit are based upon USGS review of thousands of geologic boring logs and identification of the tops of the various formations. Table 3-3 summarizes the thickness of the model layers of the six aquifers that underlie the Project Area.

The confining unit (model layer 9) that separates the upper and lower Arapahoe aquifers throughout much of the Denver Basin is not present beneath the Project Area (USGS 2011), and therefore the model simulates nearly identical physical parameters for both the upper and lower Arapahoe aquifer (model layers 8 and 10) and they are combined to represent one thicker aquifer. Beneath the Project Area, model layer 9 is generally assigned a thickness of 0.1 foot and a hydraulic conductivity value similar to the Arapahoe aquifer for model simulation purposes.

As shown in Table 3-3, the thickest aquifer interval is the Denver aquifer, with an average thickness of over 773 feet and reaching a maximum thickness of over 1,000 feet. The Upper Dawson aquifer is the thinnest aquifer unit, with an average thickness of only 54 feet beneath the Northwest Service Area and 137 feet beneath the Northeast Service Area. The Arapahoe aquifer is modeled with the most uniform thickness across the Project Area, approximately 450 feet, and is simulated by both layers 8 and 10.

Table 3-3
Summary of USGS Model Layer Thickness and Elevation for Project Area

Aquifer	Model Layer	Northeast Service Area Layer Thickness (ft)		Northwest Service Area Layer Thickness (ft)		Combined Northwest and Northeast Service Areas	
		Mean	Min / Max	Mean	Min / Max	Mean Thickness (ft)	Mean Top and Bottom Elevation (ft MSL)
Upper Dawson	2	137	10/284	54	11/116	124	6,080/5,956
Confining Layer	3	94	21/311	79	24/121	92	NC
Lower Dawson	4	180	77/360	242	11/409	209	5,979/5,770
Confining Layer	5	NC	NC	NC	NC	59	NC
Denver	6	858	686/978	674	20/1,030	773	5,731/4,958
Confining Layer	7	NC	NC	NC	NC	30	NC
Upper Arapahoe	8	234	197/282	221	105/291	228	4,734/4,506
Confining Layer	9	NP	NP	NP	NP	NP	NC
Lower Arapahoe	10	234	197/282	222	105/334	228	4,701/4,473
Confining Layer	11	NC	NC	NC	NC	389	NC
Laramie-Fox Hills	12	331	260/404	268	153/499	294	4,119/3,,825

3.3.3 Aquifer Transmissivity

The USGS assigned hydraulic conductivity values to each of the model layers based upon historic hydraulic testing performed on actual water wells, and evaluation of soil cores from water well boreholes. The hydraulic conductivity values were used by the USGS in conjunction with the silt and sand percentage of each bedrock aquifer model layer to simulate the transmissivity of each aquifer unit. This method generally provides a means to simulate the effective transmissivity of each unit. Table 3-4 provides a summary of the calculated average, minimum, and maximum model layer transmissivities for modeled aquifer intervals underlying the Project Area.

While the Denver aquifer (model layer 6) was the thickest unit, because of the low hydraulic conductivity and low percentage of silt-plus-sand, it has the lowest calculated transmissivity, averaging approximately 0.5 square feet per day (0.5 ft^2/d or 3.7 gal per day per foot, gpd/f). The aquifer unit with the highest transmissivity beneath the Project Area is the Arapahoe aquifer. The Upper Dawson aquifer also has a relatively high transmissivity, providing high water yields where the aquifer is saturated. Because of the relatively high transmissivity of the Upper Dawson and Arapahoe aquifers within the Project Area, they are highly utilized within Douglas County.

URS evaluated the transmissivity of the aquifer units underlying the Project Area using USGS model input files available on their website. The zone of highest transmissivity in the Upper Dawson is located in southeastern Douglas County, and extends north from the south border into the southern portion of the Northeast Service Area. The transmissivity of the Lower Dawson aquifer is relatively low to moderate, although several locations with higher transmissivities are shown in the eastern portion of the Northwest Service Area.

The transmissivity of the Denver aquifer, as simulated in the USGS model, is highest in the northern portion of the county, between the northern portion of Northwest and Northeast Service Areas. The transmissivity of the Arapahoe aquifer is relatively high across northern Douglas County, particularly in the north half of the Northwest Service Area and the northern third of the Northeast Service Area. For the Laramie-Fox Hills aquifer, the subsurface region with the highest transmissivity values in Douglas County is located beneath the northwest portion of the Northwest Service Area.

Table 3-4
Summary of USGS Model Layer Transmissivity

Aquifer	Model Layer	Northeast Service Area Transmissivity (ft^2/d)		Northwest Service Area Transmissivity (ft^2/d)		Combined Northwest and Northeast Service Areas Transmissivity (ft^2/d)	
		Mean	Min/Max	Mean	Min/Max	Mean	Min/Max
Upper Dawson	2	60	3.8/144	26	0.5/59	55	0.5/144
Lower Dawson	4	9	2.5/19	17	0.8/37	13	1/37
Denver	6	0.5	0.3/2.3	0.7	0.07/1.5	0.5	0.1/2
Upper Arapahoe	8	59	2.7/157	84.5	4.2/211	74	3/210
Lower Arapahoe	10	59	2.7/157	84.5	4.2/211	74	3/210
Laramie-Fox Hills	12	1	0.5/2.8	2.7	0.5/8.6	2	0.4/9

Note: Due to the absence of a confining layer between the Upper and Lower Arapahoe formations, the model simulates the Arapahoe aquifer by assigning the same properties to Layers 8 and 10.

3.3.4 Distribution of Water Well Completions

To evaluate the potential impacts to continuing groundwater extraction in the Project Area, URS obtained information on water wells permitted within Douglas County from the Colorado State Engineers Office (SEO). The SEO database lists 7,175 permitted water wells within Douglas County, and includes domestic (household), stock, irrigation, commercial, industrial, and municipal water wells. Not all of these wells are located on land overlying the Denver Basin aquifer system. There are 5,170 water wells located within Douglas County which are within the Project Area overlying the Denver Basin aquifers. Table 3-5 summarizes the number of water wells by aquifer completion in three areas; the Northeast and Northwest service areas and the region within Douglas County overlying the Denver Basin aquifers but outside of the two service areas.

Review of this table shows that the majority of water wells in the Northeast service area are completed within (e.g. screened and pumping from) the Dawson aquifer. In the Northwest service area, the majority of wells are evidently completed within the Denver aquifer. As shown in the USGS model, the Northwest service area is located at the west edge of the Denver Basin, and in this area the Upper Dawson aquifer is essentially not present, except for the area beneath the northeast portion of the service area.

Table 3-6 summarizes the number of water wells in each of the three areas by beneficial use.

