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To: Steve Walthour, General Manager, North Plains Groundwater Conservation District

From: Neil Deeds, INTERA

Date: October 18, 2016

RE: Delivery of GMA-1 Predictive Runs

1.0 INTRODUCTION

This memorandum provides a summary of the chosen Desired Future Condition (DFC) simulation performed for Groundwater Management Area (GMA) 1. The purpose of the memo is to provide roadmap between the simulation and the proposed DFC resolution executed by GMA-1 representatives, and present availability numbers that resulted from the simulation.

2.0 DESCRIPTION OF DESIRED FUTURE CONDITIONS

The members of the GMA 1 proposed the following desired future conditions (DFCs) (GMA-1 JPC, 2016):

1. Ogallala and Rita Blanca Aquifers:
    a. *"At least 40 percent of volume in storage remaining in 50 years, for the period 2012-2062 in Dallam, Hartley, Moore, and Sherman counties;"*.

        These four counties will be hereon collectively referred to as North Plains Groundwater Conservation District West, plus Hartley non-district and Moore non-district (NPGCD-West plus Hartley ND and Moore ND). The DFC statement does not discriminate between district and non-district portions of the counties.

    b. *"At least 50 percent of volume in storage remaining in 50 years, for the period 2012-2062 in Hansford, Hutchinson, Lipscomb, Ochiltree, Carson, Donley, Gray, Roberts, Wheeler, and Oldham counties; and within the Panhandle District in Armstrong and Potter Counties;"*.

        Hansford, Hutchinson (NPGCD and Hutchinson ND), Lipscomb, and Ochiltree counties will be hereon collectively referred to as North Plains Groundwater Conservation District East plus Hutchinson non-district (NPGCD-East plus Hutchinson ND). Carson, Donley, Gray, Roberts, Wheeler, Oldham, and portions of Hutchinson, Armstrong, Potter counties in Panhandle Groundwater Conservation District (PGCD) will be hereon collectively referred to as PGCD. The DFC statement does not discriminate between the district and non-district portions of Hutchinson County.

    c. *"At least 80 percent of volume in storage remaining in 50 years for the period 2012-2062, in Hemphill County;"*.

DRAFT

d. *"Approximately 20 feet of total average drawdown in 50 years for the period 2012-2062, in Randall County and within High Plains District in Armstrong and Potter Counties."*

   The DFC statement does not discriminate between district and non-district portions of Randall County.

2. Dockum Aquifer:

   a. *"At least 40 percent of the available drawdown remaining for the period 2012-2062 in 50 years for Dallam, Hartley, Moore, and Sherman Counties"*.

      The DFC statement does not discriminate between district and non-district portions of Hartley and Moore counties.

   b. *"No more than 30 feet average decline in water levels in for the period 2012-2062 in 50 years in Carson and Oldham Counties, and within the Panhandle District in Armstrong and Potter Counties;"*

   c. *"The total average drawdown is approximately 40 feet in 50 years for the period 2012-2062, in Randall County and within High Plains District in Armstrong and Potter Counties."*

      The DFC statement does not discriminate between district and non-district portions of Randall County.

3. Blaine Aquifer:

   "The members of GMA-1 affirm that GMA-1 has classified the Blaine Aquifer as non-relevant to this joint planning process in the GMA-1 Joint Planning Area."

3.0 MODEL

To evaluate the DFC we selected the High Plains Aquifer System Groundwater Availability Model (Deeds and Jigmond, 2015). The High Plains Aquifer System Groundwater Availability Model (HPASGAM) is a regional groundwater flow model that incorporates the Ogallala, Rita Blanca, Edwards-Trinity (High Plains), and Dockum aquifers.

Because 2012 was the last year of the calibrated model, 2012 was used as the reference year for comparison to a future aquifer condition. For comparison to a condition 50 years in the future, heads at the end of the stress period corresponding to 2062 were compared to the initial heads (from the end of 2012). For the predictive simulation, the last simulated year was 2070, so the run was comprised of a total of 58 annual stress periods.

4.0 ZONES

Six political zones, illustrated in Figure 1, were considered for GMA-1 for this DFC run:

1. NPGCD West, which consists of Dallam, Sherman, and NPGCD portions of Hartley and Moore counties.
2. NPGCD East, which consists of Hansford, Lipscomb, Ochiltree, and the NPGCD and ND portion of Hutchinson counties.