Table 3-5
Well Distribution by Aquifer and Location (SEO 2012)

Aquifer	Northwest Service Area	Northeast Service Area	Douglas County Outside Service Area	Total Wells
Quaternary Alluvium	0	1	2	3
Upper Dawson	12	1283	374	1669
Lower Dawson	162	829	407	1398
Dawson	179	232	423	834
Denver	802	162	223	1187
Upper Arapahoe	3	0	0	3
Lower Arapahoe	1	0	0	1
Arapahoe	217	26	53	296
Laramie Fox Hills	35	4	18	57
Laramie	3	0	0	3
All Unnamed Aquifers	741	478	505	1724
Total Wells	**2155**	**3015**	**2005**	**7175**

Table 3-6
Well Use by Location in Douglas County (SEO 2012)

Beneficial Use	Northwest Service Area	Northeast Service Area	Douglas County Outside Service Area	Total
Domestic	1777	2697	1611	6085
Household Use Only	154	187	171	512
Municipal	41	33	73	147
Industrial	68	10	33	111
Commercial	37	37	24	98
Irrigation	22	8	23	53
Stock	10	26	30	66
All beneficial uses	13	4	14	31
Fire	1	0	1	2
Recreation	0	1	0	1
Geothermal	1	0	1	2
Other	31	12	24	66
Total Wells	**2155**	**3015**	**2005**	**7175**

The USGS groundwater model simulates groundwater extraction from the various types of wells (domestic, municipal, industrial, commercial, irrigation) based upon permit information in the SEO database. Given the large number of water wells in the Project Area, and the size and complexity of the USGS flow model, it was not possible to identify and correlate each permitted water well in the SEO database with the model input. However, comparison of the SEO water well database with the USGS model coordinates indicates that there are 3,015 permitted water wells located within the Northeast Service Area, 2,155 permitted water wells located within the Northwest Service Area, and 2,005 permitted water wells located within the Douglas County Region outside of the Service Areas. Based upon comparison of the SEO permit database records and the USGS model, there is a combined total is 5,170 water wells located within the two Service Areas within the USGS model domain.

The groundwater extraction rate simulated in the USGS model for a rural domestic water well with outdoor water usage is generally 72 cubic feet per day (ft3/d). This rate is equivalent to 0.37 gallons per minute (gpm), 538 gallons per day (gpd), or 0.6 acre-feet per year (a-ft/yr). The model also includes groundwater pumping from other types of water wells, including municipal, irrigation, and commercial and industrial water wells. Pumping rates are generally based upon available records in the SEO permit database and adjusted based upon regional usage of various well types (USGS 2011, pg. 101). The water well discharge is allocated for consumptive usage and return flow, depending upon the type of water well (USGS 2011).

3.4 USGS PROJECTED GROUNDWATER LEVELS TO 2053

The USGS model was developed and calibrated to simulate groundwater development from 1880 through 2003 utilizing 16 distinct stress periods, corresponding to sequential growth of the metropolitan, suburban, and rural greater Denver area (USGS 2011). The number of water wells simulated in the model generally increased with each successive stress period. The final stress period (number 16), represents the time period from 1999 through 2003. The model input parameters for this final stress period, including climatic conditions (evapotranspiration rates and recharge from precipitation), locations of irrigated areas and irrigation rates, and pumping rates, were used to simulate two predictive model scenarios for 50 years into the future (years 2003 to 2053). Predictive scenario 1 utilized the input for stress period 16 for the next 50 years, while predictive scenario 2 modified (decreased) the pumping rates for municipal wells located in the Arapahoe aquifer to evaluate likely reductions in water level decline rates when this lower aquifer is stressed less. The USGS report concluded that results from predictive scenario 1, which maintained the same number of pumping wells and pumping rates simulated in 2003 for the next 50 years, indicated continued decline, an increase in unconfined areas of each aquifer, and continued storage loss in all model aquifer layers (USGS 2011). Note that the USGS model did not evaluate a scenario in which population, and thus pumping rates, increased between the year's 2003 and 2053.

URS evaluated the model output files for the predicted, model-simulated, decline after 50 years in each of the aquifer units associated with predictive scenario 1 only. Table 3-7 summarizes the average, minimum and maximum decline values for each of the 6 aquifers underlying the Northeast Service Area, Northwest Service Area, and Douglas County region outside of the two service areas. The average total 50-year decline within the Northeast Service Area ranges from -17 feet in the Upper Dawson to -293 feet in the Laramie-Fox Hills aquifer. When calculated as an average *annual* water level decline over a 50-year period, the range is -0.3 to -5.9 feet per year (ft/y). The USGS model predicts the Northwest Service Area and area outside of the service areas could experience a similar magnitude and range of decline as the Northeast Service Area.

Figures 3-3 through 3-7 show the distribution of total predicted decline in 2053 for the Upper Dawson, Lower Dawson, Denver, Arapahoe, and Laramie-Fox Hills aquifers, respectively.

Table 3-7
Summary of USGS Model-Simulated Decline Rates

Aquifer	Model Layer	Northeast Service Area			Northwest Service Area			Combined Northwest and Northeast Service Areas	
		50-Year Decline (ft)		Avg Annual	50-Year Decline (ft)		Avg Annual	50-Year Decline (ft)	Avg Annu
		Mean	Min / Max	Decline (ft/yr)	Mean	Min / Max	Decline (ft/yr)	Mean	Decline (ft/yr)
Upper Dawson	2	-17	-0.04 / -45	-0.3	-14	-0.6 /-80	-0.3	-16	-0.4
Lower Dawson	4	-49	-3 / -107	-1.0	-22	-2 /-80	-0.4	-40	-1.0
Denver	6	-113	-21 / -214	-2.3	-50	-4 /-112	-1.0	-97	-2
Upper Arapahoe	8	-120	-61 / -198	-2.4	-63	-6 /-104	-1.3	-103	-2
Lower Arapahoe	10	-120	-61 / -198	-2.4	-63	-6 /-121	-1.3	-103	-2
Laramie-Fox Hills	12	-293	-152 / -618	-5.9	-204	-34 /-353	-4.1	-194	-5

Note: Due to the absence of a confining layer between the Upper and Lower Arapahoe formations, the model simulates the Arapahoe aquifer by assigning the same properties to Layers 8 and 10. The model-simulated predicted decline is the same for Layers 8 and 10.

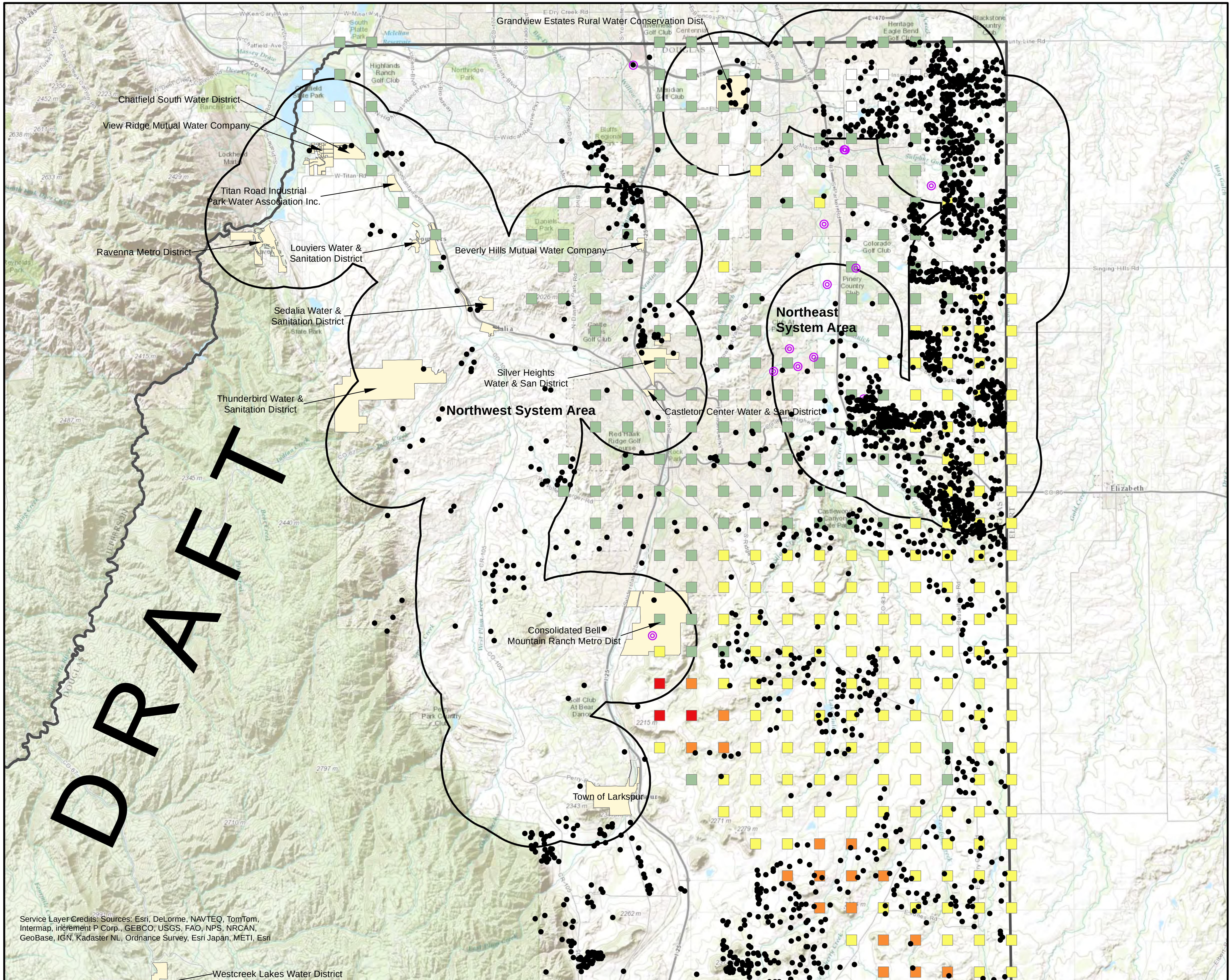
Values for the 50-year model-predicted decline amounts are color-coded on each figure. Each colored square box represents the total predicted decline in year 2053 at an individual one-mile square model cell. The total predicted decline is the same as the predicted total water level decline for the model cell. This 50-year model prediction value is divided by 50 to estimate the annual water level decline at a model cell.. Cool colors (blue and green) represent low ranges of predicted water level decline, and warm coolers (orange and red) represent higher ranges of predicted water level decline.

For the Upper Dawson aquifer (Figure 3-3), the model predicts the higher amounts of water level decline will occur along the east region of Douglas County and to the south. A similar distribution of 50-year model-predicted decline values is shown for the Lower Dawson Aquifer (Figure 3-4), although there is about twice the amount of decline predicted for the Northeast area (average of -50 feet in 50 years, or -1 foot per year).

Approximately -100 feet of water level decline is predicted by the model for the Denver aquifer (Table 3-7 and Figure 3-5), which is approximately twice the amount predicted for the Lower Dawson. Higher predicted values (greater than -150 feet over 50 years) occur in the south portion of the Northeast Service Area, and along the southern boundary of the Project Area, which may be impacted in the model from pumping in the Monument area.

Predicted water level declines in the Arapahoe Aquifer are similar as seen in the Denver Aquifer for the Northeast Service Area and south Project Area, however, in general there is less decline predicted for the Northwest Service Area (Figure 3-6).

The greatest amount of model-predicted water level decline occurs in the Laramie-Fox Hills aquifer (Table 3-7 and Figure 3-7). Average annual decline rates of -6 feet per year were predicted for the west portion of the Northeast Service Area and the east region of the Northwest Service Area. This area extends across much of the northern half of the Project Area. Noticeably lower declines are predicted by the model for the southern portion of the Northwest Service Area and the area southeast of the Project Area.



LEGEND

DWR Permitted Wells

- Municipal Well
- Domestic or Other Well
- Rural Water Service Areas
- Service Area (2 mile buffer around pipelines)

USGS Model Cell 50-year Decline (feet)

- -28 - 0
- 1 - 25
- 26 - 50
- 51 - 75
- 76 - 100

N W E S

0 3 6 Miles

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Figure 3-3
USGS Model-predicted Distribution of Decline in 2053
Upper Dawson Aquifer
(Model Layer 2)