DRAFT

3. Hemphill County UWCD (HCUWCD) which consists of Hemphill County.
4. PGCD which consists of Carson, Donley, Gray, Roberts, Wheeler, and the PGCD portion of Armstrong, Hutchinson, and Potter counties.
5. High Plains UWCD (HPUWCD) which consists of HPUWCD portions of Armstrong, Potter, and Randall counties.
6. No GCD, which consists of Oldham, and the non-district portions of Hartley, Moore, Hutchinson and Randall counties. Note that GMA 1 members decided to combine some of the non-district portions of counties in with district portions as part of an aggregate DFC.

We used the "hpas_grid_poly072015.shp" version of the model grid and the column "DFC_ZONES" contains the political zones (Figure 1). Calculations were done in the Python scripting language without intermediary files. That means the binary MODFLOW output file was read into memory without significant digits truncation. Past communication with the TWDB suggests that results may differ when the binary file is converted to some form of ASCII data. The calculations also take into account the leap years and official aquifer zones as determined by the TWDB.

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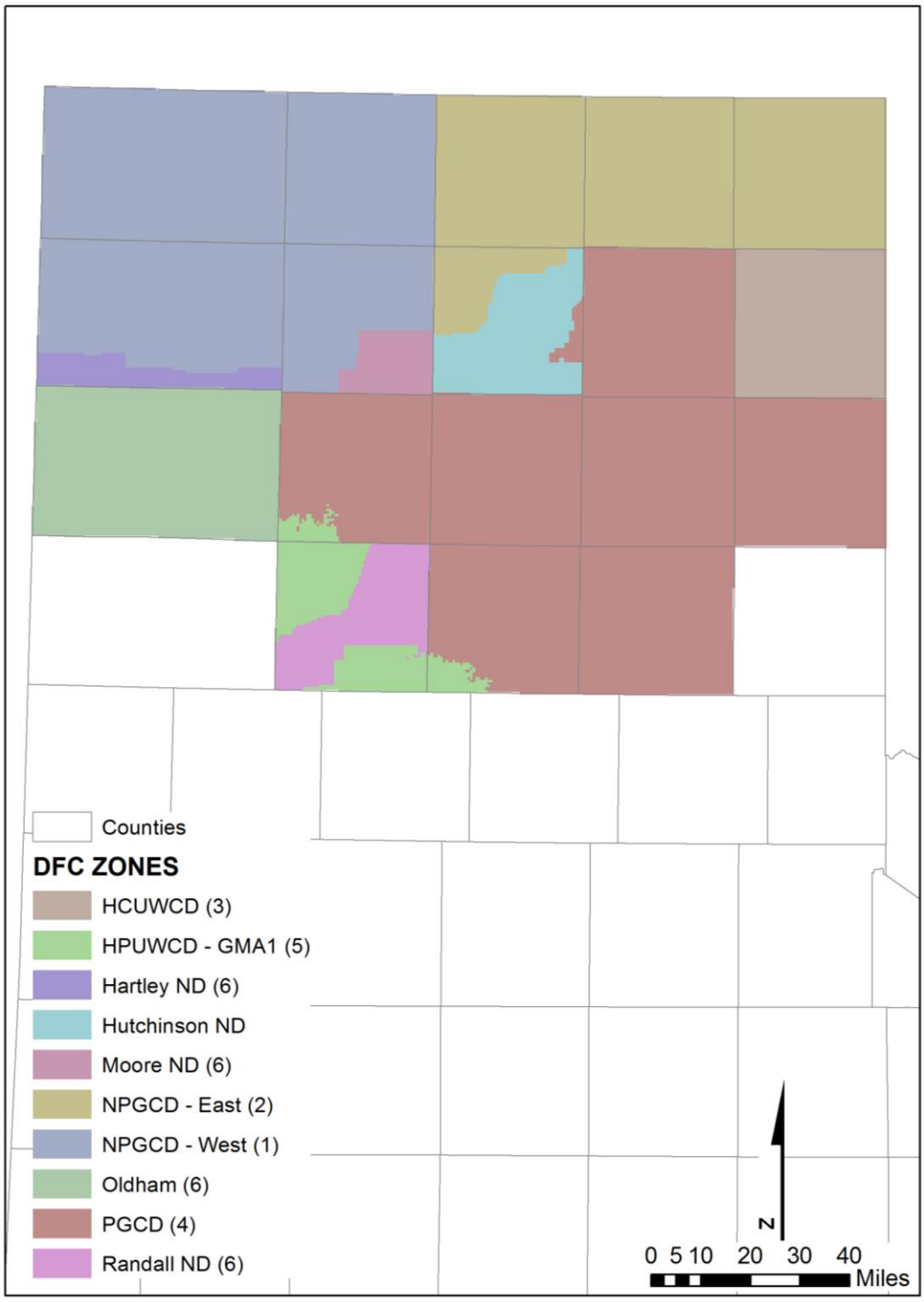