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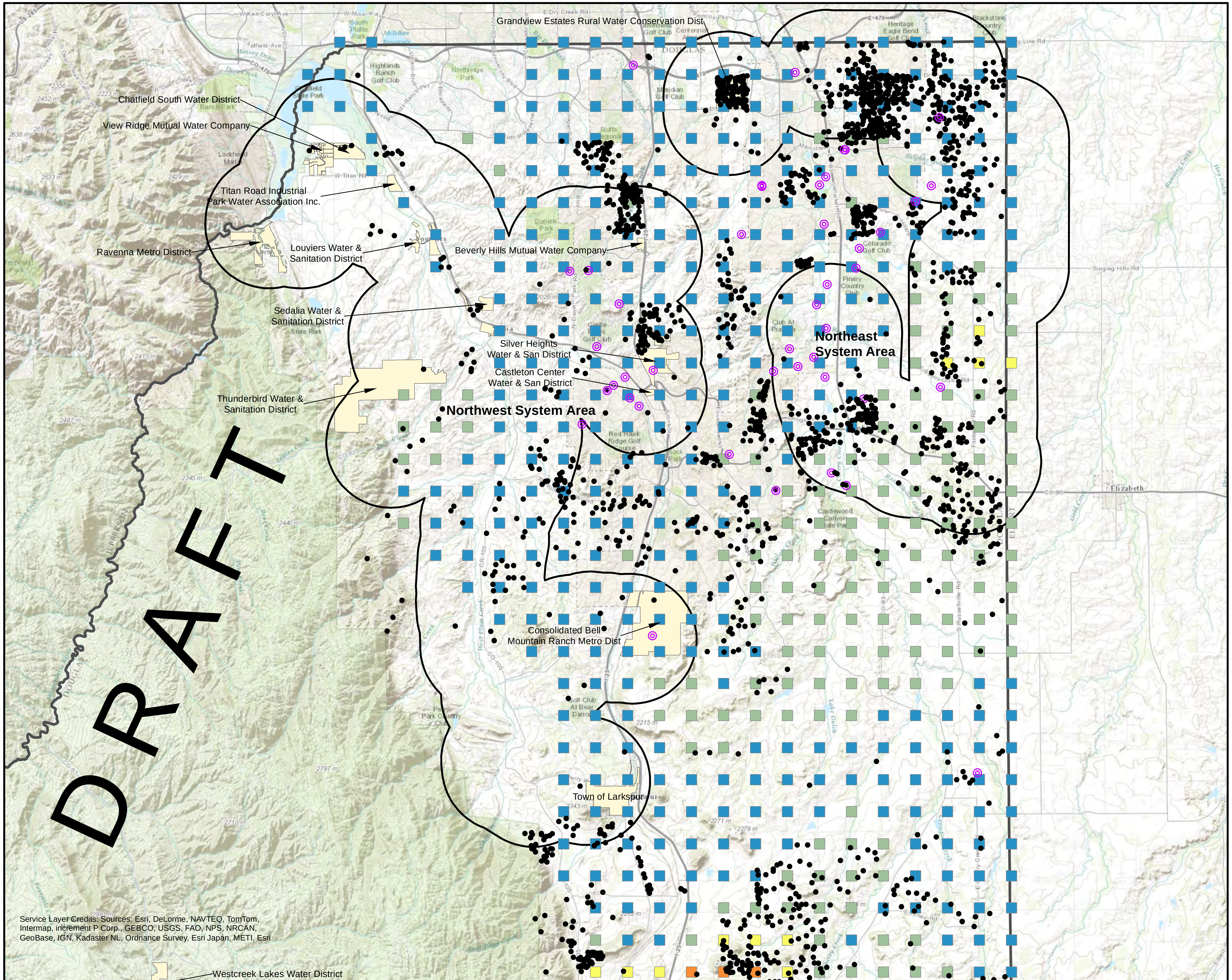

LEGEND

DWR Permitted Wells

- Municipal Well
- Domestic or Other Well

Rural Water Service Areas

Service Area
(2 mile buffer around pipelines)

USGS Model Cell
50-year Decline (feet)

- 0 - 50
- 51 - 100
- 101 - 150
- 151 - 250
- 251 - 375

N
W E
S

Miles
0 3 6

DC WaterSmart System

Figure 3-4
USGS Model-predicted Distribution of Decline in 2053
Lower Dawson Aquifer
(Model Layer 4)

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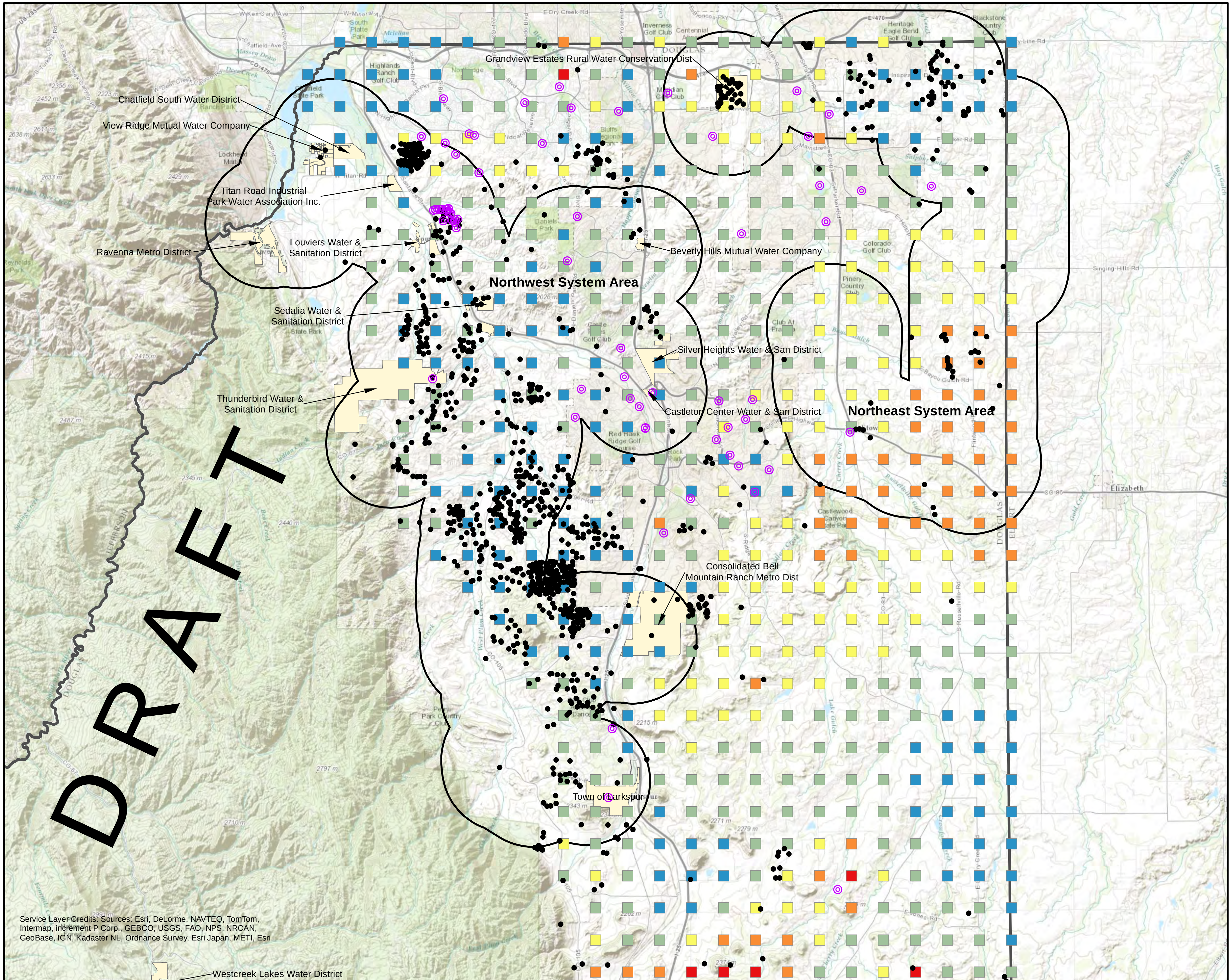

LEGEND

DWR Permitted Wells

- Municipal Well
- Domestic or Other Well
- Rural Water Service Areas
- Service Area (2 mile buffer around pipelines)

USGS Model Cell 50-year Decline (feet)

- 0 - 50
- 51 - 100
- 101 - 150
- 151 - 250
- 251 - 550

N W E S

0 3 6 Miles

DC WaterSmart System

Figure 3-5
USGS Model-predicted Distribution of Decline in 2053
Denver Aquifer
(Model Layer 6)

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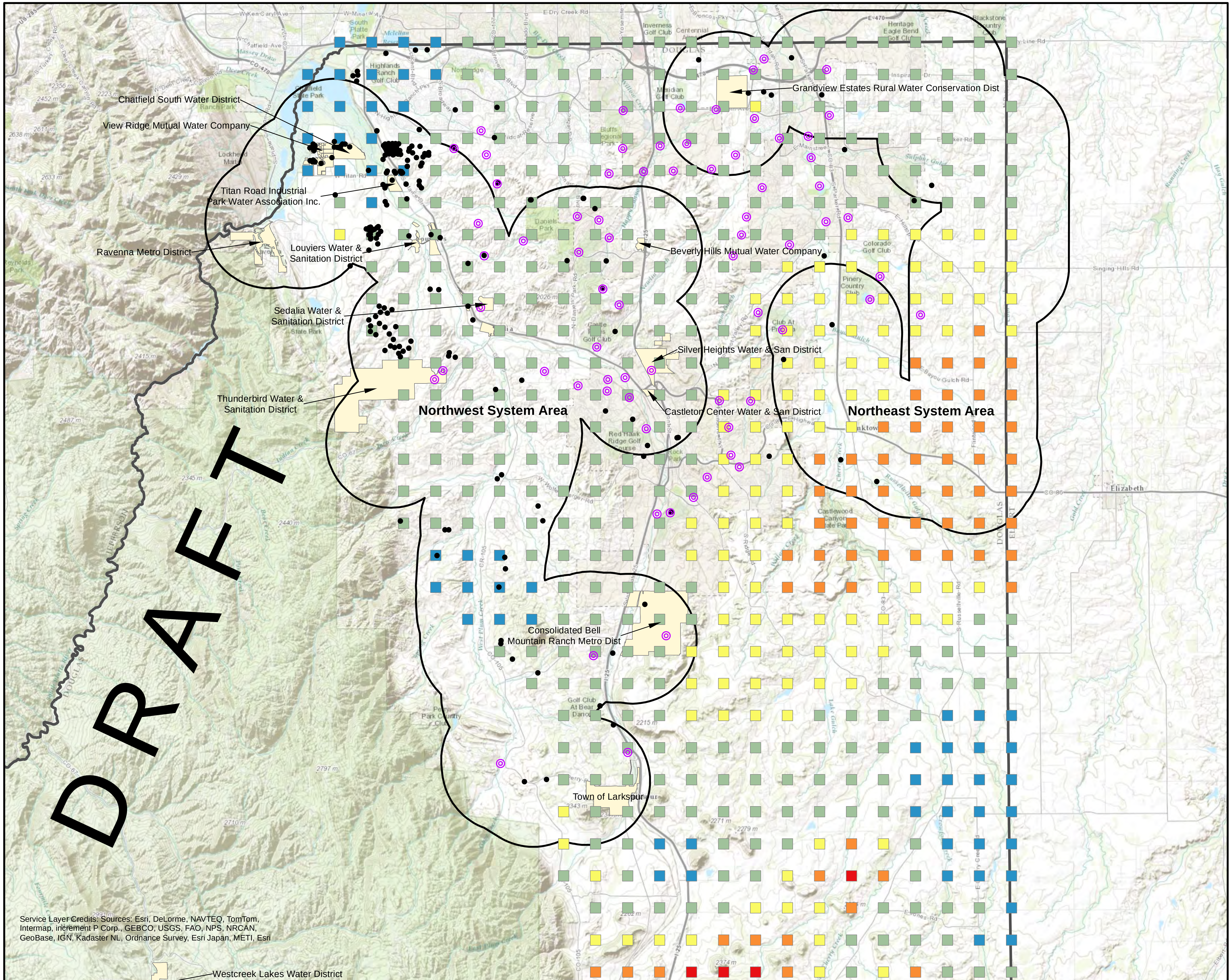

LEGEND

DWR Permitted Wells
- Municipal Well
- Domestic or Other Well
- Rural Water Service Areas
- Service Area (2 mile buffer around pipelines)

USGS Model Cell 50-year Decline (feet)
- 0 - 50
- 51 - 100
- 101 - 150
- 151 - 250
- 251 - 550

N W E S

Miles 0 3 6

DC WaterSmart System

Figure 3-6
USGS Model-predicted Distribution of Decline in 2053
Arapahoe Aquifer
(Model Layers 8 and 10)

Sub-Regional Study Areas

January 2013

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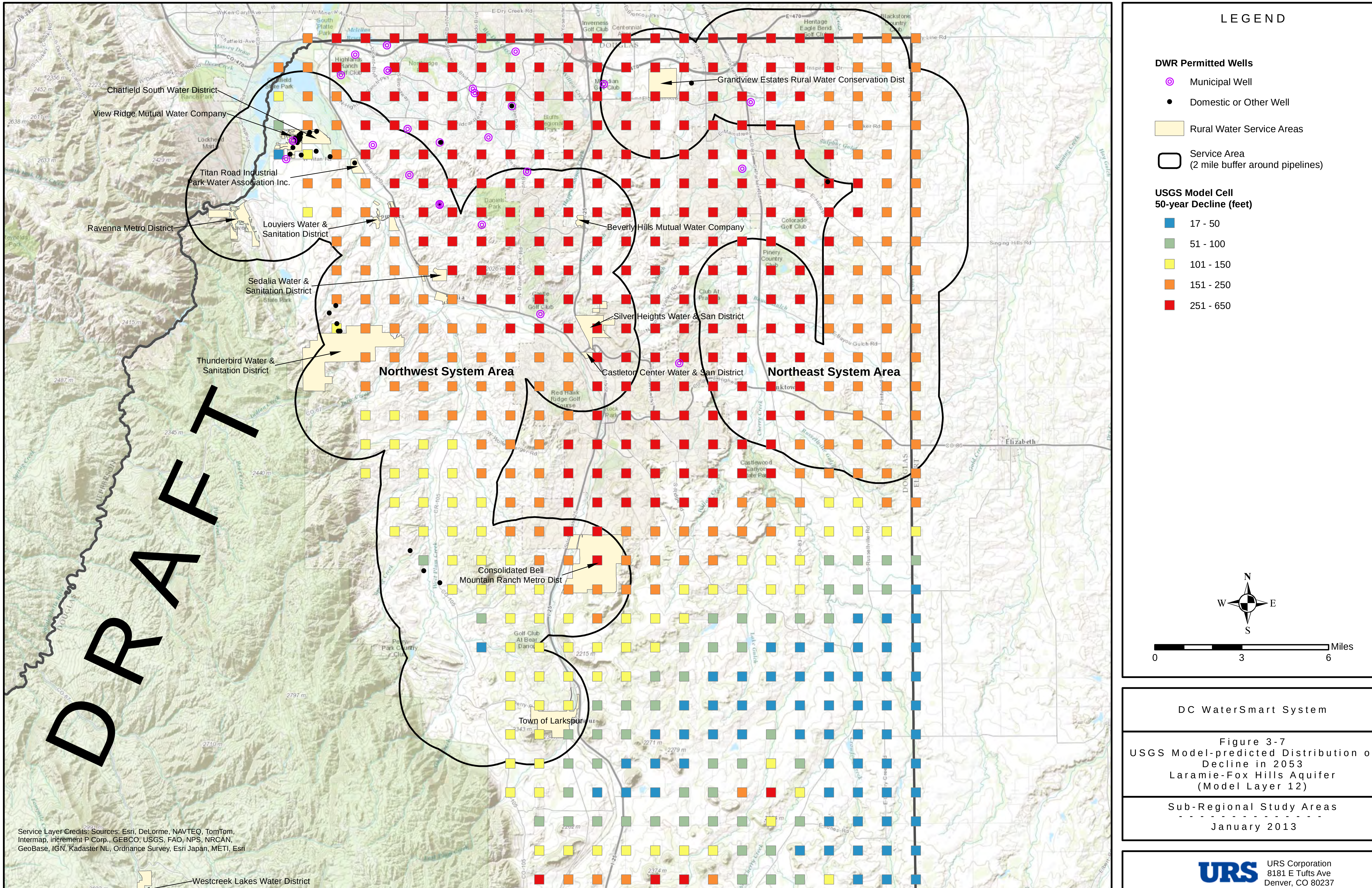