Figure 4.1: DFC Zones used in calculation of DFC metrics

5.0 METRICS AND RESULTS: OGALLALA AND RITA BLANCA AQUIFERS

5.1 Metrics

For all of the Ogallala Aquifer zones, where the target was based on a **fraction of volume remaining** after 50 years, we calculated the fraction as:

$$Fraction\ Remaining = \frac{\sum V_{2062}}{\sum V_{2012}}$$

where V_{2062} is the volume in place in a grid cell in 2062, and V_{2012} is the volume in place in a grid cell in 2012. Volumes for all cells in a zone are summed for each of the years, and the resulting fraction is the result compared to the target. If the head in a cell is at or below the layer bottom, the volume in that cell is zero.

For the case where the target was **average drawdown**, we calculated the drawdown as:

$$Average\ Drawdown = \frac{\sum(h_{2012} - h_{2062})}{n}$$

where h_{2012} is the head in a grid cell in 2012, h_{2062} is the head in a grid cell in 2062, and n is the number of grid cells. If the head in a cell is at or below the cell bottom, the cell is not considered.

For the Rita Blanca, which is confined in GMA 1, fraction remaining was calculated based on **fraction of available drawdown remaining** after 50 years:

$$addn_{i,yyyy} = h_{i,yyyy,2} - el_{i,t,2}$$

where $addn_{i,yyyy}$ is the drawdown in cell *i* in year *yyyy*, $h_{i,yyyy,2}$ is the head in cell *i* in layer 2 in year *yyyy*, and $el_{i,t,2}$ is the elevation of the top of layer 2 in cell *i*. If $h_{i,2012,2} < el_{i,t,2}$ then the cell is not considered in the average. If $h_{i,2062,2} < el_{i,t,2}$ then $addn_{i,yyyy}$ = 0, and that zero is included in the average.

The fraction available drawdown remaining for a zone is calculated as:

$$Fraction\ Remaining = \frac{\sum_{i=1}^{n} \frac{addn_{i,2062}}{addn_{i,2012}}}{n}$$

where *n* is the number of cells in the zone that were considered in the calculation. The Rita Blanca and Ogallala fraction remaining estimates were aggregated by area weighting the fractions (i.e. weighting by the number of cells considered for each of the aquifers).

5.2 Targets and Pumping

The following subsections summarize each bullet subsection in the DFC statement associated with the Ogallala and Rita Blanca aquifers, and the approach to pumping allocation for the associated areas. The bulleted subsection of the DFC statement is referenced by number and letter as described in Section 2.

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5.2.1 NPGCD West plus Hartley ND and Moore ND (1a)

Target: 0.4 aggregate fraction of volume (Ogallala) and fraction of available drawdown (Rita Blanca) remaining in 50 years, 2012-2062.

Pumping rates: Rates were set such that total predictive rates approximately matched historical rates at the beginning of the simulation. For the Ogallala, because these initial rates exceed the average rate that would achieve the target, rates were reduced through time so that final rates were significantly less than initial rates.

5.2.2 NPGCD East plus Hutchinson ND (1b)

Target: 0.5 fraction of volume remaining in 50 years, 2012-2062.

Pumping rates: Rates were fixed at an average that would achieve the target. This approximates a linear decline in saturated thickness.

5.2.3 PGCD plus Oldham County (1b)

Target: 0.5 fraction of volume remaining in 50 years, 2012-2062.