LEGEND
DWR Permitted Wells
Municipal Well
Domestic or Other Well
Rural Water Service Areas
Service Area
(2 mile buffer around pipelines)
USGS Model Cell
50-year Decline (feet)
17 - 50
51 - 100
101 - 150
151 - 250
251 - 650
N
W
E
S
Miles
0
3
6
Chatfield South Water District
View Ridge Mutual Water Company
Titan Road Industrial
Park Water Association Inc.
Ravenna Metro District
Louviers Water &
Sanitation District
Sedalia Water &
Sanitation District
Thunderbird Water &
Sanitation District
Northwest System Area
Grandview Estates Rural Water Conservation Dist
Beverly Hills Mutual Water Company
Silver Heights Water & San District
Castleton Center Water & San District
Northeast System Area
Consolidated Bell
Mountain Ranch Metro Dist
Town of Larkspur
Westcreek Lakes Water District
DRAFT
Service Layer Credits: Sources: Esri, DeLorme, NAVTEQ, TomTom,
Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN,
GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri
DC WaterSmart System
Figure 3-7
USGS Model-predicted Distribution of
Decline in 2053
Laramie-Fox Hills Aquifer
(Model Layer 12)
Sub-Regional Study Areas
January 2013
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3.5 CDWR DATA DISCUSSION

URS reviewed a second set of aquifer water level information relevant to the Project Area. The Colorado Division of Water Resources (CDWR) routinely monitors water levels in selected Denver Basin aquifer wells and publishes an annual report (Pottorff 2012). The purpose of the annual monitoring and reporting program is to present the basic data regarding depth to ground water and elevation of the occurrence of groundwater in the four bedrock aquifers in the Denver Basin (Pottorff 2012). Only a small number of the approximately 52,000 permitted groundwater wells in the Denver Basin are monitored by the CDWR.CDWR generally obtains water level measurements from each well in the spring and/or fall each year. Water level measurements are obtained when the personnel arrive at each well site, and in general, no attempt is made to determine if the pump is on or off and for how long prior to measurement the pump has been operating in this manner (CDWR 2013, personal communication).

Table 3-8 presents a summary of the average annual water level declines during the past five to ten years (maximum data range of 2002 to 2012) for 4 domestic wells and 37 municipal wells located within the two service areas. Also included are 4 domestic wells and 9 municipal wells located near the two service areas. The locations of these wells with respect to the two service areas are shown on Figure 3-8. The table identifies the wells by service area, aquifer, and well use. The locations of each of the 54 wells from the CDWR dataset were correlated to individual USGS model cell locations (row-column-layer). Table 3-8 compares the average water level decline for CDWR domestic and municipal wells located in each aquifer within each service area, to the water level decline predicted by the USGS model at model cell locations corresponding to the location of the respective CDWR water well. The USGS model predictions of water level declines at these individual cell and layer locations corresponding to CDWR-monitored water well locations will vary from the average USGS model-predicted decline for each service area presented earlier for the Project Area.

For domestic water wells completed in the Dawson aquifer, there is relatively close agreement between water level trends in "actual" domestic wells and the USGS model-predicted decline at corresponding model cell locations. However, there are relatively few domestic wells in the CDWR dataset (seven Dawson and one Denver well). Four of the Dawson domestic water wells are in the Northeast Service Area, one is located adjacent to the Northeast Service Area, and two are located in southern Douglas County.

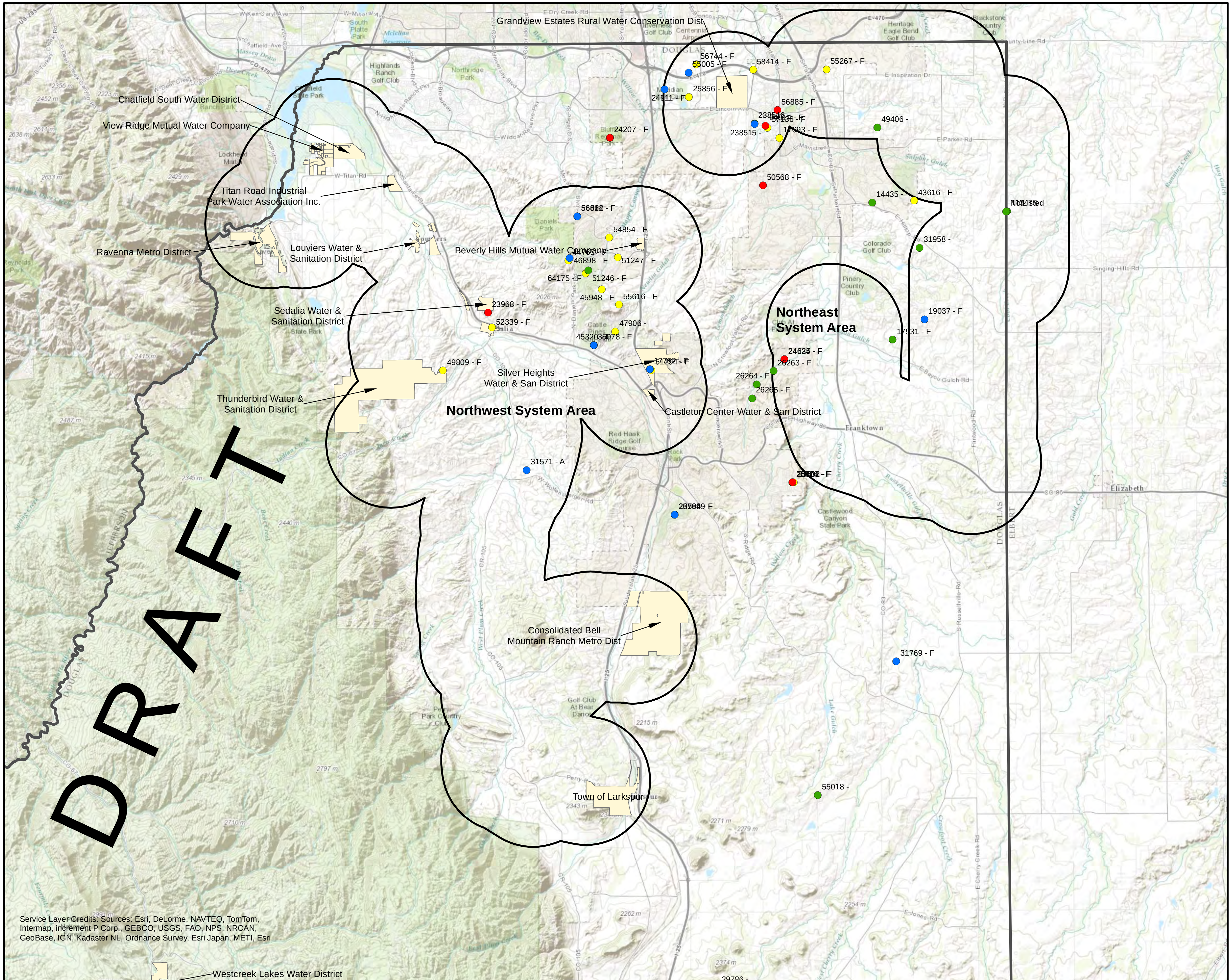
In general, for municipal wells in the Dawson aquifer in the CDWR dataset located within the two service areas, the water level trends observed in the CDWR dataset show more decline in the Dawson aquifer than the USGS model predicts. Possible explanations for the greater decline in individual wells than within the USGS model and for the greater decline in the monitored municipal wells than domestic monitored wells could include:

- The USGS model simulates the **average** water level across a one square mile model cell. The average model cell water level may not reflect a lower or higher water level(s) that occurs in a relatively small portion of the cell.
- Municipal wells are pumped at higher discharge rates and more continuously than domestic wells and generate actual regional declines.

- Intra-well drawdown interference is a significant issue for municipal wells, and does not commonly impact domestic wells.
- Because water level variations are generally greater in municipal pumping wells, the CDWR water level data collected is more variable and generally harder to interpret. Additional monitoring data provided by downhole pressure transducers within municipal wells shows the daily, weekly, and monthly variability between pumping and non-pumping periods [see data for Arapahoe Aquifer wells Castle Pines No. A-6 and A-7 (Pottorff, 2012)].

For the Denver aquifer, there is only one domestic well in the CDWR dataset within the Project Area. Water level data from the CDWR report shows a -4 foot per year (ft/y) annual decline at this well. The USGS model 50-year prediction scenario shows a -2 ft/y annual decline at this location. For municipal wells completed in the Denver aquifer, the CDWR dataset shows a greater measured water level decline than the decline predicted in the USGS model.

There are no domestic wells in the CDWR dataset in the Project Area completed within the deeper aquifers (Arapahoe and Laramie-Fox Hills). However, for municipal wells within the Denver, Arapahoe, and Laramie-Fox Hills aquifers, the CDWR water level data indicate greater annual water level declines than predicted by the USGS model (Table 3-8).



LEGEND

CDWR Locations

Well Permit Number

- Arapahoe
- Dawson
- Denver
- Laramie-Fox Hills

Rural Water Service Areas

Service Area (2 mile buffer around pipelines)

N W E S

0 3 6 Miles

DC WaterSmart System

Figure 3-8
Locations of CDWR Monitored Wells Used in Study

Sub-Regional Study Areas

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Table 3-8
Comparison of CDWR Trends and USGS Model-Predicted Annual Water Level Declines

Northwest Service Area								
		CDWR Number of Wells		CDWR Estimated Decline Rate (ft/y)		CDWR Estimated Decline Rate (ft/y)	USGS Model-Predicted Decline Rate[1] (ft/y)	USGS Model-Predicted Decline Rate[2] (ft/y)
Aquifer	Model Layer	Domestic	Municipal	Domestic	Municipal	Domestic and Municipal Well Average	Domestic / Municipal	Domestic / Municipal
Dawson	2 and 4	0	1	ND	-5	-5	-1	-0.4
Denver	6	0	5	ND	-10	-10	-1	-1
Arapahoe	8 and 10	0	12	ND	-14	-14	-2	-1
Laramie-Fox Hills	12	0	1	ND	-8	-8	-5	-4
Number of Wells		0	19	0	19	19	19 cells	NA
Average Annual Decline (19 wells/cells)				ND	-12	-12	-2	NA
Average Annual Decline (4 aquifers)				ND	-9	-9	-2	-2

ND – No Data
[1]The USGS model-predicted decline values shown correspond to the model cells where comparable CDWR-monitored water wells are located. These values are for the 50-year prediction divided by 50. This value is different than values in Table 3-7, which represent averages across the entire service area. USGS model declines are not differentiated for well type.
[2]The USGS model-predicted decline values for the entire service area, as shown in Table 3-7. USGS model declines are not differentiated for well type.

Table 3-8
Comparison of CDWR Trends and USGS Model-Predicted Annual Water Level Declines (cont'd)

Northeast Service Area								
		CDWR Number of Wells		CDWR Estimated Decline Rate (ft/y)		CDWR Estimated Decline Rate (ft/y)	USGS Model-Predicted Decline Rate[1] (ft/y)	USGS Model-Predicted Decline Rate[2] (ft/y)
Aquifer	Model Layer	Domestic	Municipal	Domestic	Municipal	Domestic and Municipal Well Average	Domestic / Municipal	Domestic / Municipal
Dawson	2 and 4	4	3	-1	-9	-5	-1	-1
Denver	6	0	5	ND	-1	-1	-2	-2
Arapahoe	8 and 10	0	7	ND	-10	-10	-2	-2
Laramie-Fox Hills	12	0	3	ND	-17	-17	-10	-6
Number of Wells		4	18	4	18	22	22 cells	NA
Average Annual Decline (wells)				-1	-9	-7	-3	NA
Average Annual Decline (4 aquifers)				-1	-9	-8	-4	-3

[1]The USGS model-predicted decline values shown correspond to the model cells where comparable CDWR-monitored water wells are located. These values are for the 50-year prediction divided by 50. This value is different than values in Table 3-7, which represent averages across the entire service area. USGS model declines are not differentiated for well type.
[2]The USGS model-predicted decline values for the entire service area, as shown in Table 3-7. USGS model declines are not differentiated for well type.