Pumping rates: Rates were set to approximate a water level decline of 1.25% per year.

5.2.4 HCUWCD (1c)

Target: 0.8 fraction of volume remaining in 50 years, 2012-2062.

Pumping rates: Rates were fixed at an average that would achieve the target.

5.2.5 HPUWCD (1d)

Target: Approximately 20 feet of total average drawdown in 50 years, 2012-2062.

Pumping rates: Rates were set to approximate an exponential decline in saturated thickness.

5.3 Results

Table 5.1 shows the fraction remaining for each of the areas described in previous sections 5.2.1 – 5.2.4. Table 5.2 shows the average drawdown for the HPUWCD area described in Section 5.2.5. In all cases, the aggregate metric meets the target DFC.

Table 5.3 shows the available groundwater in the combined Ogallala and Rita Blanca by county and district.

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Table 5.1: Fraction remaining by zone for the Ogallala Aquifer in GMA-1.

Ogallala	Fraction Remaining from 2012					
Zone	**'20**	**'30**	**'40**	**'50**	**'62**	**'70**
North Plains GCD – West plus Hartley ND and Moore ND	0.84	0.68	0.55	0.47	0.40	0.38
North Plains GCD – East plus Hutchinson ND	0.94	0.83	0.72	0.62	0.50	0.42
Hemphill County UWCD	0.98	0.93	0.89	0.84	0.80	0.77
Panhandle GCD	0.93	0.81	0.70	0.60	0.50	0.44

Table 5.2: Average drawdown by zone for the Ogallala Aquifer in GMA-1.

Ogallala	Average Drawdown (feet)					
County	**2020**	**2030**	**2040**	**2050**	**2062**	**2070**
High Plains Water District						
Armstrong	2	5	8	10	12	13
Potter	2	4	7	9	12	14
Randall	4	9	14	18	22	24
District Total	3	8	13	16	20	22

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Table 5.3: Available groundwater in the Ogallala and Rita Blanca aquifers for the counties comprising GMA-1. All rates for Ogallala except those reported for the Rita Blanca in Dallam County

	Available Groundwater (afy)							
Region	**2015**	**2016**	**2020**	**2030**	**2040**	**2050**	**2062**	**2070**
North Plains GCD								
Dallam – Ogallala	305,394	395,833	382,325	281,006	220,012	160,745	97,105	65,036
Dallam – Rita Blanca	6,197	6,191	6,207	6,197	6,177	6,145	6,151	5,914
Dallam Total	311,591	402,024	388,532	287,203	226,189	166,890	103,256	70,950
Hansford	169,191	276,822	275,769	272,655	271,968	270,280	269,478	269,128
Hartley	353,307	450,493	398,674	271,523	212,902	154,432	90,842	58,539
Hutchinson	59,153	74,151	62,975	64,522	65,831	66,075	65,956	64,791
Lipscomb	39,006	55,112	267,540	266,710	267,370	266,591	266,556	266,546
Moore	167,811	235,480	215,441	172,620	139,703	105,016	67,650	47,446
Ochiltree	84,963	115,225	244,446	243,931	244,670	244,050	244,085	244,094
Sherman	288,843	364,947	399,146	348,894	282,462	212,744	136,775	93,843
District Total	1,473,864	1,974,251	2,252,523	1,928,057	1,711,095	1,486,078	1,244,597	1,115,337
Hemphill County UWCD								
Hemphill	21,935	55,176	52,338	52,217	52,409	52,305	52,340	52,358
Panhandle GCD								
Armstrong	7,495	57,669	58,142	53,413	48,302	43,461	38,080	34,782
Carson	129,714	181,368	192,661	184,263	170,395	153,767	134,054	121,448
Donley	39,476	69,404	75,012	76,288	73,162	67,872	60,901	56,275
Gray	41,540	171,475	181,601	175,267	163,099	148,713	131,744	121,136
Hutchinson	74	10,106	15,777	16,740	15,197	13,324	11,454	10,171
Potter	7,349	15,775	17,015	15,820	14,480	13,162	11,609	10,644
Roberts	79,284	359,716	431,798	455,129	428,388	390,246	342,747	311,054
Wheeler	13,534	114,844	130,782	138,810	137,761	132,311	123,308	116,837
District Total	318,466	980,357	1,102,788	1,115,730	1,050,784	962,856	853,897	782,347

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[1]2015 rates are identical to the last year of the calibrated model (2012) except in NPGCD where other rates were provided by NPGCD staff.

Table 5.4 continued: Available groundwater in the Ogallala Aquifer for the counties comprising GMA-1.

Ogallala	Available Groundwater (afy)							
County	**2015**	**2016**	**2020**	**2030**	**2040**	**2050**	**2062**	**2070**
High Plains Water District								
Armstrong	1,073	1,484	1,289	1,048	868	722	591	521
Potter	149	225	225	224	225	223	220	218
Randall	26,175	39,322	39,190	37,987	32,566	28,333	24,458	22,482
District Total	27,397	41,031	40,704	39,259	33,659	29,278	25,269	23,221
No GCD								
Hartley	240	18,432	19,581	17,638	14,566	11,147	7,457	5,246
Hutchinson	5,643	18,853	16,492	14,432	13,390	12,973	13,170	14,395
Moore	2,237	8,167	8,956	8,597	7,612	6,186	4,532	3,585
Oldham	13,775	40,879	44,721	40,203	33,513	26,206	18,617	16,165
Randall	18,039	23,890	24,894	23,944	21,923	19,471	16,541	14,684
Total	39,934	110,221	114,644	104,814	91,004	75,983	60,317	54,075
GMA-1 Total	1,881,596	3,161,036	3,562,997	3,240,077	2,938,951	2,606,500	2,236,420	2,027,337

[1]2015 rates are identical to the last year of the calibrated model (2012) except in NPGCD where other rates were provided by NPGCD staff.

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6.0 METRICS AND RESULTS: DOCKUM AQUIFER

6.1 Metrics

For the Dockum Aquifer zones, the target was based on an average **fraction of available drawdown remaining** after 50 years. Only the lower Dockum Aquifer was considered, which corresponds to model layer 4. The fraction was calculated differently whether a model cell was designated as "outcrop" or "confined" in the MODFLOW BAS package. This designation was made a priori, and was not changed based on the position of the simulated head in reference to the layer top.

If IBOUND==71 in the BAS package, which designates lower Dockum outcrop, available drawdown in a cell was calculated as follows:

$$addn_{i,yyyy} = h_{i,yyyy,4} - el_{i,b,4}$$

where $addn_{i,yyyy}$ is the available drawdown in cell i in year $yyyy$, $h_{i,yyyy,4}$ is the head in cell i in layer 4 in year $yyyy$, and $el_{i,b,4}$ is the elevation of the bottom of layer 4 in cell i. If $h_{i,2012,4} < el_{i,b,4}$ then the cell is not considered in the average. If $h_{i,2062,4} < el_{i,b,4}$ then $addn_{i,yyyy} = 0$, and that zero is included in the average.

If IBOUND==72 in the BAS package, which designates confined lower Dockum, available drawdown in a cell was calculated as follows:

$$addn_{i,yyyy} = h_{i,yyyy,4} - el_{i,t,4}$$

where $addn_{i,yyyy}$ is the available drawdown in cell i in year $yyyy$, $h_{i,yyyy,4}$ is the head in cell i in layer 4 in year $yyyy$, and $el_{i,t,4}$ is the elevation of the top of layer 4 in cell i. If $h_{i,2012,4} < el_{i,t,4}$ then the cell is not considered in the average. If $h_{i,2062,4} < el_{i,t,4}$ then $addn_{i,2062} = 0$, and that zero is included in the average.

The fraction available drawdown remaining for a zone is calculated as:

$$Fraction\ remaining = \frac{\sum_{i=1}^{n} \frac{addn_{i,2062}}{addn_{i,2012}}}{n}$$

where n is the number of cells in the zone that were considered in the calculation. All cells (both IBOUND==71 and IBOUND==72) were used in the calculation of a single value for the zone.

6.2 Targets and Pumping

The following subsections summarize each bullet subsection in the DFC statement associated with the Dockum Aquifer, and the approach to pumping allocation for the associated areas. The bulleted subsection of the DFC statement is referenced by number and letter as described in Section 2.

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6.2.1 NPGCD West plus Hartley ND and Moore ND (1a)

Target: 0.4 fraction of available drawdown remaining in 50 years, 2012-2062.

Pumping rates: Rates were set to approximate a linear decline in heads.

6.2.2 PGCD plus Oldham County (1b)

Target: 30 feet of total average drawdown in 50 years, 2012-2062.

Pumping rates: Rates were set to approximate a water level decline of 1.25% per year.

6.2.3 HPUWCD plus Randall ND (1c)

Target: 40 feet of total average drawdown in 50 years, 2012-2062.

Pumping rates: Rates were set to approximate an exponential decline.

6.3 Results

Table 6.1 shows the fraction remaining for the area described in previous section 5.2.1, while Table 6.2 shows the average drawdown for the areas described in previous section 6.2.2-6.2.3. In all cases, the aggregate metric meets the target DFC. Note that the aggregate average for PGCD is 30 feet, which can be combined with the 30 foot average for Oldham county (Section 6.2.2) to result in 30 feet. Similarly, the aggregate average for HPUWCD of 40 feet can be combined with the 40 foot average for Randal County ND (Section 6.2.3) to result in 40 feet.

Table 6.3 shows the available groundwater in the Dockum Aquifer by county and district.

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Table 6.1: Fraction of available drawdown by zone for the Dockum Aquifer in GMA-1.

Dockum	Fraction of Available Drawdown Remaining from 2012					
Zone	**2020**	**2030**	**2040**	**2050**	**2062**	**2070**
North Plains GCD – West plus Hartley ND and Moore ND	0.89	0.75	0.62	0.51	0.40	0.33

Table 6.2: Average drawdown by zone for the Dockum Aquifer in GMA-1.

Dockum	Average Drawdown (feet)					
County	**2020**	**2030**	**2040**	**2050**	**2062**	**2070**
Panhandle GCD						
Armstrong	5	13	20	27	34	38
Carson	6	15	23	30	37	42
Potter	4	10	16	21	26	29
District Total	4	11	18	24	30	34
High Plains Water District						
Armstrong	1	3	7	10	15	18
Potter	3	9	16	24	32	37
Randall	9	19	28	36	45	50
District Total	8	16	25	32	40	45
No GCD						
Oldham	4	11	18	24	30	34
Randall	7	16	24	32	40	45

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Table 6.3: Available groundwater in the Dockum Aquifer for the counties comprising GMA-1.

Dockum	Available Groundwater (afy)							
County	**2015**	**2016**	**2020**	**2030**	**2040**	**2050**	**2062**	**2070**
North Plains GCD								
Dallam	2,755	14,234	14,231	14,188	14,224	14,184	14,183	14,183
Hartley	1,793	13,063	11,633	10,766	10,552	10,559	10,895	11,326
Moore	1,604	5,072	4,814	4,531	4,505	4,416	4,261	4,158
Sherman	484	127	127	127	127	127	92	87
District Total	6,636	32,496	30,805	29,612	29,408	29,286	29,431	29,754
Panhandle GCD								
Armstrong	138	5,658	7,150	9,023	9,614	9,704	9,493	9,270
Carson	29	53	68	108	140	169	203	225
Potter	914	32,021	38,909	39,112	37,037	34,504	31,557	29,665
District Total	1,081	37,732	46,127	48,243	46,791	44,377	41,253	39,160
High Plains Water District								
Armstrong	33	166	96	0	0	0	0	0
Potter	434	29	21	0	0	0	0	0
Randall	1,597	1,575	2,195	2,714	2,961	3,111	3,228	3,289
District Total	2,064	1,770	2,312	2,714	2,961	3,111	3,228	3,289
No GCD								
Hartley	226	42,620	43,766	44,269	44,525	44,303	43,941	43,521
Moore	0	230	419	575	528	509	497	481
Oldham	1,128	111,290	129,354	128,828	120,848	111,196	99,735	92,701
Randall	1,006	6,320	9,007	11,302	11,941	12,002	11,806	11,555
Total	2,360	160,460	182,546	184,974	177,842	168,010	155,979	148,258
GMA-1 Total	12,141	232,458	261,790	265,543	257,002	244,784	229,891	220,461

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