Table 3-8

Comparison of CDWR Trends and USGS Model-Predicted Annual Water Level Declines (cont'd)

Wells Located Proximate to Both Service Areas								
		CDWR Number of Wells		CDWR Estimated Decline Rate (ft/y)		CDWR Estimated Decline Rate (ft/y)	USGS Model-Predicted Decline Rate[1] (ft/y)	USGS Model-Predicted Decline Rate[2] (ft/y)
Aquifer	Model Layer	Domestic	Municipal	Domestic	Municipal	Domestic and Municipal Well Average	Domestic / Municipal	Domestic / Municipal
Dawson	2 and 4	3	4	-2	-13	-8	-2	-1
Denver	6	1	1	-4	-0.3	-2	-2	-2
Arapahoe	8 and 10	0	1	ND	-33	-33	-3	-2
Laramie-Fox Hills	12	0	3	ND	-18	-18	-9	-4
Number of Wells		4	9			13	13 cells	NA
Average Annual Decline (wells)				-2	-15	-11	-3	NA
Average Annual Decline (4 aquifers)				-3	-16	-15	-4	-2

ND – No Data

[1]The USGS model-predicted decline values shown correspond to the model cells where comparable CDWR-monitored water wells are located. These values are for the 50-year prediction divided by 50. This value is different than values in Table 3-7, which represent averages across the entire service area. USGS model declines are not differentiated for well type.

[2]The USGS model-predicted decline values for the entire service area, as shown in Table 3-7. USGS model declines are not differentiated for well type.

The data shown in Table 3-8 represents water level trends for CDWR monitored water wells located within the Project Area during the period from 2002 to 2012. However, water level declines have occurred in the Denver Basin aquifers beneath the Project Area corresponding to the initial development of groundwater in the region. The USGS transient groundwater flow model was calibrated with 16 individual and sequential stress periods beginning in 1880 and ending on December 31, 2003. The USGS utilized additional historic water level information and historic CDWR monitoring data for calibration targets over the transient calibration time period (USGS 2011). The USGS report includes maps of regional water level change ("simulated change in hydraulic head") for the period from 1880 to 2003 in Chapter B (Figures B51-B62). Hydrographs comparing simulated hydraulic head and water level measurements from CDWR-monitored water wells are shown in the USGS report (2011) for each of the modeled aquifers. A summary and comparison of the overall change in water level simulated by the model from 1880 to 2003 and historic water level declines based on the older CDWR-monitored wells within Douglas County and presented in the USGS (2011) report are shown in Table 3-9.

Table 3-9
Summary of USGS Model-Simulated Change in Hydraulic Head and Historic CDWR Water Level Data

Aquifer	Model Layer	Douglas County	
		Total Simulated Head Change 1880 - 2003 (Total Decline in Feet)*	CDWR Monitored Well Historic Water Level*
		Min / Max	Decline Rate (ft/y)
Upper Dawson	2	0 / -277	-10 (1994 to 2003)
Lower Dawson	4	0 / -500	-1.0 (1984-2003) -20 (1998-2003) -3 (1988-2002)
Denver	6	-50 / -250	-22 (1993-2002)
Upper Arapahoe	8	Aquifer layer combined with Lower Arapahoe	Upper and Lower Arapahoe not-differentiated
Lower Arapahoe	10	-100 / -400	-27 (1987-2002)
Laramie-Fox Hills	12	-100 / -1000	-54 (1988-2000, southwest Arapahoe County, nearest well shown)

*Note: Total simulated head change represents USGS model-simulated potentiometric decline in water level during model calibration period. CDWR historic decline rates are calculated from water level measurement trends presented in Chapter B of the USGS model report (2011).

3.6 SUMMARY

The number of groundwater users in Douglas County has increased with the growth in population over the past 20 years. There are currently over 7,000 water wells permitted in Douglas County, and over 5,000 of these permitted wells are located within the Northwest and Northeast service areas. These wells pump groundwater from the Dawson, Denver, Arapahoe, and Laramie-Fox Hills aquifers. The volume of groundwater pumped annually from each aquifer generally exceeds the annual volume of recharge to the aquifer. This results in continued aquifer decline and loss of storage in the Denver Basin Aquifers. The amount of aquifer decline varies geographically and seasonally. However, with increasing population and groundwater demand regional water levels in the Project Area will continue to decline.

The amount of water level decline is difficult to predict. URS evaluated water level declines predicted by the USGS numerical flow model from a model-scenario extending out to the year 2053. Additionally, URS evaluated water level measurements of permitted domestic and municipal water wells published for approximately 50 Denver Basin wells located within the Project Area.

Table 3-10 summarizes the average annual water level declines for the service areas utilizing both the USGS model predictions and the CDWR water level monitoring data. The USGS model predictions likely represent the low side of the possible range of potential water level declines for the two service areas between 2003 and 2050. The water level decline trends estimated from the CDWR monitoring data likely represent a high side of water level declines for the two service areas based upon domestic and municipal water wells in the service areas between roughly 2002 and 2012. Individual water wells within the Project Area may experience higher or lower water level declines in the future. Annual water level declines presented here show a generally increasing trend from the Dawson aquifer down to the Laramie-Fox Hills aquifer. This trend may be related to the fact that there are generally only municipal water wells completed in the deeper aquifers, and few domestic water wells in the deeper aquifers. Domestic water wells are pumped at a fraction of the pumping rate of most municipal water supply wells. While the USGS model future scenarios predict water level declines in all 4 aquifers over a 50-year period from -1 to -8 ft/y, the largest decline rate is predicted for the Laramie-Fox Hills aquifer. Review of water level measurement data provided by the CDWR for the period from 2002 through 2012 shows large water level declines in municipal water wells completed in all 4 aquifers, ranging from approximately -5 ft/y to -17 ft/y.

Based upon the USGS model predictions and the CDWR monitoring data for wells in the Project Area, annual water level declines for the Dawson aquifer range from -0.9 ft/y to -13 ft/y (Table 3-8). Annual water level declines for the Denver, Arapahoe, and Laramie-Fox Hills aquifers range from -0.3 ft/y to -10 ft/y, -10 ft/y to -33 ft/y, and -8 ft/y to -18 ft/y, respectively

In general, the USGS model under-predicts the annual amount of decline displayed by the CDWR water well dataset. Water level declines in the deeper aquifers, subject to greater municipal well pumping, are generally greater than the amount of water level decline predicted by the USGS model simulations. However, the USGS model-predicted water level declines for domestic wells in the Dawson aquifer are similar to declines measured recently in several Dawson domestic wells monitored in the area by the CDWR.

Continued use of groundwater for water supply in the Project area will result in continued water level declines. The absolute magnitude of declines will vary depending upon climatic factors and variations, population growth, water conservation practices, domestic versus municipal water wells, use of surface water supplies in nearby communities, and site-specific hydrogeologic factors (aquifer thickness, transmissivity, well completion intervals, age of well). A range of potential water level declines is presented in Table 3-10, summarizing declines in the four Denver Basin aquifers located beneath the two combined service areas. The decline rate estimates are based upon the USGS groundwater model predictions and evaluation of water level measurements for CDWR monitored wells within the two combined service areas between roughly 2002 and 2012.

Table 3-10
Summary by Aquifer of Predicted and Historic Annual Water Level Declines Averaged for the Two Service Areas

Average Annual Water Level Decline (ft/y)		
Aquifer	**USGS Model Predicted in Service Areas**	**CDWR Domestic/ Municipal Well Average within Service Areas circa 2002-2012**
Dawson	-1	-5
Denver	-2	-6
Arapahoe	-2	-12
Laramie-Fox Hills	-5	-13

Notes: