Oklahoma Comprehensive Water Plan

Senate Bill 1410 Aquifer Recharge Work Group

Final Report
Aquifer Recharge Pilot Project Site Evaluation

June 28, 2010

This study was funded through an agreement with the Oklahoma Water Resources Board under its authority to update the Oklahoma Comprehensive Water Plan, the state's long-range water planning strategy, due for submittal to the State Legislature in 2012. Results from this and other studies have been incorporated where appropriate in the OCWP's technical and policy considerations. The general goal of the OCWP is to ensure reliable water supplies for all Oklahomans through integrated and coordinated water resources planning and to provide information so that water providers, policy-makers, and water users can make informed decisions concerning the use and management of Oklahoma's water resources.

Prepared by CDM under an agreement with the Oklahoma Water Resources Board

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Detailed Analysis of Recharge Region Number 2, Ogallala Aquifer near Woodward

Appendix A - Recharge Region 2

Recharge Region 2 is located in the vicinity of the town of Woodward, with the Ogallala/High Plains aquifer providing storage for a potential AR project. According to the U.S. Census Bureau, the town of Woodward had an estimated population of approximately 12,299 individuals in 2008; year 2000 census data indicated 11,853 individuals (U.S. Census Bureau). For this recharge region, the demand location was identified as the PWS wells for the town of Woodward, and the source for the potential recharge project was identified as Wolf Creek. Two potential recharge areas were identified within this recharge region based on proximity to the source and demand, available freeboard in the aquifer, and groundwater flow direction. One recharge area is located in the northeast portion of the recharge region, and one in the southeast portion of the recharge region (see Figure A-1). Recharge area 2, in the northeast portion, was selected based on its closer proximity to Wolf Creek. Thus, the following detailed analysis includes only a discussion of recharge area 2.

1. Demand, Source, and Storage Considerations

The following table summarizes several aspects of the recharge area related to source water availability, local demand, ability of the source to meet the demand, and storage capacity. Proximity data is shown on Figure A-1, and available freeboard is shown on Figure A-2.

Source Basin	Basin 20533
Sufficient Legally Available Water for Pilot Project	Yes
Source Stream	Wolf Creek. Probable point of diversion near confluence with Sixteenmile Creek
Nearest Gage	USGS 07236000, approximately 1 mile upstream of probable point of diversion. Period of record 1942 to 1976. Alluvial irrigation well development since POR suggests that only high flows may be usable.
Gage POR and below average precipitation	15 years during the gage POR are below average precipitation years. 1966 selected as representative of approximately the 25th percentile of precipitation and occurred within the POR
Representative year flows (source availability)	Annual Flow: 28,684 AF
	Seasonal Distribution: Jan-Feb, Dec 20%; Mar-May 23%; Jun-Aug 45%; Sept-Nov 12%
Local Demand (Woodward)	Annual Total 15,000 AFY
Demand Density (PWS Wells)	7 wells within 1 mile radius, 4 wells within 2 mile radius. Indicates productive region of aquifer and storage capacity
Source availability as percent of pilot project demand (minimum of local demand or 1,000 AF*)	Annual basis: 100%
	Seasonally: Jan-Feb,Dec 0%; Mar-May 100%; Jun-Aug 0%; Sept-Nov 0%

Aquifer Storage Availability	Specific Yield = 0.15
	0.4 square mile area (radius 0.4 miles) with 25 foot increase in water levels required. Storage capacity is sufficient while maintaining at least 15 feet depth to water
	1 square mile area (radius 0.6 miles) with 10 foot increase in water levels. Storage capacity is sufficient while maintaining at least 15 feet depth to water

Based on the availability of flows and the ability of those flows to meet the pilot project demands, the source water availability receives a **moderate** score. This is due to the presence of irrigation wells completed since the gaged year.

The storage capacity requirement is less than the available storage in the aquifer below the 15 foot threshold; therefore storage availability receives a **high** score.

Based on the location of wells in close proximity to the recharge area, the demand proximity receives a **high** score.

Also, based on the number of wells (five to ten) within one mile of the recharge area, demand density receives a **high** score.

The source of water identified for Recharge Region 2 is Wolf Creek. Recharge area 2 is located greater than two miles from Wolf Creek, and thus receives a **low** score for source proximity.

2. Water Quality

Water quality analysis included the following criteria: source water quality for non-degradation; native groundwater quality; and groundwater geochemical interactions with source water. The following table presents water quality data for those parameters that have an MCL. The MCL was exceeded in at least one recharge area in the State if the parameter is listed. Parameters that did not have any samples collected for the Recharge Region are listed but do not display the min, max, and mean rows. Parameters in **bold** exceed the MCL.

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/Ponds	Gage # 07236000
Aluminum	ug/L	200	#	10	0	0
			min	**300**		
			max	**300**		
			mean*	**300**		
Antimony	ug/L	6	#	0	0	0
Arsenic	ug/L	10	#	0	26	0
			min		10	

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/Ponds	Gage # 07236000
			max		10	
			mean*		10	
Beryllium	ug/L	4	#	0	0	0
Cadmium	ug/L	5	#	0	26	0
			min		1.0	
			max		5.0	
			mean*		2.7	
Chloride	mg/L	250**	#	19	154	44
			min	4.0	0	8.3
			max	154	165	177
			mean*	10	95	103
Chlorine	mg/L	4	#	0	0	0
Chromium	ug/L	100	#	0	26	0
			min		5.0	
			max		10	
			mean*		6.9	
Fecal Coliform	cfu / 100 ml		#	0	32	
			min		50	
			max		2000	
			mean*		232	
Iron	ug/L	300	#	10	0	0
			min	20		
			max	20		
			mean*	20		
Lead	ug/L	15	#	0	26	0
			min		3.0	
			max		10	
			mean*		4.4	
Manganese	ug/L	50	#	10	0	0
			min	5.0		
			max	5.0		
			mean*	5.0		
Mercury	ug/L	2	#	0	26	0
			min		0.05	
			max		0.50	
			mean*		0.29	
Nitrate / Nitrite+Nitrate (as N)	mg/L	10	#	19	154	4
			min	0	0.05	0.32
			max	**16**	1.6	9.0
			mean*	2.9	0.50	1.7
pH	SU	6.5-8.5**	#	17	128	23
			min	7.3	6.5	7.5
			max	8.3	**9.0**	8.3
			mean*	7.7	8.1	7.9
Selenium	ug/L	50	#	0	26	0

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/Ponds	Gage # 07236000
			min		5.0	
			max		10	
			mean*		5.6	
Sulfate	mg/L	250**	#	18	154	18
			min	4.8	0	11
			max	**570**	164	124
			mean*	12	73	50
Thallium	ug/L	2	#	0	26	0
			min		**3.0**	
			max		**10**	
			mean*		**4.6**	
Total dissolved solids	mg/L	500**	#	13	194	18
			min	213	0	214
			max	**1320**	**6621**	**674**
			mean*	301	214	455
Toxaphene	ug/L	3	#	0	0	0
*mean - geometric mean						
** Secondary MCL						

The following table presents the native groundwater quality and the source water quality, including general water quality parameters and water geochemistry factors.

Parameter	Units		Groundwater	Streams/Rivers/Ponds	Gage # 07236000
Alkalinity	mg/L as CaCO3	#	18	0	0
		min	149		
		max	253		
		mean*	197		
Bicarbonate	mg/L	#	8	0	23
		min	182		114
		max	308		272
		mean*	247		220
Calcium	mg/L	#	12	0	7
		min	8.0		37
		max	74		98
		mean*	47		75
Carbonate	mg/L	#	8	152	23
		min	0	5.0	0
		max	2.0	3330	2.0
		mean*	2.0	221	2.0
Chloride	mg/L	#	19	154	44
		min	4.0	0	8.3
		max	154	165	177
		mean*	10	95	103

Parameter	Units		Groundwater	Streams/Rivers/Ponds	Gage # 07236000
Fluoride	mg/L	#	10	0	1
		min	0.24		0.70
		max	0.51		0.70
		mean*	0.37		0.70
Hardness	mg/L as CaCO3	#	9	0	33
		min	170		110
		max	730		330
		mean*	249		239
Magnesium	mg/L	#	10	0	7
		min	5.0		5.2
		max	6.0		24
		mean*	5.6		17
Nitrate / Nitrite+Nitrate (as N)	mg/L as N	#	19	154	4
		min	0	0.05	0.32
		max	16	1.6	9.0
		mean*	2.9	0.50	1.7
Nitrite (as N)	mg/L as N	#	0	146	0
		min		0.05	
		max		1.1	
		mean*		0.05	
Orthophosphate	mg/L	#	0	154	
		min		0.01	0
		max		0.07	
		mean*		0.01	
pH	SU	#	17	128	23
		min	7.3	6.5	7.5
		max	8.3	9.0	8.3
		mean*	7.7	8.1	7.9
Phosphorus	mg/L as P	#	0	0	0
Silica	mg/L as SiO2	#	2	0	0
		min	30		
		max	38		
		mean*	34		
Sulfate	mg/L	#	18	154	18
		min	4.8	0.0	11
		max	570	164	124
		mean*	12	73	50
Temperature	deg C	#	4	128	0
		min	17	-0.10	
		max	23	34	
		mean*	19	16	
Total dissolved solids	mg/L	#	13	194	18
		min	213	0	214
		max	1320	6621	674
		mean*	301	214	455

Parameter	Units		Groundwater	Streams/Rivers/Ponds	Gage # 07236000
Total suspended solids (TSS)	mg/L	#	0	72	
		min		1.0	0
		max		142	
		mean*		17	
Langelier's Saturation Index**	LSI	#	6	0	0
		min	-1.2		
		max	0.94		
		mean*	0.18		
*mean - geometric mean					

In general, the source water quality appeared to be good, and may even improve groundwater quality due to lower nitrate concentrations. Nitrite and phosphorus concentrations were also low, suggesting limited nutrient impact. Parameters with exceedances of MCLs included thallium and TDS. Chloride concentrations were also higher in the source water than in groundwater. The low TSS concentrations suggest that filtration would likely not be required. The only problem with the source water quality is higher TDS, which had a geometric mean concentration that was higher than that of the groundwater. Thus, the source water quality received a **moderate** score due to the TDS concentration. The groundwater conditions appear to be favorable, although the maximum nitrate, sulfate, and TDS concentrations exceeded the MCL. This resulted in a **moderate** score for native groundwater quality.

Based on the Langelier's index, the groundwater geochemistry is near neutral for scaling and dissolution, indicating minimal geochemical instability that would impact AR operations. Source water sampling did not include all the parameters necessary to calculate the Langelier's index. However, total hardness values are similar, and the pH is similar, suggesting that the geochemical conditions are of the source water are comparable to that of the groundwater. Thus, the geochemical interaction criterion will receive a **moderate** score, primarily due to the data gap for the Langelier's index.

3. Hydrogeologic Suitability

Hydrogeologic suitability of the Ogallala aquifer includes an evaluation of transmissivity, residence time, and general aquifer properties. The Ogallala aquifer is a sandstone aquifer that is unconfined in the immediate vicinity of the Recharge Region, as indicated on Figure A-4. Groundwater flow in the vicinity of the Recharge Region generally travels in a northern direction, toward the local stream system. Major nearby alluvial systems are located primarily to the north of the Recharge Region, at Wolf Creek and the North Canadian River. The Ogallala aquifer potentially contributes to these watersheds and their tributaries, as indicated by areas in red on Figure A-2. The following table provides a summary of aquifer properties and approximate residence time.

Parameter	Value	Source
Transmissivity	670 to 1,740 ft^2/day	USGS
Specific Yield	0.11 to 0.185	AWI

Well Yield	5 to 500 GPM	AWI
% of Recharge Lost in 180 Days	0	Glover
Number of Days Until 25% Loss	>1,680 days	Glover
Distance to Discharge	2.6 miles	N/A

Based on the aquifer properties, transmissivity received a **high** score.

Based on the Glover calculations, the residence time criterion received a **high** score.

4. Cost: Operation and Maintenance (O&M) and Capital

A table showing the primary cost considerations and whether they apply to the recharge area is presented below.

	Treatment – High TSS	Treatment - Other	Gravity Feed	Forcemain/ Pipeline	Injection Well - Available	Injection Well - Construct	Spreading Basin
Recharge area 2				X	X		

The relatively good water quality of the source water will require minimal treatment, if any, prior to injection into the aquifer. Due to the topography of the region, a force-main pipeline will be required to deliver water to the recharge project. The depth to water at the Recharge Region is prohibitive of a spreading basin, although the existing PWS wells in the vicinity may be usable for AR. Based on these factors, the Recharge Region received a **moderate** score for capital cost. The O&M cost received a **moderate** score due to maintenance of the force-main and AR well(s).

5. Qualitative Considerations

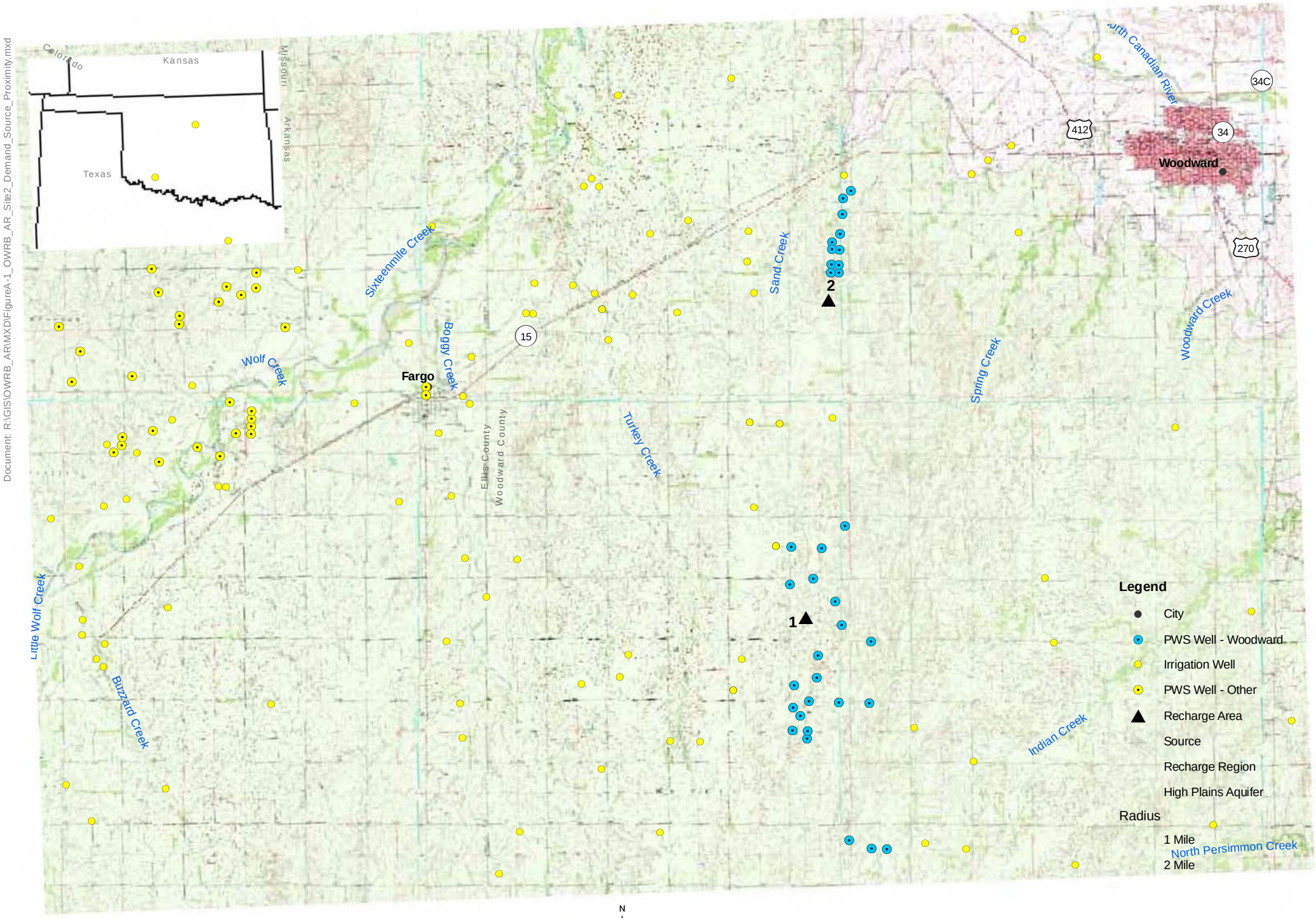
Based on the assumed project size of 1,000 acre-feet, seven percent of the total demand will be met. Thus, qualitative considerations received a **low** score.

6. Summary

The following table presents a summary of the scores and reasoning for assignment of those scores for Recharge Region 2.

Criterion	Score	Reasoning
Source Availability	Moderate	Gage 1 mile upstream; adequate flows, but dated period of record

		and well installations since
Demand Proximity (distance from recharge area)	High	PWS wells within 1 mile
Source Proximity (distance from recharge area)	Low	Wolf Creek > 2 miles
Available Freeboard and Ability to Meet Demand	High	Plentiful volume to meet recharged volume
Demand Density (number of wells)	Moderate	5 to 10 wells within 1 mile
Source Quality for Non-degradation	Moderate	Low nitrate, low TSS, higher TDS
Native Groundwater Quality	Moderate	Some MCL exceedances
Geochemical Interactions of Source and Groundwater	Moderate	Langelier's not available for source; similar pH and hardness
Transmissivity	High	Good aquifer properties for AR
Residence Time	High	No losses within 180 days, >1,680 days to 25% loss
Cost (O&M)	Moderate	No pretreatment; operation of AR wells and pipeline
Cost (capital)	Moderate	Pipeline, retrofit AR wells
Qualitative Considerations	Low	7% of total demand



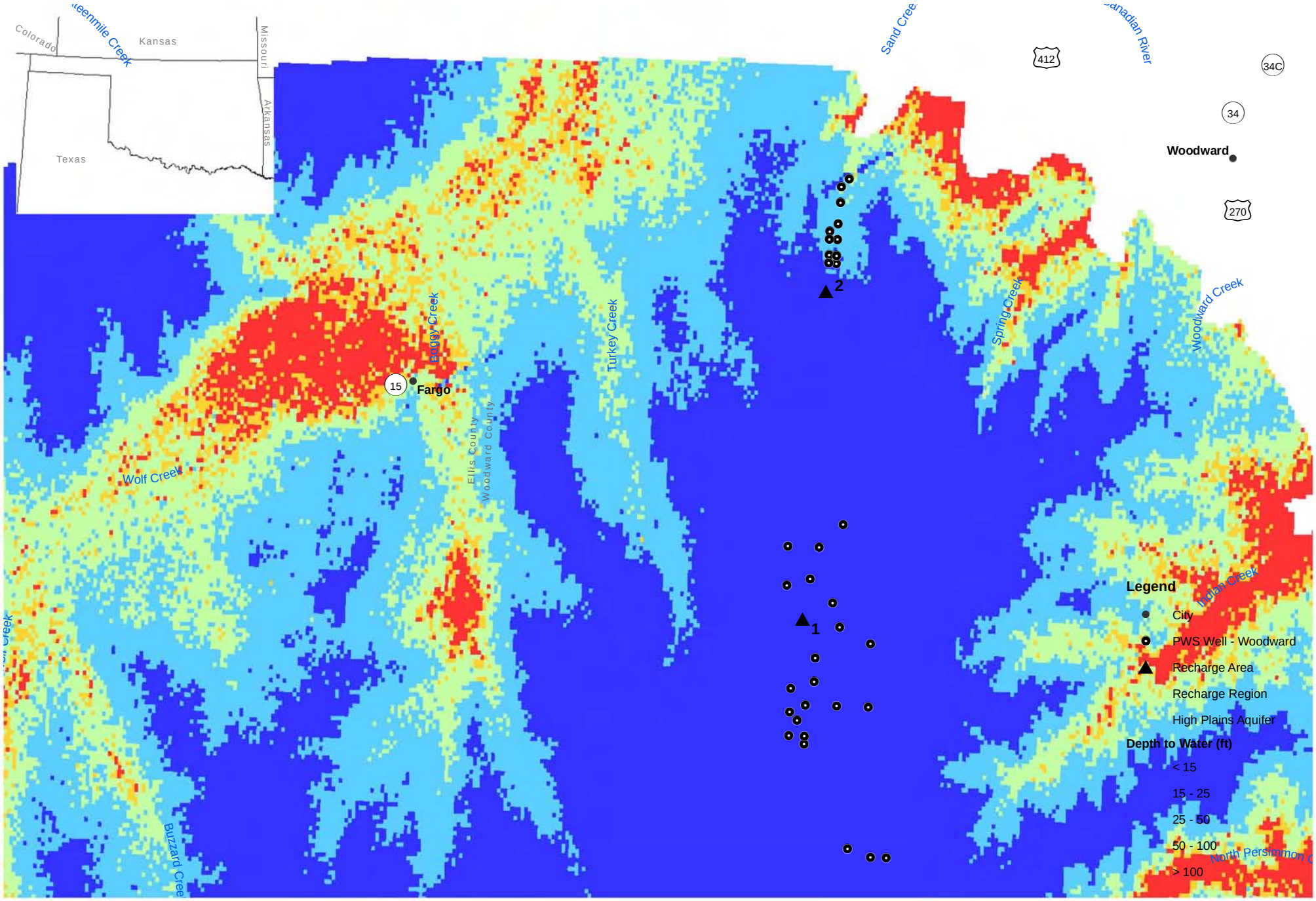
Document: R:\GIS\OWRB_AR\MXD\FigureA-1_OWRB_AR_Site2_Demand_Source_Proximity.mxd

N
W E
S

0 1 2 4
Miles

Site 2 Demand and Source Proximity

FIGURE A-1



OWRB State of Oklahoma Water Resources Board the water agency

US Army Corps of Engineers

CDM

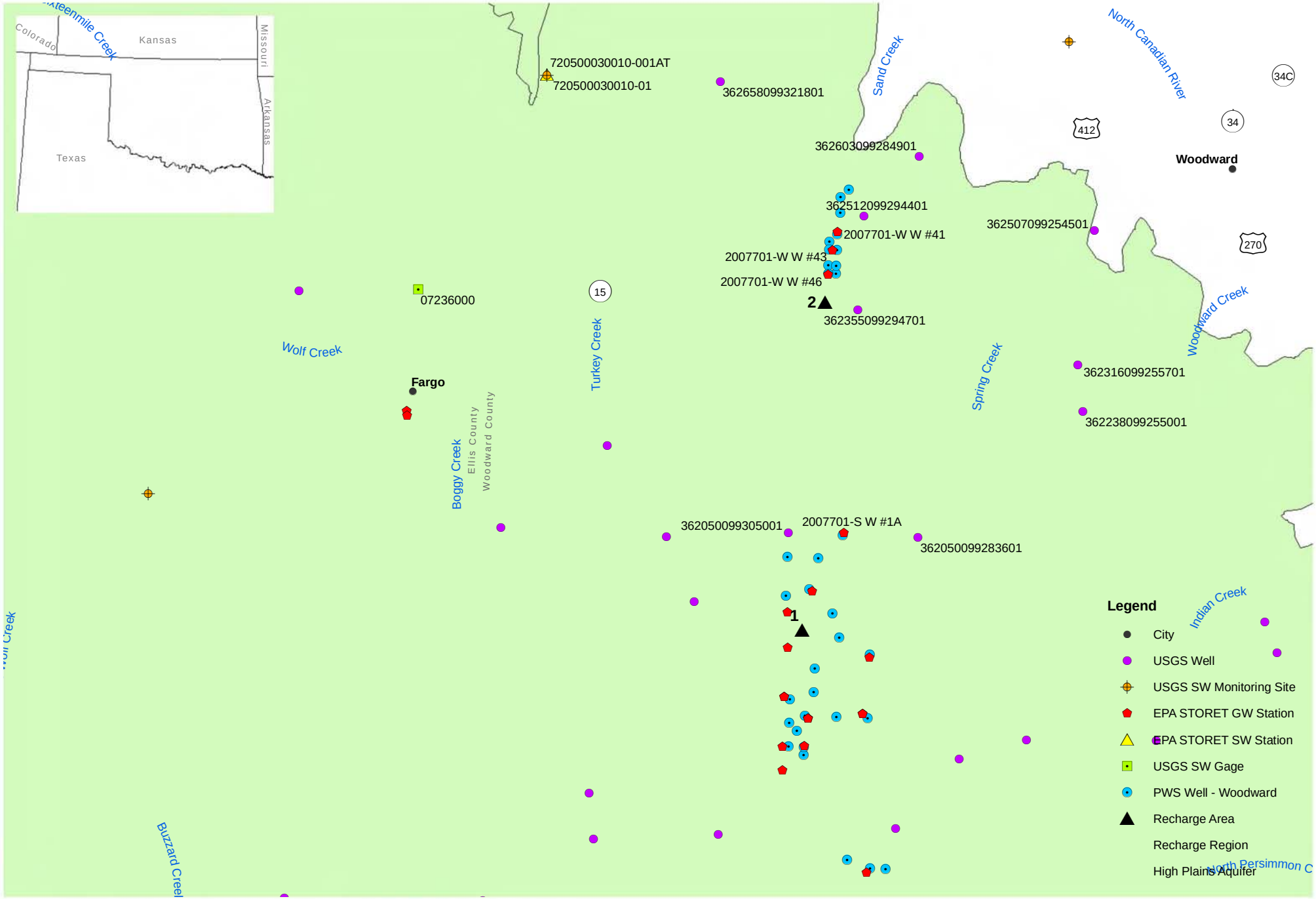
Oklahoma Comprehensive Water Plan OCWP

N W E S

0 1 2 4 Miles

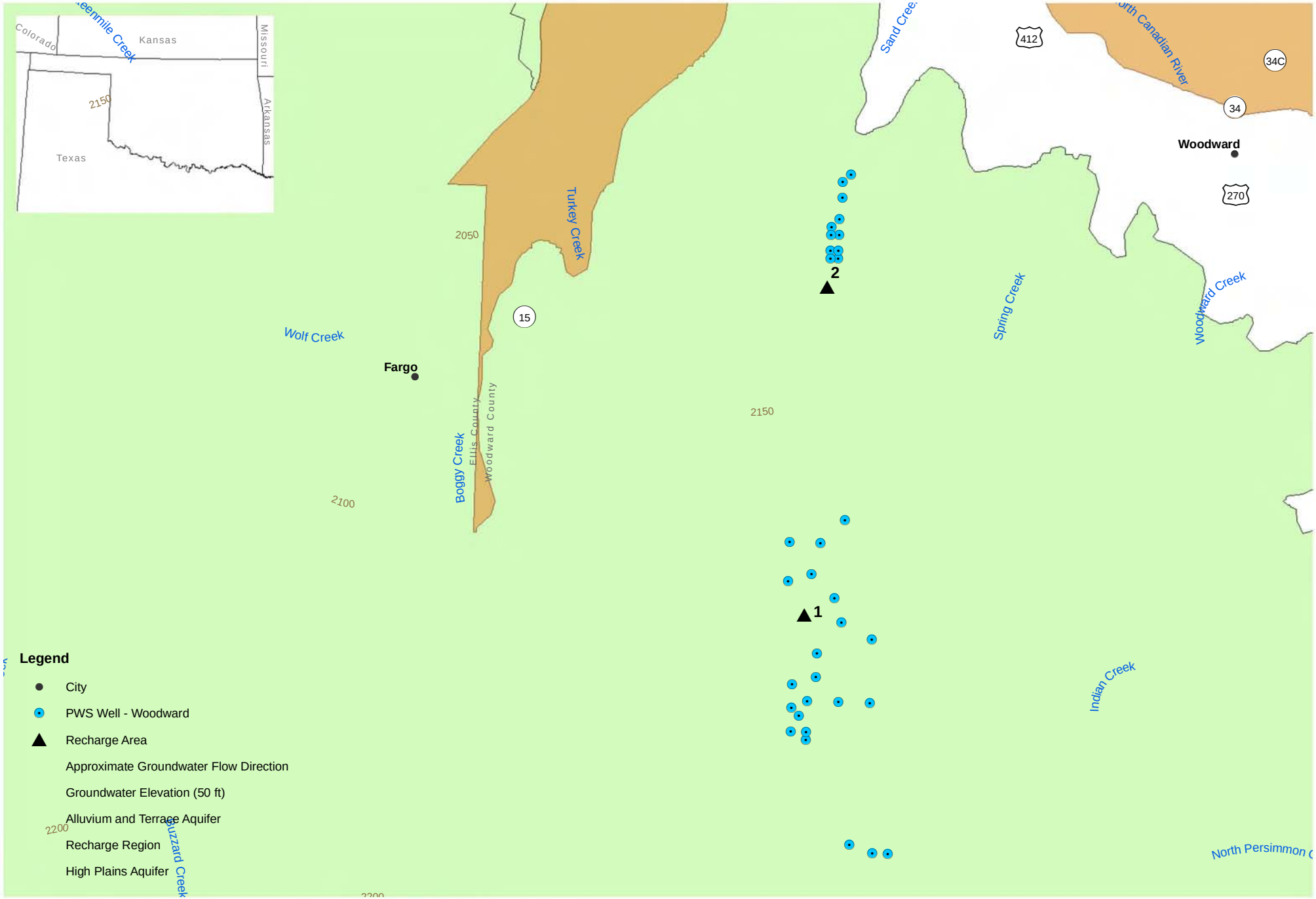
Site 2 Depth to Water

FIGURE A-2



Site 2 Surface and Groundwater Quality Sample Locations

FIGURE A-3



Site 2 Hydrogeology

FIGURE A-4

Appendix B
Detailed Analysis of Recharge Region Number 4, Rush Springs Aquifer near Weatherford

Appendix B - Recharge Region 4

Recharge Region 4 is located in the vicinity of the town of Weatherford, with the Rush Springs aquifer providing storage for an AR project. According to the U.S. Census Bureau, the town of Weatherford had an estimated population of approximately 10,185 individuals in 2008; year 2000 census data indicated 9,859 individuals (U.S. Census Bureau). For this recharge region, the demand location was identified as the PWS wells for the town of Weatherford, and the source for the potential recharge project was identified as Deer Creek. One potential recharge area was identified within this recharge region based on proximity to the source and demand, available freeboard in the aquifer, and groundwater flow direction. The recharge area is located in the eastern portion of the recharge region (see Figure B-1).

1. Demand, Source, and Storage Considerations

The following table summarizes several aspects of the recharge area related to source water availability, local demand, ability of the source to meet the demand, and storage capacity. Proximity data is shown on Figure B-1, and available freeboard is shown on Figure B-2.

Source Basin	Basin 20630
Sufficient Legally Available Water for Pilot Project	Yes
Source Stream	Deer Creek. Probable point of diversion approximately 2 miles north of recharge area.
Nearest Gage	USGS 07228400, approximately 7 miles downstream of probable point of diversion. Period of record 1960 to 1963; 1977 to 1980. No known major land use changes in the contributing basin since end of the period of record. Only use high flows due to age of selected year.
Gage POR and below average precipitation	3 years during the gage POR are below average precipitation years. 1963 selected as representative of approximately the 25th percentile of precipitation and occurred within the POR
Representative year flows (source availability)	Annual Flow: 24,213 AF
	Seasonal Distribution: Jan-Feb, Dec 21%; Mar-May 33%; Jun-Aug 26%; Sept-Nov 21%
Local Demand (Weatherford)	Annual Total 9,958 AFY
Demand Density (PWS Wells)	17 wells within 1 mile radius, 8 wells within 2 mile radius. Indicates productive region of aquifer and storage capacity
Source availability as percent of pilot project demand (minimum of local demand or 1,000 AF*)	Annual basis: 100%
	Seasonally: Jan-Feb,Dec 0%; Mar-May 100%; Jun-Aug 0%; Sept-Nov 0%
Aquifer Storage Availability	Specific Yield = 0.24

	0.3 square mile area (radius 0.3 miles) with 25 foot increase in water levels required. Storage capacity is sufficient while maintaining at least 15 feet depth to water
	0.7 square mile area (radius 0.5 miles) with 10 foot increase in water levels. Storage capacity is sufficient while maintaining at least 15 feet depth to water

Based on the availability of flows and the ability of those flows to meet the pilot project demands, the source water availability receives a **moderately low** score. This is due to the gage location and period of record.

The storage capacity requirement is less than the available storage in the aquifer below the 15 foot threshold; therefore storage availability receives a **high** score.

Based on the location of wells in close proximity to the recharge area, the demand proximity receives a **high** score.

Also, based on the number of wells (greater than ten) within one mile of the recharge area, demand density receives a **high** score.

The source of water identified for Recharge Region 4 is Deer Creek. Recharge area 1 is located within two miles of the source, and thus receives a **moderate** score for source proximity.

2. Water Quality

Water quality analysis included the following criteria: source water quality for non-degradation; native groundwater quality; and groundwater geochemical interactions with source water. The following table presents water quality data for those parameters that have an MCL. The MCL was exceeded in at least one recharge area in the State if the parameter is listed. Parameters that did not have any samples collected for the Recharge Region are listed but do not display the min, max, and mean rows. Parameters in **bold** exceed the MCL.

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/Ponds	Gage # 07228400
Aluminum	ug/L	200	#	10	0	7
			min	1.6		0
			max	**300**		**300**
			mean*	165		119
Antimony	ug/L	6	#	2		1
			min	0.14		**350**
			max	**350**		**350**
			mean*	**7.0**		**350**

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/Ponds	Gage # 07228400
Arsenic	ug/L	10	#	3	0	7
			min	10		3.0
			max	**18**		**13**
			mean*	**12**		5.7
Beryllium	ug/L	4	#	2	0	1
			min	0.01		**10**
			max	**10**		**10**
			mean*	0.32		**10**
Cadmium	ug/L	5	#	2	0	3
			min	0.04		1.0
			max	5.0		**10**
			mean*	0.45		3.7
Chloride	mg/L	250**	#	11	0	122
			min	9.8		0.30
			max	54		45
			mean*	15		17
Chlorine	mg/L	4	#	0	0	0
Chromium	ug/L	100	#	3	0	5
			min	1.7		0
			max	10		20
			mean*	5.5		13
Fecal Coliform	cfu / 100 ml		#	0	0	
Iron	ug/L	300	#	10	0	7
			min	10		10
			max	**3065**		50
			mean*	43		15
Lead	ug/L	15	#	3	0	3
			min	0.37		0
			max	**100**		**100**
			mean*	12		**67**
Manganese	ug/L	50	#	10	0	7
			min	1.0		30
			max	**60**		**110**
			mean*	6.3		**66**
Mercury	ug/L	2	#	1	0	7
			min	0.50		0
			max	0.50		0.50
			mean*	0.50		0.23
Nitrate / Nitrite+Nitrate (as N)	mg/L	10	#	10	40	44
			min	0.05	0.05	0
			max	8.1	2.1	6.6
			mean*	2.4	0.64	0.60

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/Ponds	Gage # 07228400
pH	SU	6.5-8.5**	#	10	44	123
			min	6.8	7.4	7.0
			max	7.9	**8.6**	**8.8**
			mean*	7.5	7.9	8.0
Selenium	ug/L	50	#	2	0	5
			min	0.40		0
			max	5.0		5.0
			mean*	1.4		2.2
Sulfate	mg/L	250**	#	11	4	139
			min	11	**477**	58
			max	**497**	**787**	**1060**
			mean*	161	**613**	**434**
Thallium	ug/L	2	#	2	0	1
			min	0.04		**200**
			max	**200**		**200**
			mean*	**2.8**		**200**
Total dissolved solids	mg/L	500**	#	12	44	182
			min	277	**668**	203
			max	**1100**	**1281**	**1790**
			mean*	499	**925**	**848**
Toxaphene	ug/L	3	#	0	0	0
*mean - geometric mean						
** Secondary MCL						

The following table presents the native groundwater quality and the source water quality, including general water quality parameters and water geochemistry factors.

Parameter	Units		Groundwater	Streams/Rivers/Ponds	Gage # 07228400
Alkalinity	mg/L as CaCO3	#	11	0	67
		min	106		86
		max	323		282
		mean*	144		174
Bicarbonate	mg/L	#	3	0	65
		min	127		60
		max	130		338
		mean*	129		184
Calcium	mg/L	#	10	0	97
		min	58		55
		max	157		320
		mean*	102		178
Carbonate	mg/L	#	3	42	64
		min	0	480	0
		max	0	1390	8.0
		mean*		840	6.7

Chloride	mg/L	#	11	0	122
		min	9.8		0.30
		max	54		45
		mean*	15		17
Fluoride	mg/L	#	10	0	21
		min	0.20		0.30
		max	0.55		0.70
		mean*	0.34		0.36
Hardness	mg/L as CaCO3	#	4	0	118
		min	220		140
		max	450		1200
		mean*	329		572
Magnesium	mg/L	#	10	0	98
		min	7.0		3.9
		max	22		99
		mean*	14		34
Nitrate / Nitrite+Nitrate (as N)	mg/L as N	#	10	40	44
		min	0.05	0.05	0
		max	8.1	2.1	6.6
		mean*	2.4	0.64	0.60
Nitrite (as N)	mg/L as N	#	0	40	0
		min		0.05	
		max		0.08	
		mean*		0.05	
Orthophosphate	mg/L	#	0	40	
		min		0.01	0
		max		0.13	
		mean*		0.02	
pH	SU	#	10	44	123
		min	6.8	7.4	7.0
		max	7.9	8.6	8.8
		mean*	7.5	7.9	8.0
Phosphorus	mg/L as P	#	0	0	0
Silica	mg/L as SiO2	#	3	0	20
		min	21		7.0
		max	24		22
		mean*	23		17
Sulfate	mg/L	#	11	4	139
		min	11	477	58
		max	497	787	1060
		mean*	161	613	434
Temperature	deg C	#	4	44	73
		min	18	3.9	0
		max	18	33	32
		mean*	18	17	14
Total dissolved	mg/L	#	12	44	182

solids		**min**	277	668	203
		max	1100	1281	1790
		mean*	499	925	848
Total suspended solids (TSS)	mg/L	#	0	0	
		min			0
		max			
		mean*			
Langelier's Saturation Index**	LSI	#	8	0	61
		min	-0.42		-0.76
		max	1.4		1.6
		mean*	0.62		0.77
*mean - geometric mean					
**Langelier's Index (LSI)					

In general, the source water quality appeared to be good, and may even improve groundwater quality due to lower nitrate concentrations. Potential problems are associated with exceedences (and higher concentrations than in groundwater) of sulfate and TDS. Thus, the source water quality received a **low** score due to the higher TDS concentration. The groundwater conditions are in general favorable, although several parameters exceeded the MCL. This resulted in a **moderately low** score for native groundwater quality.

Based on the Langelier's index, the groundwater and source water geochemistry is slightly positive for scaling and dissolution, indicating some scaling potential that could impact AR operations. However, because the indices are very similar, this suggests that minimal change would occur due to mixing of the water. Thus, the geochemical interaction criterion will receive a **moderate** score, primarily due to the possibility for scaling to occur.

3. Hydrogeologic Suitability

Hydrogeologic suitability of the Rush Springs aquifer includes an evaluation of transmissivity, residence time, and general aquifer properties. The Rush Springs aquifer is a sandstone aquifer that is unconfined in the immediate vicinity of the Recharge Region, as indicated on Figure B-4. Groundwater flow in the vicinity of the Recharge Region generally travels in an eastern direction, toward the local stream system. There are no major nearby alluvial systems, although minor systems may be present at Deer Creek. The Rush Springs aquifer potentially contributes to these watersheds and their tributaries, as indicated by areas in red on Figure B-2. The following table provides a summary of aquifer properties and approximate residence time.

Parameter	**Value**	**Source**
Transmissivity	670 to 1,740 ft^2/day	USGS
Specific Yield	0.13 to 0.34	AWI
Well Yield	200 to 600 GPM	AWI
% of Recharge Lost in 180	0	Glover

Days		
Number of Days Until 25% Loss	>1,680 days	Glover
Distance to Discharge	1.7 miles	N/A

Based on the aquifer properties, transmissivity received a **high** score.

Based on the Glover calculations, the residence time criterion received a **high** score.

4. Cost: Operation and Maintenance (O&M) and Capital

A table showing the primary cost considerations and whether they apply to the recharge area is presented below.

	Treatment – High TSS	Treatment – Other	Gravity Feed	Forcemain/ Pipeline	Injection Well - Available	Injection Well - Construct	Spreading Basin
Recharge Area 1		X		X	X		

The poor water quality of the source water will require treatment prior to injection into the aquifer. Due to the topography of the region, a force-main pipeline will be required to deliver water to the recharge project. The depth to water at the Recharge Region is prohibitive of a spreading basin, although the existing PWS wells in the vicinity may be usable for AR. Based on these factors, the Recharge Region received a **low** score for capital cost. The O&M cost received a **moderately low** score due to maintenance of the force-main and AR well(s), and operation of a treatment plant.

5. Qualitative Considerations

Based on the assumed project size of 1,000 acre-feet, ten percent of the total demand will be met. Thus, qualitative considerations received a **moderate** score.

6. Summary

The following table presents a summary of the scores and reasoning for assignment of those scores for Recharge Region 4.

Criterion	Score	Reasoning
Source Availability	Moderately low	Gage 7 miles downstream; old period of record

Demand Proximity (distance from recharge area)	High	PWS wells within 1 mile
Source Proximity (distance from recharge area)	Moderate	Deer Creek < 2 miles
Available Freeboard and Ability to Meet Demand	High	Plentiful volume to meet recharged volume
Demand Density (number of wells)	High	> 10 wells within 1 mile
Source Quality for Non-degradation	Low	Low nitrate, low TSS, higher TDS
Native Groundwater Quality	Moderately Low	Some MCL exceedences
Geochemical Interactions of Source and Groundwater	Moderate	Similar LSI, some potential for scaling
Transmissivity	High	Good aquifer properties
Residence Time	High	No losses within 180 days, >1,680 days to 25% loss
Cost (O&M)	Moderately Low	Pretreatment; operation of AR wells and pipeline
Cost (capital)	Low	Pipeline, retrofit AR wells, construct treatment plant
Qualitative Considerations	Moderate	10% of total demand

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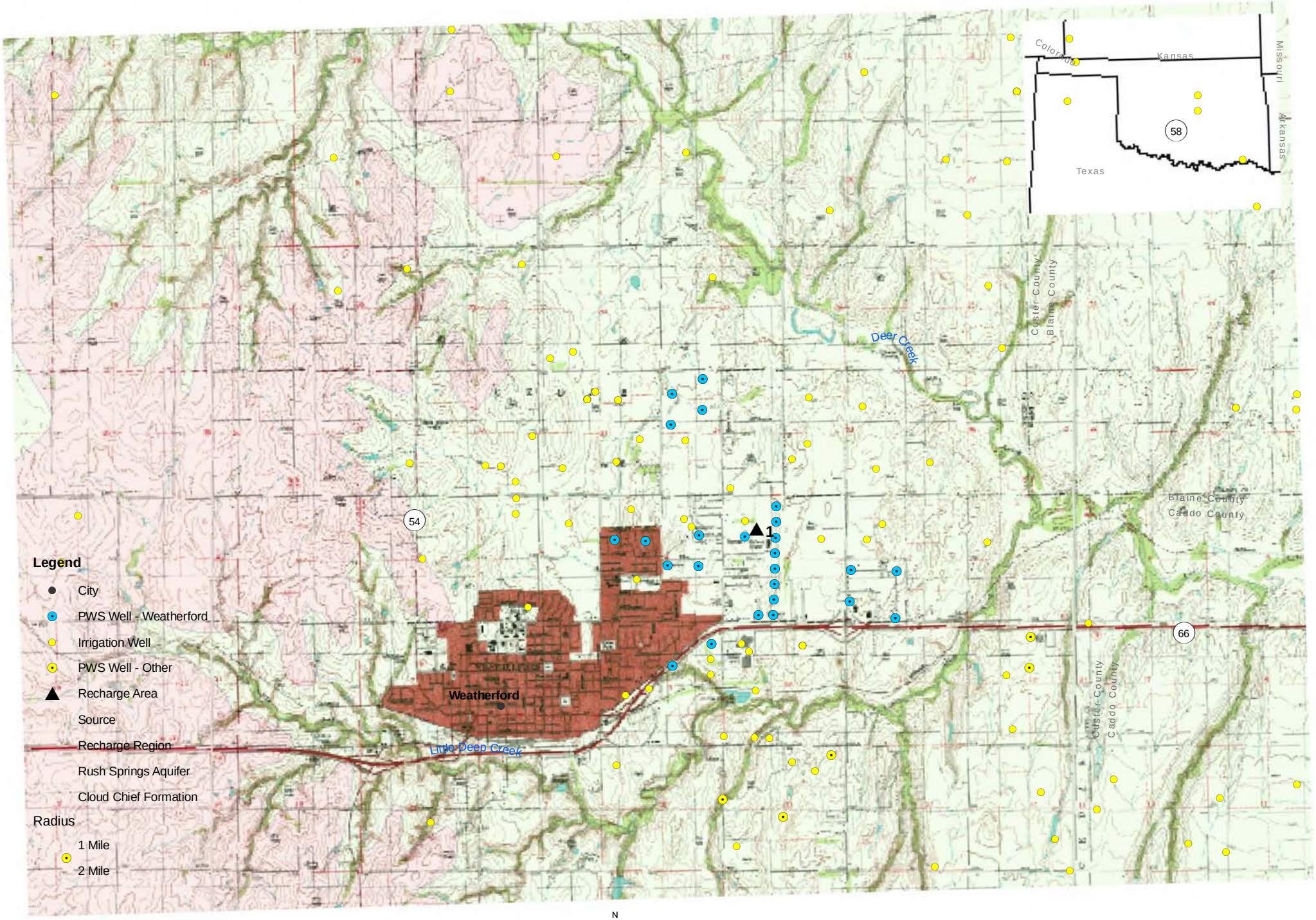

N
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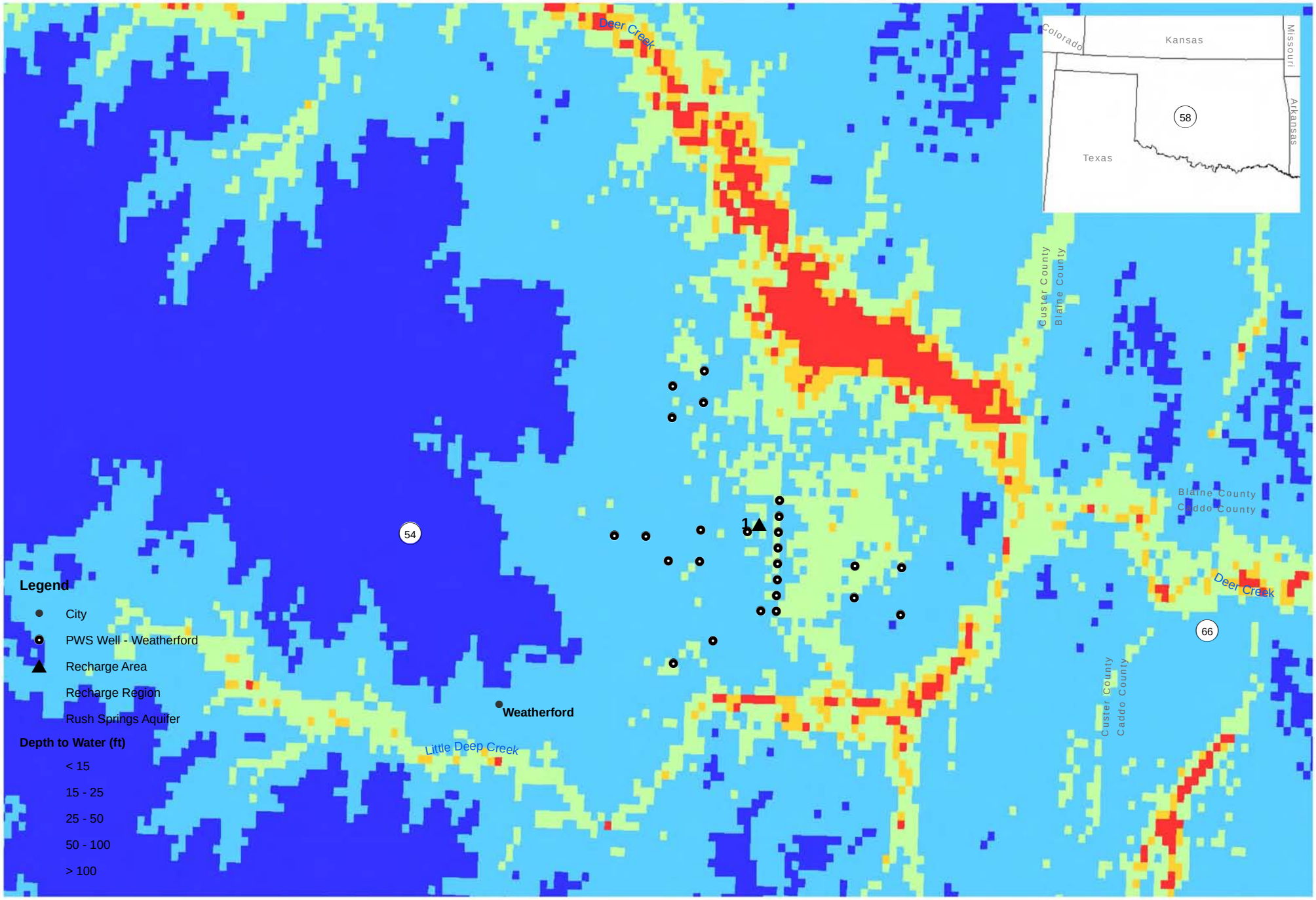
0 0.5 1 2 Miles

Site 4 Demand and Source Proximity

FIGURE B-1



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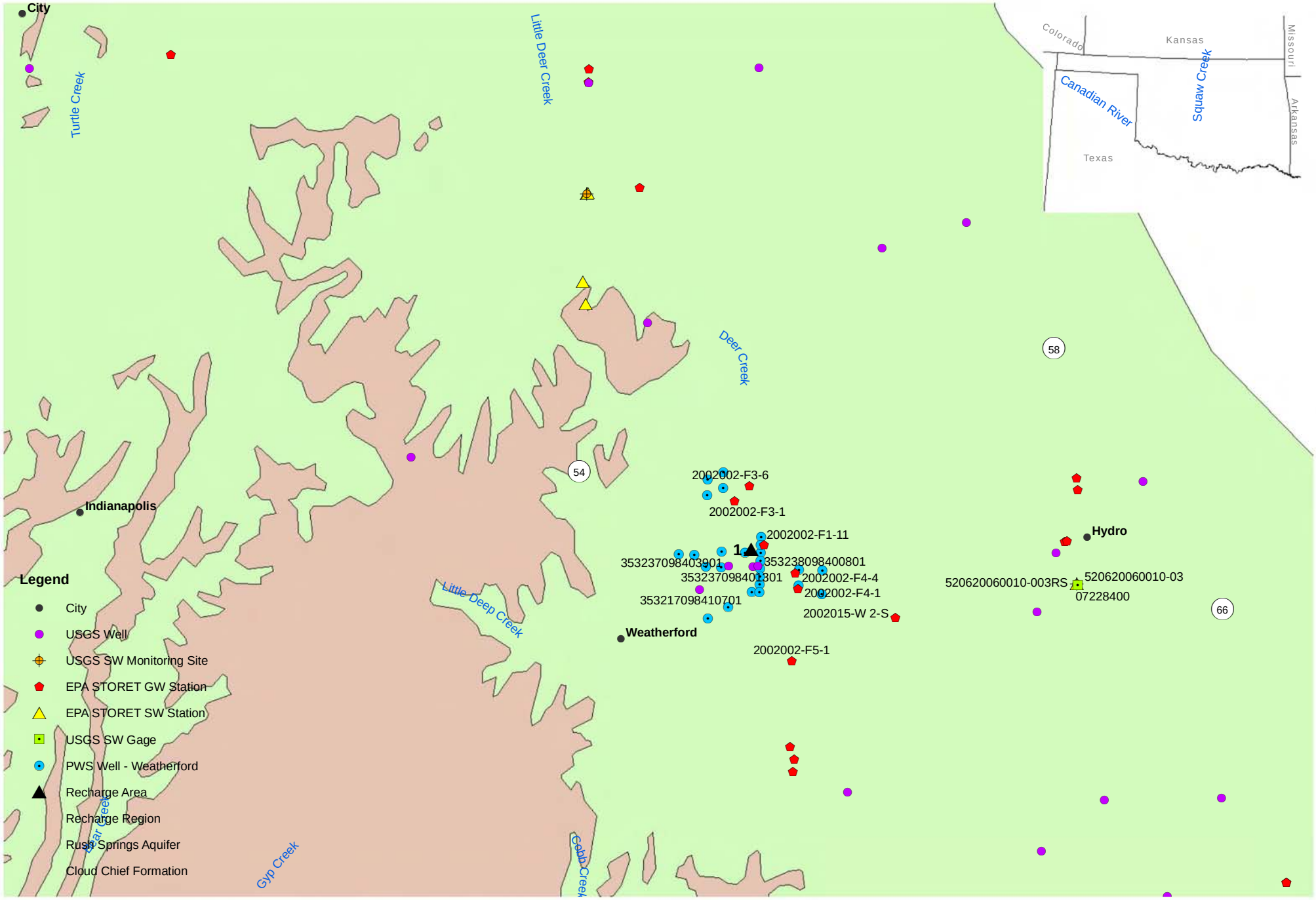
Miles

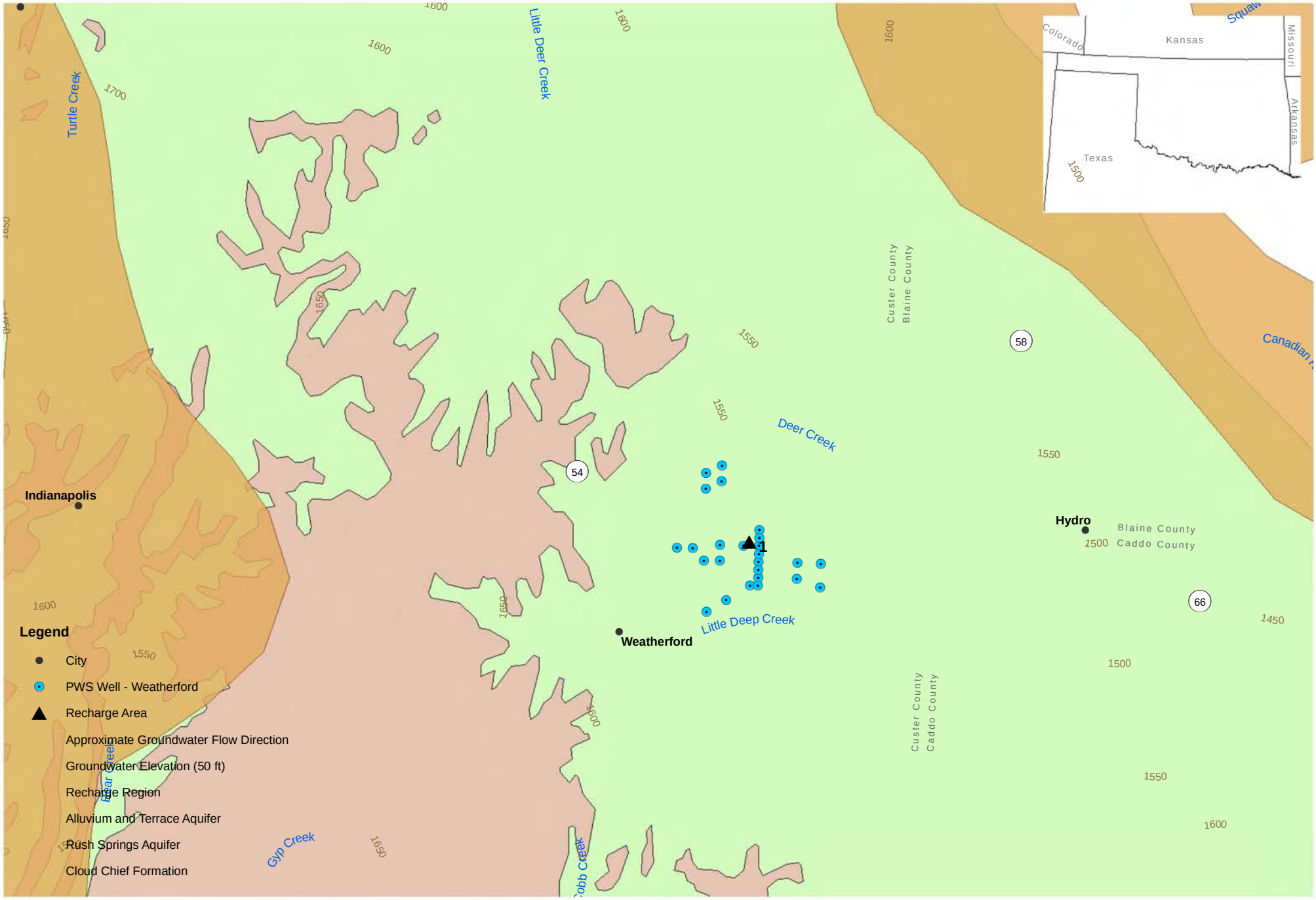
Site 4 Depth to Water

FIGURE B-2



Site 4 Surface and Groundwater Quality Sample Locations

FIGURE B-3



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0 1 2 4
Miles

Site 4 Hydrogeology

FIGURE B-4

Appendix C
Detailed Analysis of Recharge Region Number 6, Rush Springs Aquifer near Marlow

Appendix C - Recharge Region 6

Recharge Region 6 is located in the vicinity of the town of Marlow, with the Rush Springs aquifer providing storage for an AR project. According to the U.S. Census Bureau, the town of Marlow had an estimated population of approximately 4,599 individuals in 2008; year 2000 census data indicated 4,592 individuals (U.S. Census Bureau). For this recharge region, the demand location was identified as the PWS wells for the town of Marlow, and the source for the potential recharge project was identified as Little Beaver Creek. Two potential recharge areas were identified within this recharge region based on proximity to the source and demand, available freeboard, and groundwater flow direction. One potential recharge area is located in the northern portion of the recharge region, and one in the southeast portion of the recharge region (see Figure C-1). Recharge area 1, in the southeast portion, was selected based on its closer proximity to greater freeboard, and closer proximity to PWS wells. Thus, the following detailed analysis includes only a discussion of recharge area 1.

1. Demand, Source, and Storage Considerations

The following table summarizes several aspects of the recharge area related to source water availability, local demand, ability of the source to meet the demand, and storage capacity. Proximity data is shown on Figure C-1, and available freeboard is shown on Figure C-2.

Source Basin	Basin 11202
Sufficient Legally Available Water for Pilot Project	Yes
Source Stream	Little Beaver Creek. Probable point of diversion 2 miles north of confluence with Buckhorn Creek
Nearest Gage	USGS 07313000, approximately 15 miles downstream of probable point of diversion. Period of record 1948 to 1963. No known major land use changes in the contributing basin since end of the period of record. Only use high flows due to age of selected year.
Gage POR and below average precipitation	9 years during the gage POR are below average precipitation years. 1954 selected as representative of approximately the 25th percentile of precipitation and occurred within the POR
Representative year flows (source availability)	Annual Flow: 33,696 AF
	Seasonal Distribution: Jan-Feb,Dec 4%; Mar-May 91%; Jun-Aug 6%; Sept-Nov 0%
Local Demand (Marlow)	Annual Total 4,800 AFY
Demand Density (PWS Wells)	11 wells within 1 mile radius, 3 wells within 2 mile radius. Indicates productive region of aquifer and storage capacity
Source availability as percent of pilot project demand (minimum of local demand or 1,000 AF*)	Annual basis: 100%
	Seasonally: Jan-Feb,Dec 0%; Mar-May 100%; Jun-Aug 0%; Sept-Nov 0%

Aquifer Storage Availability	Specific Yield = 0.24
	0.3 square mile area (radius 0.3 miles) with 25 foot increase in water levels required. Storage capacity is sufficient while maintaining at least 15 feet depth to water
	0.7 square mile area (radius 0.5 miles) with 10 foot increase in water levels. Storage capacity is sufficient while maintaining at least 15 feet depth to water

Based on the availability of flows and the ability of those flows to meet the pilot project demands, the source water availability receives a **low** score. This is due to the gage location and period of record.

The storage capacity requirement is less than the available storage in the aquifer below the 15 foot threshold; therefore storage availability receives a **high** score.

Based on the location of wells in close proximity to the recharge area, the demand proximity receives a **high** score.

Also, based on the number of wells (greater than ten) within one mile of the recharge area, demand density receives a **high** score.

The source of water identified for Recharge Region 6 is Little Beaver Creek. Recharge area 1 is located greater than two miles from the source, and thus receives a **low** score for source proximity.

2. Water Quality

Water quality analysis included the following criteria: source water quality for non-degradation; native groundwater quality; and groundwater geochemical interactions with source water. The following table presents water quality data for those parameters that have an MCL. The MCL was exceeded in at least one recharge area in the State if the parameter is listed. Parameters that did not have any samples collected for the Recharge Region are listed but do not display the min, max, and mean rows. Parameters in **bold** exceed the MCL.

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/Ponds	Gage # 07313000
Aluminum	ug/L	200	#	20	0	0
			min	140		
			max	**300**		
			mean*	**239**		
Antimony	ug/L	6	#	1		0
			min	**350**		
			max	**350**		
			mean*	**350**		

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/Ponds	Gage # 07313000
Arsenic	ug/L	10	#	7	0	0
			min	10		
			max	10		
			mean*	10		
Beryllium	ug/L	4	#	1	0	0
			min	**10**		
			max	**10**		
			mean*	**10**		
Cadmium	ug/L	5	#	2	0	0
			min	0.50		
			max	5.0		
			mean*	1.6		
Chloride	mg/L	250**	#	29	6	201
			min	6.4	16	12
			max	109	19	**2280**
			mean*	16	17	149
Chlorine	mg/L	4	#	0	7	0
			min		**17**	
			max		**176**	
			mean*		**65**	
Chromium	ug/L	100	#	7	0	0
			min	10		
			max	10		
			mean*	10		
Fecal Coliform	cfu / 100 ml		#	0	0	
Iron	ug/L	300	#	20	0	6
			min	10		0
			max	**2400**		0
			mean*	31		
Lead	ug/L	15	#	7	0	0
			min	**45**		
			max	**100**		
			mean*	**89**		
Manganese	ug/L	50	#	20	0	0
			min	5.0		
			max	**640**		
			mean*	8.1		
Mercury	ug/L	2	#	1	0	0
			min	0.50		
			max	0.50		
			mean*	0.50		
Nitrate / Nitrite+Nitrate (as N)	mg/L	10	#	27	11	334
			min	0.01	0.05	0
			max	**26**	1.0	7.0

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/Ponds	Gage # 07313000
			mean*	1.5	0.23	1.1
pH	SU	6.5-8.5**	#	20	15	85
			min	7.0	7.4	7.0
			max	8.1	**8.6**	**8.7**
			mean*	7.4	7.8	8.0
Selenium	ug/L	50	#	1	0	0
			min	5.0		
			max	5.0		
			mean*	5.0		
Sulfate	mg/L	250**	#	29	6	181
			min	13	144	23
			max	**2000**	163	**396**
			mean*	107	153	216
Thallium	ug/L	2	#	1	0	0
			min	**200**		
			max	**200**		
			mean*	**200**		
Total dissolved solids	mg/L	500**	#	30	8	191
			min	184	215	194
			max	**2120**	**540**	**4020**
			mean*	491	335	**882**
Toxaphene	ug/L	3	#	0	0	0
*mean - geometric mean						
** Secondary MCL						

The following table presents the native groundwater quality and the source water quality, including general water quality parameters and water geochemistry factors.

Parameter	Units	Groundwater	Streams/Rivers/Ponds	Gage # 07313000
Alkalinity	mg/L as CaCO3	30	0	172
		16		75
		378		366
		157		203
Bicarbonate	mg/L	11	5	192
		20	102	92
		364	447	446
		135	245	238
Calcium	mg/L	22	7	175
		33	20	28
		343	181	348
		90	72	121
Carbonate	mg/L	7	0	113
		0		0

Parameter	Units	Groundwater	Streams/Rivers/Ponds	Gage # 07313000
		0		16
				7.3
Chloride	mg/L	29	6	201
		6.4	16	12
		109	19	2280
		16	17	149
Fluoride	mg/L	21	0	6
		0.10		0.30
		1.1		0.50
		0.27		0.37
Hardness	mg/L as CaCO3	16	0	192
		52		110
		2300		1400
		378		496
Magnesium	mg/L	22	7	175
		15	6.0	9.2
		130	63	182
		23	41	49
Nitrate / Nitrite+Nitrate (as N)	mg/L as N	27	11	334
		0.01	0.05	0
		26	1.0	7.0
		1.5	0.23	1.1
Nitrite (as N)	mg/L as N	0	4	0
			0.05	
			0.05	
			0.05	
Orthophosphate	mg/L	0	6	
			0.01	0
			0.03	
			0.01	
pH	SU	20	15	85
		7.0	7.4	7.0
		8.1	8.6	8.7
		7.4	7.8	8.0
Phosphorus	mg/L as P	0	0	0
Silica	mg/L as SiO2	7	0	6
		4.3		13
		27		25
		18		18
Sulfate	mg/L	29	6	181
		13	144	23
		2000	163	396
		107	153	216
Temperature	deg C	10	0	82
		16		1.7

Parameter	Units	Groundwater	Streams/Rivers/Ponds	Gage # 07313000
		20		28
		18		11
Total dissolved solids	mg/L	30	8	191
		184	215	194
		2120	540	4020
		491	335	882
Total suspended solids (TSS)	mg/L	0	0	
Langelier's Saturation Index**	LSI	17	0	0
		-1.0		
		1.3		
		0.39		
*mean - geometric mean				
**Langelier's Index (LSI)				

In general, the source water quality appeared to be good. Parameters with exceedences of MCLs included chloride, sulfate, and TDS, and were also higher in the source water than in groundwater. Thus, the source water quality received a **low** score due to the TDS concentration. The groundwater conditions appear to be somewhat poor, with multiple parameters exceeding the MCL. This resulted in a **moderately low** score for native groundwater quality.

Based on the Langelier's index, the groundwater geochemistry is near neutral for scaling and dissolution, indicating minimal geochemical instability that would impact AR operations. Source water sampling did not include all the parameters necessary to calculate the Langelier's index. However, total hardness values and pH values are greater in the source water than groundwater, suggesting that the geochemical conditions of the source water are more likely to cause scaling than the groundwater. Thus, the geochemical interaction criterion will receive a **moderately low** score due to the data gap for the Langelier's index and likelihood of interactions.

3. Hydrogeologic Suitability

Hydrogeologic suitability of the Rush Springs aquifer includes an evaluation of transmissivity, residence time, and general aquifer properties. The Rush Springs aquifer is a sandstone aquifer that is unconfined in the immediate vicinity of the Recharge Region, as indicated on Figure C-4. Groundwater flow in the vicinity of the Recharge Region generally flows outward in a radial manner, toward the local stream systems. There are no major nearby alluvial systems, although minor systems may be present at Little Beaver Creek. The Rush Springs aquifer potentially contributes to these watersheds and their tributaries, as indicated by areas in red on Figure C-2. The following table provides a summary of aquifer properties and approximate residence time.

Parameter	Value	Source
Transmissivity	670 to 1,870 ft^2/day	AWI

Specific Yield	0.13 to 0.34	AWI
Well Yield	200 to 600 GPM	AWI
% of Recharge Lost in 180 Days	25	Glover
Number of Days Until 25% Loss	180	Glover
Distance to Discharge	0.3 miles	N/A

Based on the aquifer properties, transmissivity received a **high** score.

Based on the Glover calculations, the residence time criterion received a **moderate** score.

4. Cost: Operation and Maintenance (O&M) and Capital

A table showing the primary cost considerations and whether they apply to a recharge area is presented below.

	Treatment – High TSS	Treatment - Other	Gravity Feed	Forcemain/ Pipeline	Injection Well - Available	Injection Well - Construct	Spreading Basin
Recharge Area 1		X		X		X	

The relatively poor water quality of the source water will require prior to injection into the aquifer. Due to the topography of the region, a force-main pipeline will be required to deliver water to the recharge project. The depth to water at the Recharge Region is prohibitive of a spreading basin, and the existing PWS wells in the vicinity are located in an area with less than 15 feet of freeboard, making them unable to be utilized. Thus, injection wells will need to be installed. Based on these factors, the Recharge Region received a **low** score for capital cost. The O&M cost received a **moderately low** score due to maintenance of the force-main and AR well(s), and operation of the treatment system.

5. Qualitative Considerations

Based on the assumed project size of 1,000 acre-feet, 21 percent of the total demand will be met. Thus, qualitative considerations received a **moderate** score.

6. Summary

The following table presents a summary of the scores and reasoning for assignment of those scores for Recharge Region 6.

Criterion	Score	Reasoning

Source Availability	Low	Gage 15 miles downstream; old period of record
Demand Proximity (distance from recharge area)	High	PWS wells within 1 mile
Source Proximity (distance from recharge area)	Low	Little Beaver Creek > 2 miles
Available Freeboard and Ability to Meet Demand	High	Plentiful volume to meet recharged volume
Demand Density (number of wells)	High	> 10 wells within 1 mile
Source Quality for Non-degradation	Low	MCL exceedences, higher TDS
Native Groundwater Quality	Moderately Low	MCL exceedences
Geochemical Interactions of Source and Groundwater	Moderately Low	Langelier's not available for source; higher pH and hardness
Transmissivity	High	Good aquifer properties for AR
Residence Time	Moderate	25% loss within 180 days, 180 days to 25% loss
Cost (O&M)	Moderately Low	Pretreatment; operation of AR wells and pipeline
Cost (capital)	Low	Pipeline, install AR wells, treatment system
Qualitative Considerations	Moderate	21% of demand met

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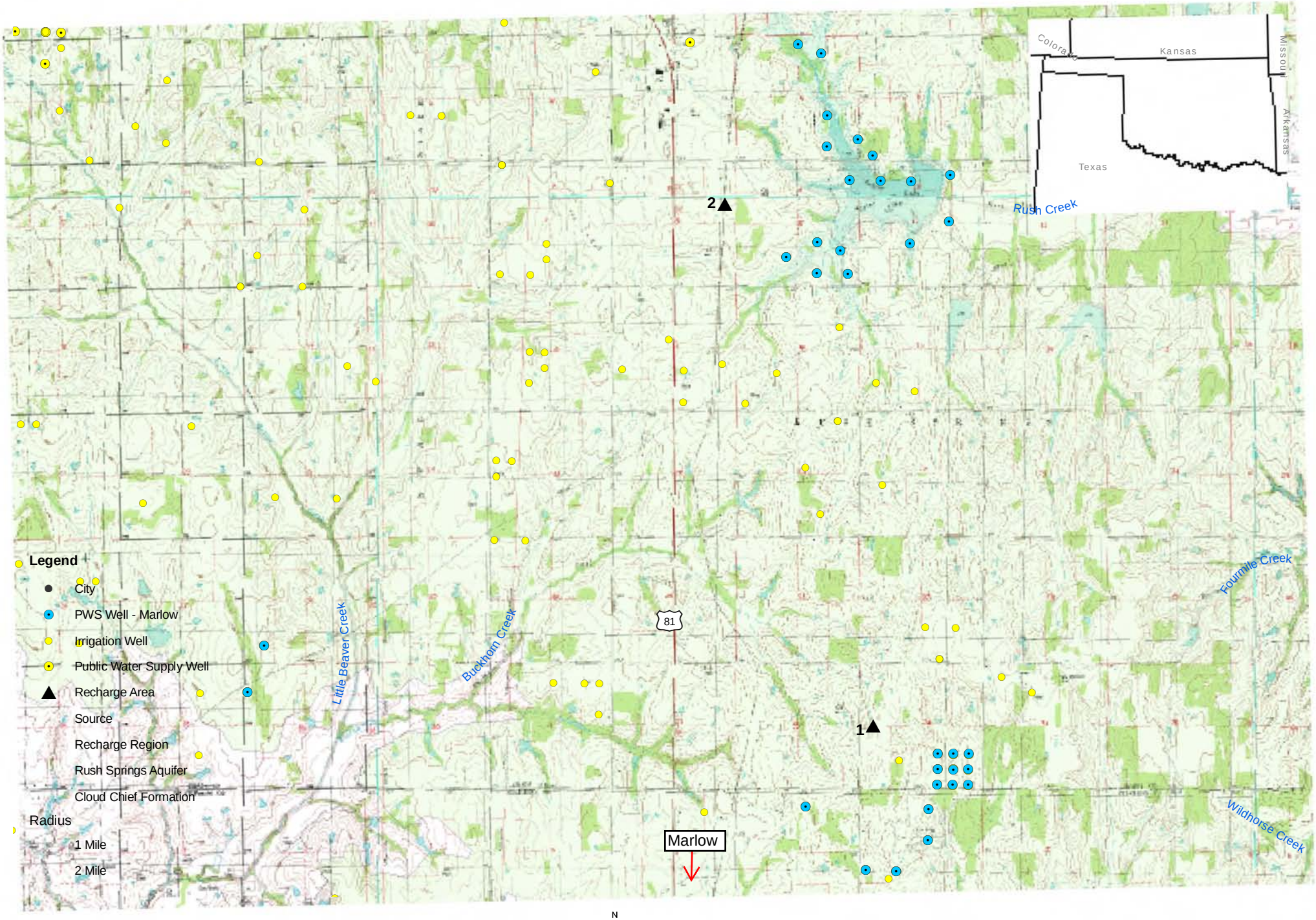

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0 0.5 1 2
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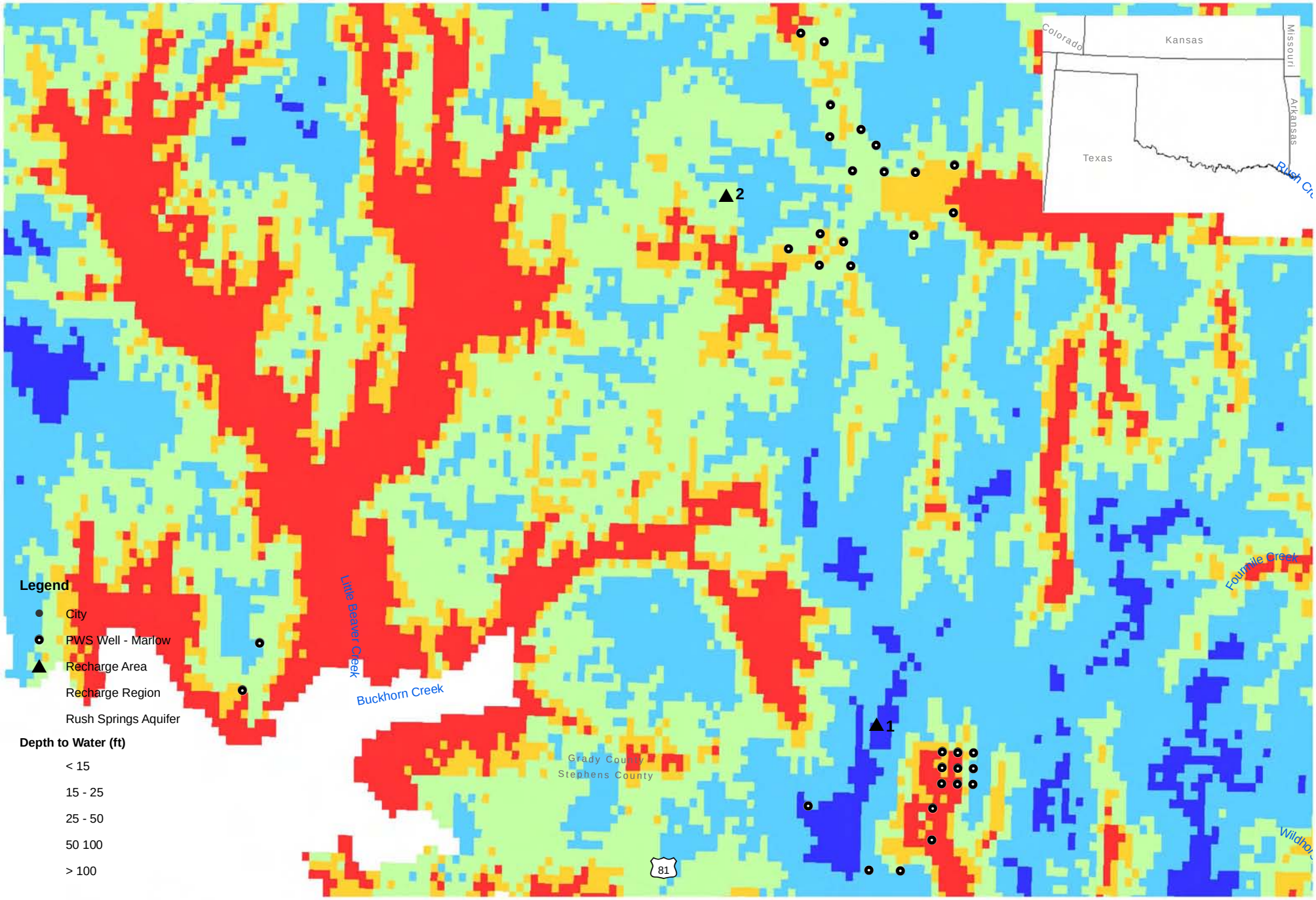
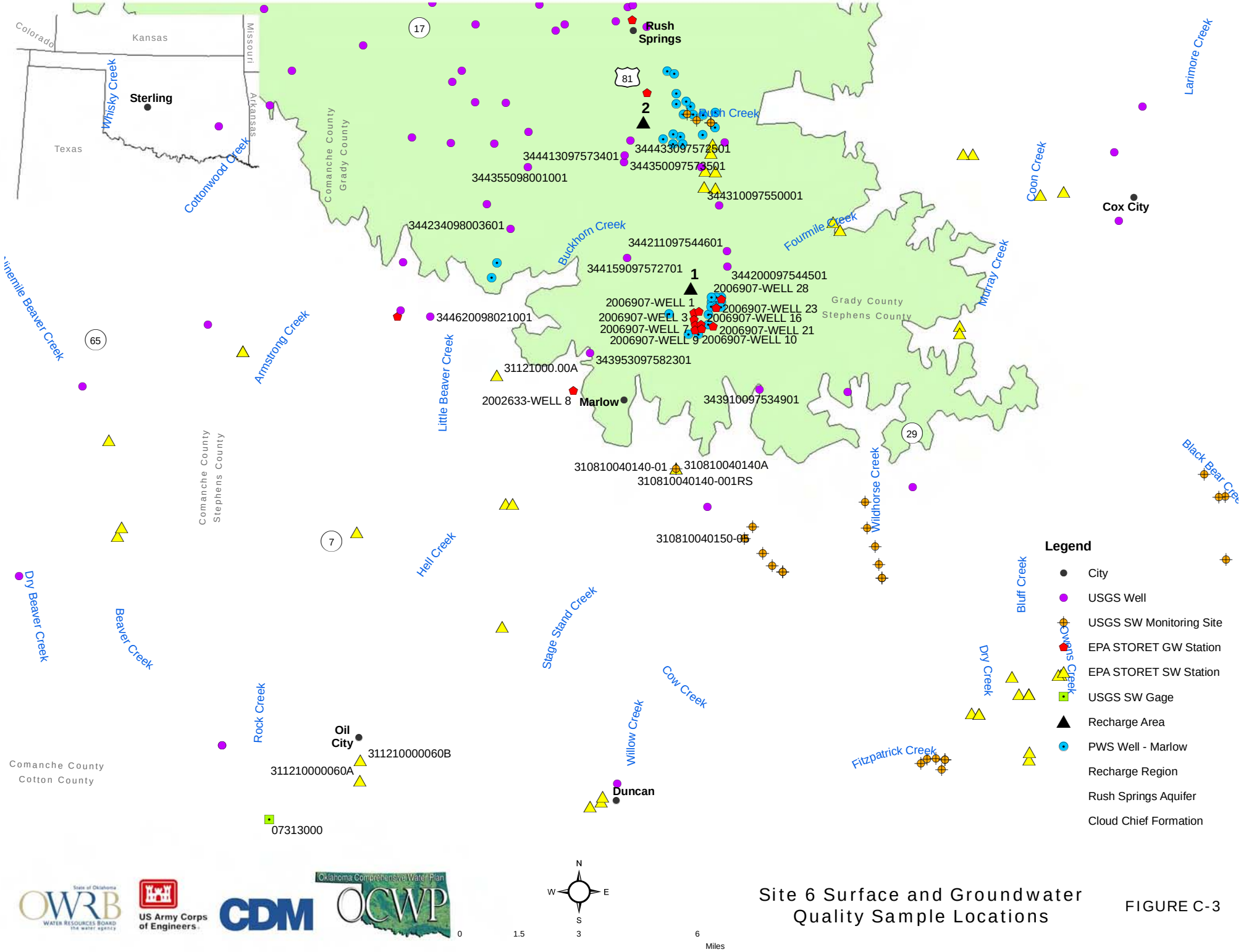
Site 6 Demand and Source Proximity

FIGURE C-1



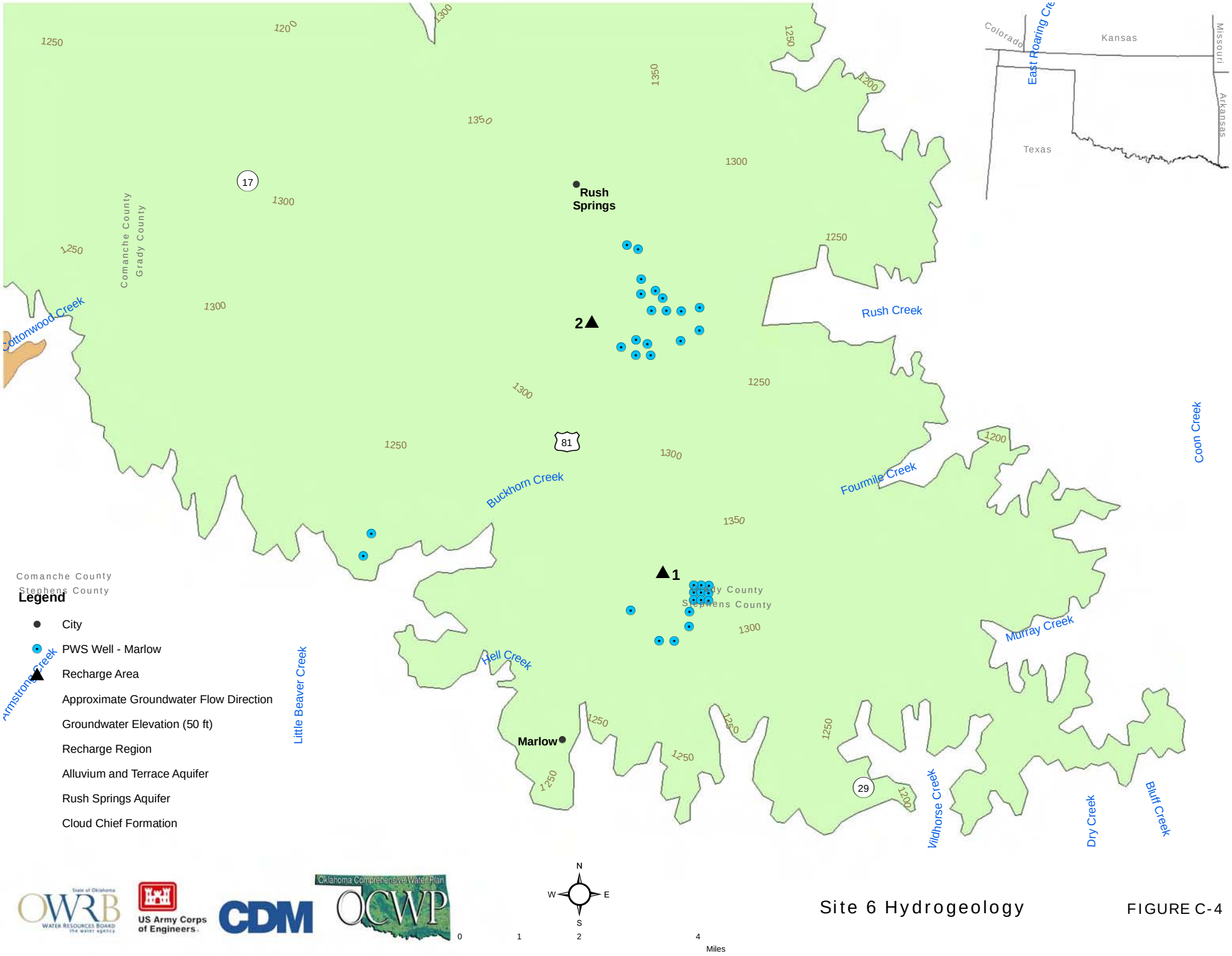
Site 6 Depth to Water

FIGURE C-2



Site 6 Surface and Groundwater Quality Sample Locations

FIGURE C-3



Site 6 Hydrogeology

FIGURE C-4

Appendix D
Detailed Analysis of Recharge Region Number 8, Central Oklahoma/Garber Wellington Aquifer near Norman

Appendix D - Recharge Region 8

Recharge Region 8 is located in the vicinity of the town of Norman, with the Central Oklahoma/Garber Wellington aquifer providing storage for an AR project. According to the U.S. Census Bureau, the town of Norman had an estimated population of approximately 106,957 individuals in 2008; year 2000 census data indicated 95,694 individuals (U.S. Census Bureau). For this recharge region, the demand location was identified as the PWS wells for the town of Norman, and the source for the potential recharge project was identified as Elm Creek/Lake Thunderbird/Lake Stanley Draper. Two potential recharge areas were identified based on proximity to the source and demand, available freeboard in the aquifer, and groundwater flow direction. One recharge area is located in the central portion of the recharge region, and one in the southeast portion of the recharge region. Recharge area 2, in the southeast portion, was selected based on its presence within greater freeboard, and closer proximity to PWS wells and sources of water. Thus, the following detailed analysis includes only a discussion of recharge area 2.

1. Demand, Source, and Storage Considerations

The following table summarizes several aspects of the recharge area related to source water availability, local demand, ability of the source to meet the demand, and storage capacity. Proximity data is shown on Figure D-1, and available freeboard is shown on Figure D-2.

Source Basin	Basin 20802
Sufficient Legally Available Water for Pilot Project	Unknown
Source Stream	Elm Creek/Lake Stanley Draper/Lake Thunderbird. Probable point of diversion near confluence with Rock Creek
Nearest Gage	None. Likely would rely on releases from either lake. No known major land use changes in the contributing basin since end of the period of record.
Gage POR and below average precipitation	N/A
Representative year flows (source availability)	N/A
	N/A
Local Demand (Norman)	Annual Total 88,000 AFY
Demand Density (PWS Wells)	7 wells within 1 mile radius, 5 wells within 2 mile radius. Indicates productive region of aquifer and storage capacity
Source availability as percent of pilot project demand (minimum of local demand or 1,000 AF*)	N/A
	N/A
Aquifer Storage Availability	Storativity = 0.0002
	313 square mile area (radius 10 miles) with 25 foot increase in water levels required. Storage capacity is insufficient to maintain at least 15 feet depth to water

	781 square mile area (radius 16 miles) with 10 foot increase in water levels. Storage capacity is insufficient to maintain at least 15 feet depth to water

Based on the availability of flows and the ability of those flows to meet the pilot project demands, the source water availability receives a **low** score. This is due to a lack of confirmed flow availability.

The storage capacity requirement is greater than the available storage in the aquifer below the 15 foot threshold; therefore storage availability receives a **low** score.

Based on the location of wells in close proximity to the recharge area, the demand proximity receives a **high** score.

Also, based on the number of wells (five to ten) within one mile of the recharge area, demand density receives a **moderately high** score.

The source of water identified for Recharge Region 8 is Elm Creek/Lake Stanley Draper/Lake Thunderbird. Recharge area 1 is located within two miles of the source, and thus receives a **moderate** score for source proximity.

2. Water Quality

Water quality analysis included the following criteria: source water quality for non-degradation; native groundwater quality; and groundwater geochemical interactions with source water. The following table presents water quality data for those parameters that have an MCL. The MCL was exceeded in at least one recharge area in the State if the parameter is listed. Parameters that did not have any samples collected for the Recharge Region are listed but do not display the min, max, and mean rows. Parameters in **bold** exceed the MCL.

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/Ponds
Aluminum	ug/L	200	#	7	0
			min	10	
			max	**4440**	
			mean*	69	
Antimony	ug/L	6	#	1	
			min	1.0	
			max	1.0	
			mean*	1.0	
Arsenic	ug/L	10	#	4	1
			min	0.50	10
			max	1.1	10
			mean*	0.79	10
Beryllium	ug/L	4	#	4	0

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/Ponds
			min	0.50	
			max	1.0	
			mean*	0.84	
Cadmium	ug/L	5	#	1	1
			min	1.0	1.0
			max	1.0	1.0
			mean*	1.0	1.0
Chloride	mg/L	250**	#	70	26
			min	5.6	5.0
			max	**708**	23
			mean*	18	8.7
Chlorine	mg/L	4	#	0	0
Chromium	ug/L	100	#	67	1
			min	4.0	5.0
			max	80	5.0
			mean*	9.9	5.0
Fecal Coliform	cfu / 100 ml		#	0	0
Iron	ug/L	300	#	70	0
			min	4.0	
			max	**24400**	
			mean*	**425**	
Lead	ug/L	15	#	1	1
			min	10	5.0
			max	10	5.0
			mean*	10	5.0
Manganese	ug/L	50	#	68	0
			min	2.0	
			max	**850**	
			mean*	41	
Mercury	ug/L	2	#	1	1
			min	0.10	0.50
			max	0.10	0.50
			mean*	0.10	0.50
Nitrate / Nitrite+Nitrate (as N)	mg/L	10	#	6	34
			min	0.34	0.05
			max	2.2	0.49
			mean*	0.82	0.12
pH	SU	6.5-8.5**	#	70	0
			min	6.8	
			max	**8.6**	
			mean*	7.8	
Selenium	ug/L	50	#	66	1
			min	0.20	5.0
			max	**150**	5.0
			mean*	5.4	5.0

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/Ponds
Sulfate	mg/L	250**	#	73	25
			min	3.0	10
			max	222	33
			mean*	12	18
Thallium	ug/L	2	#	0	1
			min		**5.0**
			max		**5.0**
			mean*		**5.0**
Total dissolved solids	mg/L	500**	#	14	0
			min	178	
			max	**1650**	
			mean*	308	
Toxaphene	ug/L	3	#	0	0
*mean - geometric mean					
** Secondary MCL					

The following table presents the native groundwater quality and the source water quality, including general water quality parameters and water geochemistry factors.

Parameter	Units		Groundwater	Streams/Rivers/Ponds
Alkalinity	mg/L as CaCO3	#	73	0
		min	64	
		max	300	
		mean*	187	
Bicarbonate	mg/L	#	3	0
		min	185	
		max	306	
		mean*	231	
Calcium	mg/L	#	70	0
		min	7.0	
		max	75	
		mean*	35	
Carbonate	mg/L	#	3	1
		min	0	37
		max	0	37
		mean*		37
Chloride	mg/L	#	70	26
		min	5.6	5.0
		max	708	23
		mean*	18	8.7
Fluoride	mg/L	#	67	0
		min	0.10	
		max	1.8	
		mean*	0.27	

Parameter	Units		Groundwater	Streams/Rivers/Ponds
Hardness	mg/L as CaCO3	#	69	0
		min	34	
		max	340	
		mean*	175	
Magnesium	mg/L	#	70	0
		min	4.0	
		max	36	
		mean*	21	
Nitrate / Nitrite+Nitrate (as N)	mg/L as N	#	6	34
		min	0.34	0.05
		max	2.2	0.49
		mean*	0.82	0.12
Nitrite (as N)	mg/L as N	#	1	34
		min	0.01	0.05
		max	0.01	0.07
		mean*	0.01	0.05
Orthophosphate	mg/L	#	0	34
		min		0.01
		max		0.15
		mean*		0.01
pH	SU	#	70	0
		min	6.8	
		max	8.6	
		mean*	7.8	
Phosphorus	mg/L as P	#	3	0
		min	40	
		max	40	
		mean*	40	
Silica	mg/L as SiO2	#	64	0
		min	4.0	
		max	37	
		mean*	6.5	
Sulfate	mg/L	#	73	25
		min	3.0	10
		max	222	33
		mean*	12	18
Temperature	deg C	#	6	0
		min	13	
		max	17	
		mean*	16	
Total dissolved solids	mg/L	#	14	0
		min	178	
		max	1650	
		mean*	308	
Total suspended solids (TSS)	mg/L	#	0	1
		min		18

Parameter	Units		Groundwater	Streams/Rivers/Ponds
		max		18
		mean*		18
Langelier's Saturation Index**	LSI	#	6	0
		min	-1.2	
		max	1.00	
		mean*	0.47	
*mean - geometric mean				
**Langelier's Index (LSI)				

In general, the source water quality appeared to be good, and may even improve groundwater quality due to lower nitrate concentrations. Only thallium had exceedences of MCLs (likely due to detection limit higher than the MCL), although many parameters lacked data. Also, there were no samples for TDS, suggesting that additional data collection is needed for this location. Thus, the source water quality received a **moderate** score due to the lack of data. The groundwater conditions overall were favorable, although the maximum concentrations of some parameters exceeded the MCL. This resulted in a **moderately high** score for native groundwater quality.

Based on the Langelier's index, the groundwater geochemistry is near neutral for scaling and dissolution, indicating minimal geochemical instability that would impact AR operations. Source water sampling did not include all the parameters necessary to calculate the Langelier's index, and also did not include hardness or pH. Thus, the geochemical interaction criterion will receive a **moderately low** score, primarily due to the data gap for the Langelier's index.

3. Hydrogeologic Suitability

Hydrogeologic suitability of the Central Oklahoma/Garber Wellington aquifer includes an evaluation of transmissivity, residence time, and general aquifer properties. The Central Oklahoma aquifer is a sandstone aquifer that is both confined and unconfined in the immediate vicinity of the Recharge Region. Groundwater flow in the vicinity of the Recharge Region generally travels in an eastern direction, toward the local stream system, as indicated on Figure D-4. There are no major nearby alluvial systems, although minor alluvial systems are likely present at Elm Creek or near the lakes. The Central Oklahoma aquifer contributes to these creeks and their tributaries, as indicated by areas in red on Figure D-2. The following table provides a summary of aquifer properties and approximate residence time.

Parameter	Value	Source
Transmissivity	535 to 936 ft^2/day	AWI
Storativity	0.0002	AWI
Well Yield	100 to 300 GPM	AWI
% of Recharge Lost in 180 Days	88.5	Glover

Number of Days Until 25% Loss	<10	Glover
Distance to Discharge	1 mile	N/A

Based on the aquifer properties, transmissivity received a **moderate** score.

Based on the Glover calculations, the residence time criterion received a **low** score.

4. Cost: Operation and Maintenance (O&M) and Capital

A table showing the primary cost considerations and whether they apply to the Recharge Region is presented below.

	Treatment – High TSS	Treatment – Other	Gravity Feed	Forcemain/ Pipeline	Injection Well - Available	Injection Well - Construct	Spreading Basin
Recharge Area 2				X	X		

The relatively good water quality of the source water will require minimal treatment, if any, prior to injection into the aquifer, although further characterization is required. Due to the topography of the region, a force-main pipeline will be required to deliver water to the recharge project. The depth to water at the Recharge Region is prohibitive of a spreading basin, although the existing PWS wells in the vicinity may be usable for AR. Based on these factors, the Recharge Region received a **moderate** score for capital cost. The O&M cost received a **moderate** score due to maintenance of the force-main and AR well(s).

5. Qualitative Considerations

Based on the assumed project size of 1,000 acre-feet, one percent of the total demand will be met. Thus, qualitative considerations received a **low** score.

6. Summary

The following table presents a summary of the scores and reasoning for assignment of those scores for Recharge Region 8.

Criterion	Score	Reasoning
Source Availability	Low	No confirmed flow availability (no gages)

Demand Proximity (distance from recharge area)	High	PWS wells within 1 mile
Source Proximity (distance from recharge area)	Moderate	Source < 2 miles
Available Freeboard and Ability to Meet Demand	Low	Unable to meet recharged volume
Demand Density (number of wells)	Moderately high	5 to 10 wells within 1 mile
Source Quality for Non-degradation	Moderate	Minimal exceedences, lack of data
Native Groundwater Quality	Moderately High	Low TDS, minimal MCL exceedances
Geochemical Interactions of Source and Groundwater	Moderately Low	Langelier's not available for source
Transmissivity	Moderate	Decent aquifer properties for AR
Residence Time	Low	88.5% loss within 180 days, <10 days to 25% loss
Cost (O&M)	Moderate	No pretreatment; operation of AR wells and pipeline
Cost (capital)	Moderate	Pipeline, retrofit AR wells
Qualitative Considerations	Low	1% of total demand

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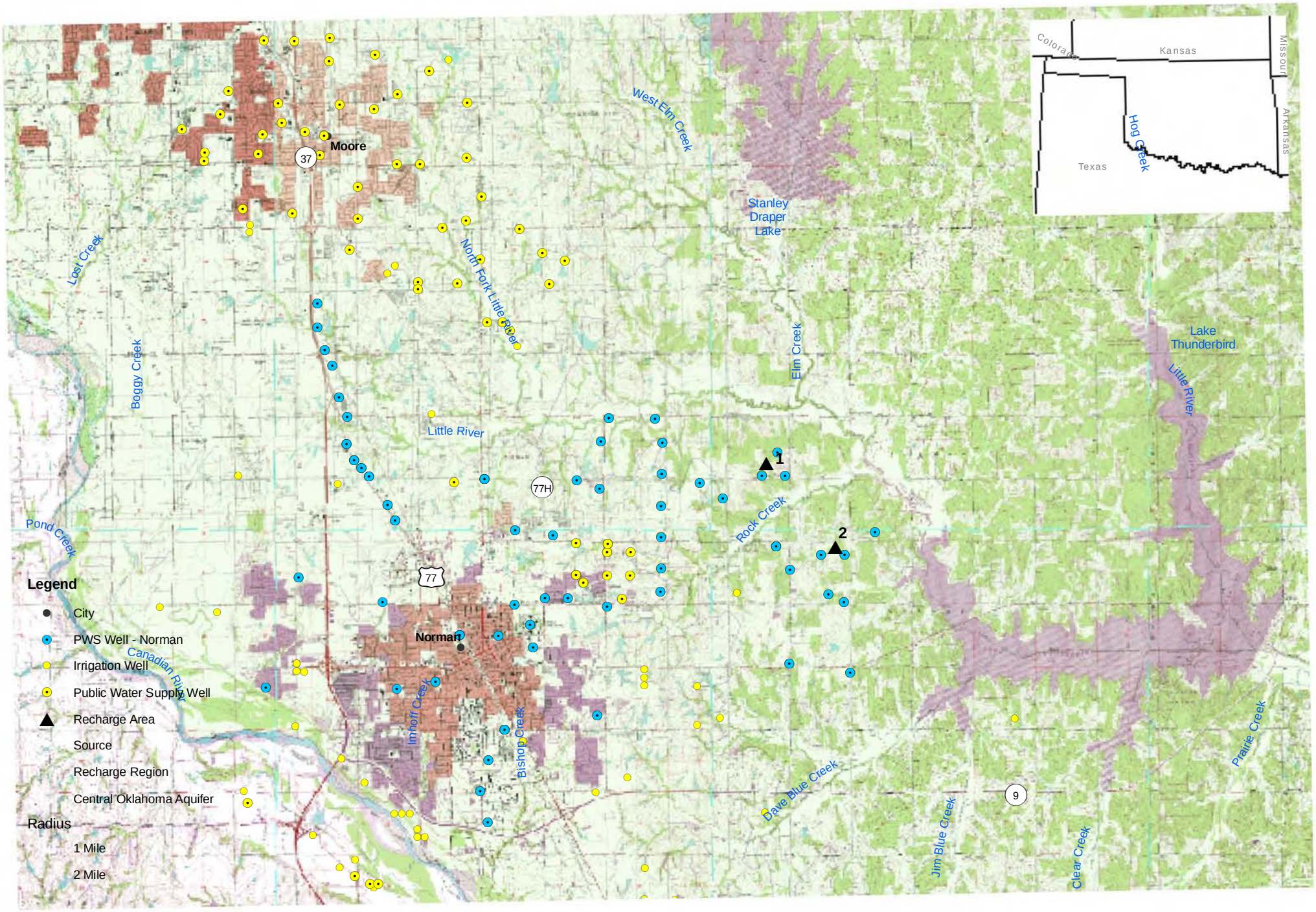

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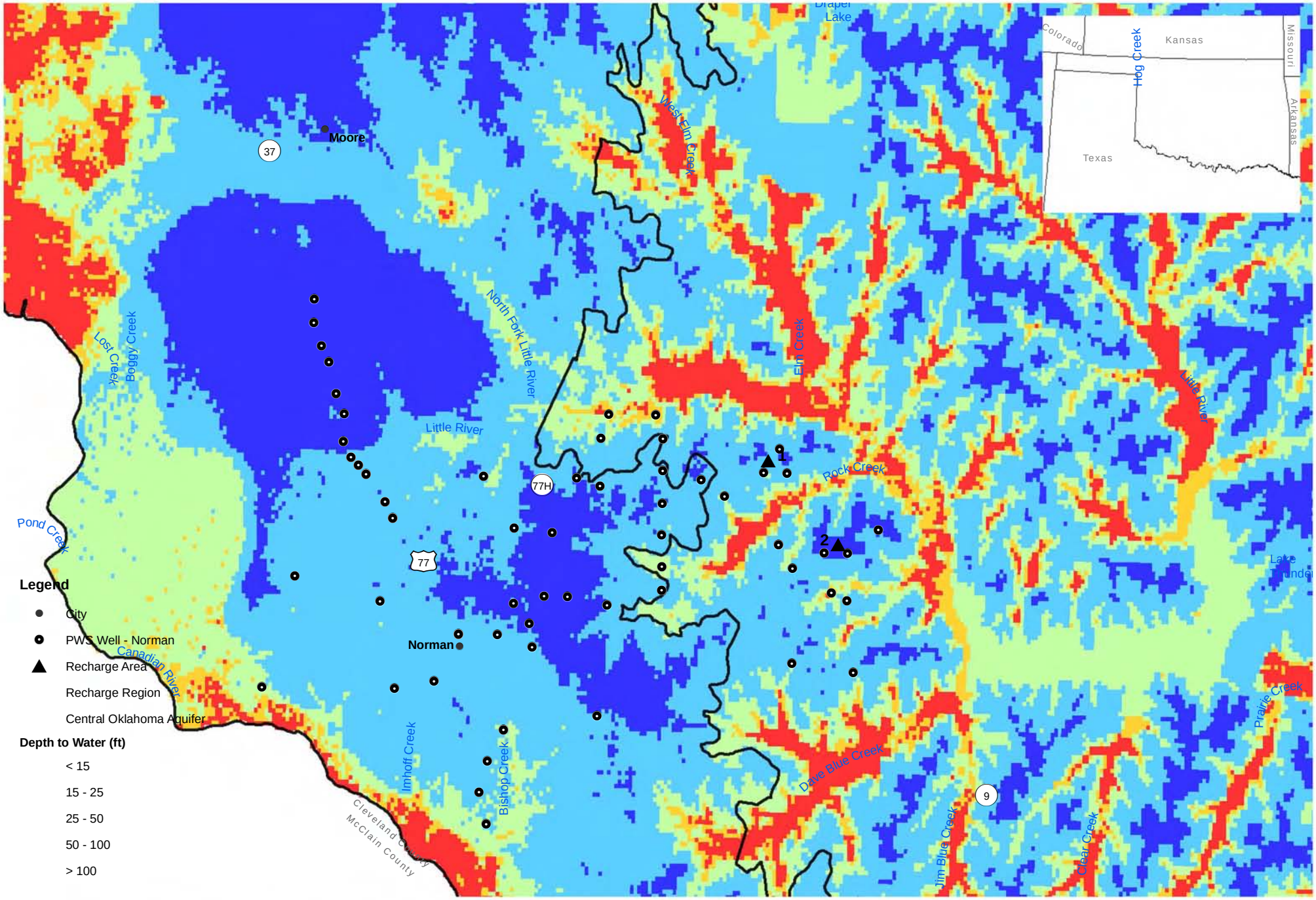
Miles

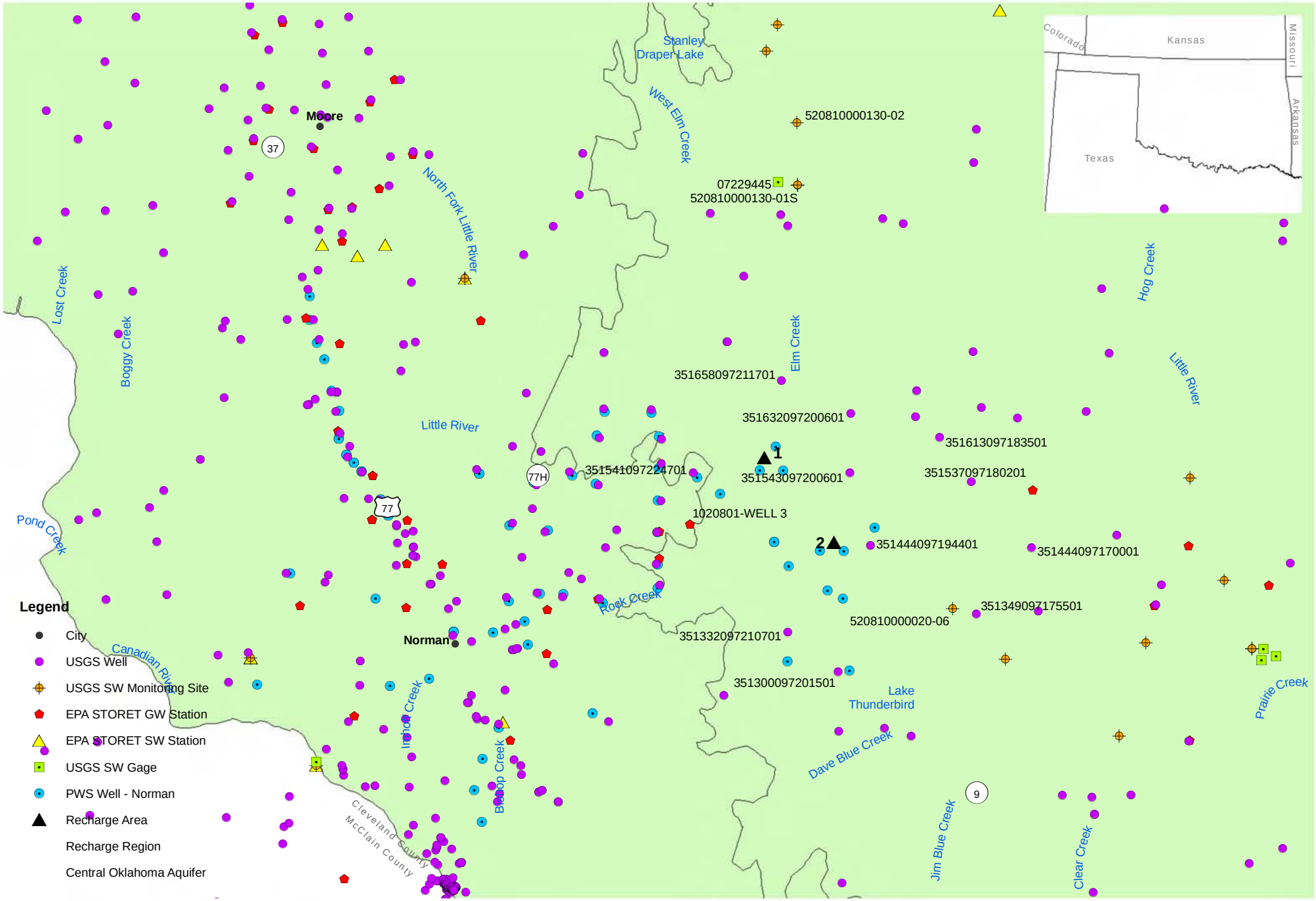
Site 8 Demand and Source Proximity

FIGURE D-1



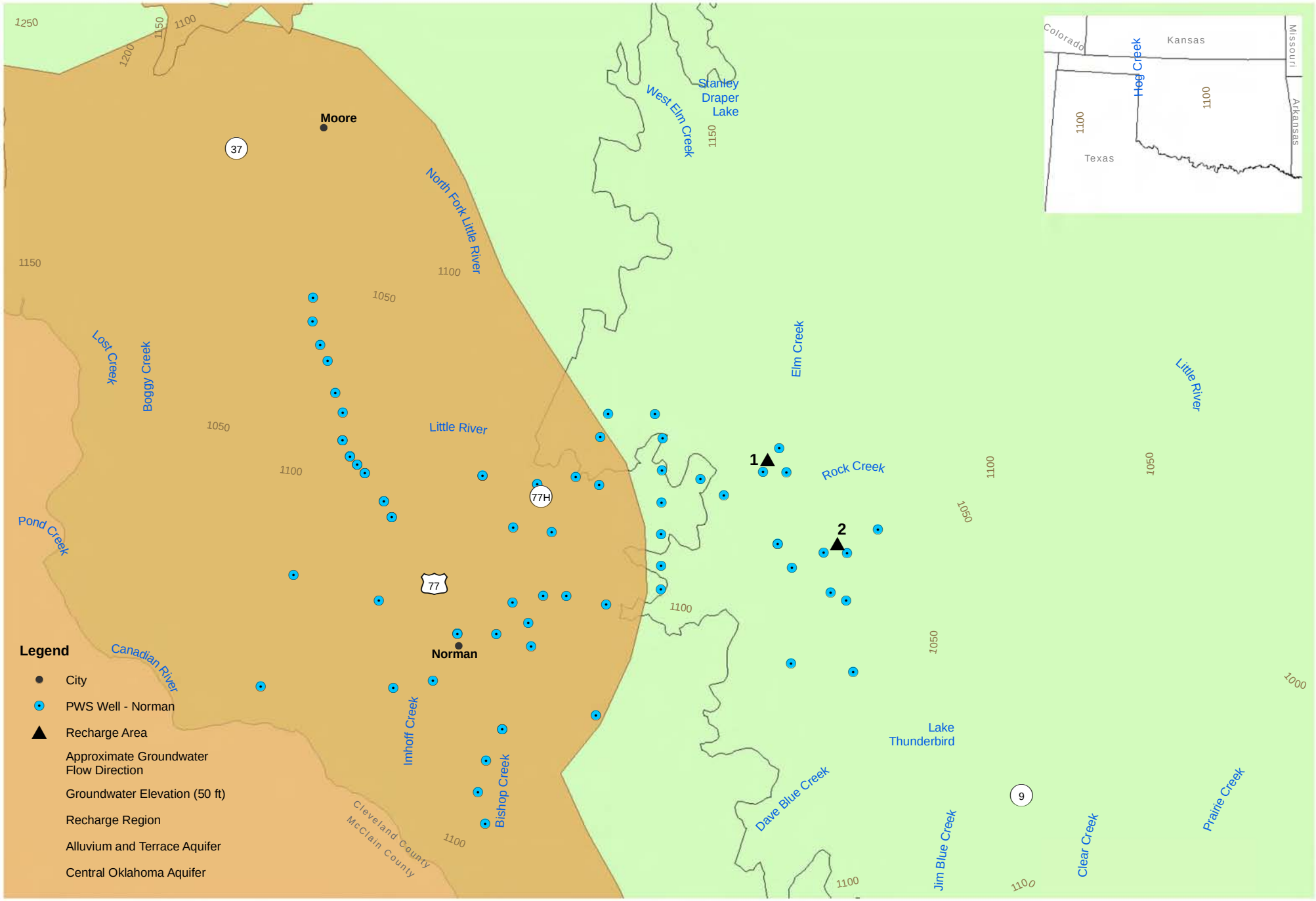
Site 8 Depth to Water

FIGURE D-2



Site 8 Surface and Groundwater Quality Sample Locations

FIGURE D-3



Site 8 Hydrogeology

FIGURE D-4

Appendix E
Detailed Analysis of Recharge Region Number 9, Vamoosa Ada Aquifer near Seminole

Appendix E - Recharge Region 9

Recharge Region 9 is located in the vicinity of the town of Seminole, with the Vamoosa Ada aquifer providing storage for an AR project. This Recharge Region was identified as a possible supplement to either the town of Seminole or Shawnee, although either town would be required to install wells in the vicinity to recover the stored water. According to the U.S. Census Bureau, the town of Seminole had an estimated population of approximately 6,804 individuals in 2008; year 2000 census data indicated 6,899 individuals (U.S. Census Bureau). The town of Shawnee had an estimated population of 30,562 individuals in 2008; year 2000 census data indicated 28,692 individuals (U.S. Census Bureau). For this recharge region, the demand location was identified as the town of Seminole, and the source for the potential recharge project was identified as the North Canadian River. One potential recharge area was identified based on the proximity to the town of Seminole and location of available freeboard in the aquifer. The potential recharge area was identified in the eastern portion of the recharge region (see Figure E-1).

1. Demand, Source, and Storage Considerations

The following table summarizes several aspects of the recharge area related to source water availability, local demand, ability of the source to meet the demand, and storage capacity. Proximity data is shown on Figure E-1, and available freeboard is shown on Figure E-2.

Source Basin	Basin 20510
Sufficient Legally Available Water for Pilot Project	Yes; conditionally available based on Canton Reservoir yield
Source Stream	North Canadian River. Probable point of diversion near confluence with Shan Creek
Nearest Gage	USGS 07241800, approximately 25 miles upstream of probable point of diversion. Period of record 2001 to 2008. No known major land use changes in the contributing basin since end of the period of record.
Gage POR and below average precipitation	4 years during the gage POR are below average precipitation years. 2003 selected as representative of approximately the 25th percentile of precipitation and occurred within the POR
Representative year flows (source availability)	Annual Flow: 196,054 AF
	Seasonal Distribution: Jan-Feb,Dec 26%; Mar-May 37%; Jun-Aug 18%; Sept-Nov 19%
Local Demand (Seminole)	Annual Total 6,800 AFY
Demand Density (PWS Wells)	0 wells within 1 mile radius, 0 wells within 2 mile radius. Indicates productive region of aquifer and storage capacity
Source availability as percent of pilot project demand (minimum of local demand or 1,000 AF*)	Annual basis: 100%
	Seasonally: Jan-Feb,Dec 100%; Mar-May 100%; Jun-Aug 100%; Sept-Nov 100%

Aquifer Storage Availability	Storativity = 0.0002
	313 square mile area (radius 10 miles) with 25 foot increase in water levels required. Storage capacity is insufficient to maintain at least 15 feet depth to water
	781 square mile area (radius 16 miles) with 10 foot increase in water levels. Storage capacity is insufficient to maintain at least 15 feet depth to water

Based on the availability of flows and the ability of those flows to meet the pilot project demands, the source water availability receives a **moderately high** score. This is due to the conditional availability based on Canton Reservoir.

The storage capacity requirement is greater than the available storage in the aquifer below the 15 foot threshold; therefore storage availability receives a **low** score.

Because the town of Seminole is greater than two miles from the recharge area, the demand proximity receives a **low** score.

Also, based on the number of wells (none) within one mile of the recharge area, demand density receives a **low** score.

The source of water identified for Recharge Region 9 is the North Canadian River. Recharge area 1 is located greater than two miles from the source, and thus receives a **low** score for source proximity.

2. Water Quality

Water quality analysis included the following criteria: source water quality for non-degradation; native groundwater quality; and groundwater geochemical interactions with source water. The following table presents water quality data for those parameters that have an MCL. The MCL was exceeded in at least one recharge area in the State if the parameter is listed. Parameters that did not have any samples collected for the Recharge Region are listed but do not display the min, max, and mean rows. Parameters in **bold** exceed the MCL.

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/Ponds
Aluminum	ug/L	200	#	12	0
			min	**300**	
			max	**300**	
			mean*	**300**	
Antimony	ug/L	6	#	0	
Arsenic	ug/L	10	#	0	0
Beryllium	ug/L	4	#	0	0
Cadmium	ug/L	5	#	0	0

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/Ponds
Chloride	mg/L	250**	#	20	0
			min	10	
			max	174	
			mean*	41	
Chlorine	mg/L	4	#	0	0
Chromium	ug/L	100	#	0	0
Fecal Coliform	cfu / 100 ml		#	0	16
			min		40
			max		300
			mean*		112
Iron	ug/L	300	#	12	0
			min	72	
			max	**606**	
			mean*	180	
Lead	ug/L	15	#	0	0
Manganese	ug/L	50	#	12	0
			min	8.0	
			max	22	
			mean*	14	
Mercury	ug/L	2	#	0	0
Nitrate / Nitrite+Nitrate (as N)	mg/L	10	#	12	18
			min	0.05	0.05
			max	0.10	2.7
			mean*	0.06	0.72
pH	SU	6.5-8.5**	#	18	18
			min	**5.4**	6.7
			max	8.0	**9.2**
			mean*	7.2	8.0
Selenium	ug/L	50	#	0	0
Sulfate	mg/L	250**	#	20	0
			min	11	
			max	180	
			mean*	31	
Thallium	ug/L	2	#	0	0
Total dissolved solids	mg/L	500**	#	28	18
			min	140	305
			max	**641**	**647**
			mean*	353	489
Toxaphene	ug/L	3	#	0	10
			min		0.03
			max		0.03
			mean*		0.03
*mean - geometric mean					
** Secondary MCL					

The following table presents the native groundwater quality and the source water quality, including general water quality parameters and water geochemistry factors.

Parameter	Units		Groundwater	Streams/Rivers/Ponds
Alkalinity	mg/L as CaCO3	#	20	0
		min	35	
		max	380	
		mean*	193	
Bicarbonate	mg/L	#	0	0
Calcium	mg/L	#	20	0
		min	12	
		max	71	
		mean*	49	
Carbonate	mg/L	#	0	18
		min		166
		max		316
		mean*		222
Chloride	mg/L	#	20	0
		min	10	
		max	174	
		mean*	41	
Fluoride	mg/L	#	20	0
		min	0.07	
		max	1.1	
		mean*	0.19	
Hardness	mg/L as CaCO3	#	8	0
		min	49	
		max	400	
		mean*	184	
Magnesium	mg/L	#	20	0
		min	4.5	
		max	67	
		mean*	19	
Nitrate / Nitrite+Nitrate (as N)	mg/L as N	#	12	18
		min	0.05	0.05
		max	0.10	2.7
		mean*	0.06	0.72
Nitrite (as N)	mg/L as N	#	0	18
		min		0.05
		max		0.37
		mean*		0.08
Orthophosphate	mg/L	#	0	18
		min		0.03
		max		0.93
		mean*		0.30
pH	SU	#	18	18
		min	5.4	6.7

Parameter	Units		Groundwater	Streams/Rivers/Ponds
		max	8.0	9.2
		mean*	7.2	8.0
Phosphorus	mg/L as P	#	0	0
Silica	mg/L as SiO2	#	8	0
		min	7.6	
		max	25	
		mean*	16	
Sulfate	mg/L	#	20	0
		min	11	
		max	180	
		mean*	31	
Temperature	deg C	#	2	18
		min	27	5.1
		max	27	25
		mean*	27	15
Total dissolved solids	mg/L	#	28	18
		min	140	305
		max	641	647
		mean*	353	489
Total suspended solids (TSS)	mg/L	#	0	0
Langelier's Saturation Index**	LSI	#	13	0
		min	-2.6	
		max	0.92	
		mean*	0.14	
*mean - geometric mean				
**Langelier's Index (LSI)				

In general, the source water quality appeared to be good. Nitrate and TDS concentrations were slightly higher in the source water than groundwater, but remained below MCLs. Thus, the source water quality received a **moderately high** score due to the slightly higher mean concentrations. The groundwater conditions also appear to be good, with minimal MCL exceedences. This resulted in a **moderately high** score for native groundwater quality.

Based on the Langelier's index, the groundwater geochemistry is near neutral for scaling and dissolution, indicating minimal geochemical instability that would impact AR operations. Source water sampling did not include all the parameters necessary to calculate the Langelier's index, and did not include hardness. The pH values for the source water are slightly higher, suggesting that the geochemical conditions may be slightly unbalanced between the source water and groundwater. Thus, the geochemical interaction criterion will receive a **moderately low** score, primarily due to the data gap for the Langelier's index and difference in pH.

3. Hydrogeologic Suitability

Hydrogeologic suitability of the Vamoosa Ada aquifer includes an evaluation of transmissivity, residence time, and general aquifer properties. The Vamoosa Ada aquifer is a confined sandstone aquifer in the immediate vicinity of the Recharge Region, although unconfined portions are located east of the Recharge Region. Groundwater flow in the vicinity of the Recharge Region generally travels in a northern direction, toward the North Canadian River, as indicated on Figure E-4. Major nearby alluvial systems are located primarily to the north of the Recharge Region along the North Canadian and its tributaries. The Vamoosa Ada aquifer likely contributes to these, as indicated by areas in red on Figure E-2. The following table provides a summary of aquifer properties and approximate residence time.

Parameter	**Value**	**Source**
Transmissivity	70 to 490 ft^2/day	AWI
Storativity	0.0002	AWI
Specific Yield	0.12	AWI
Well Yield	25 to 150 GPM	AWI
% of Recharge Lost in 180 Days	87	Glover
Number of Days Until 25% Loss	<10	Glover
Distance to Discharge	0.7 miles	N/A

Based on the aquifer properties, transmissivity received a **low** score.

Based on the Glover calculations and distance to alluvial systems, the residence time criterion received a **low** score.

4. Cost: Operation and Maintenance (O&M) and Capital

A table showing the primary cost considerations and whether they apply to the recharge region is presented below.

	Treatment – High TSS	Treatment - Other	Gravity Feed	Forcemain/ Pipeline	Injection Well - Available	Injection Well - Construct	Spreading Basin
Recharge area 1				X		X	

The relatively good water quality of the source water will require minimal treatment, if any, prior to injection into the aquifer. Due to the topography of the region, a force-main pipeline will be required to deliver water to the recharge project. The depth to water at the Recharge Region is prohibitive of a

spreading basin, and no wells exist in the vicinity. Thus, AR wells will need to be constructed for a pilot project. Based on these factors, the Recharge Region received a **low** score for capital cost. The O&M cost received a **moderate** score due to maintenance of the force-main and AR well(s).

5. Qualitative Considerations

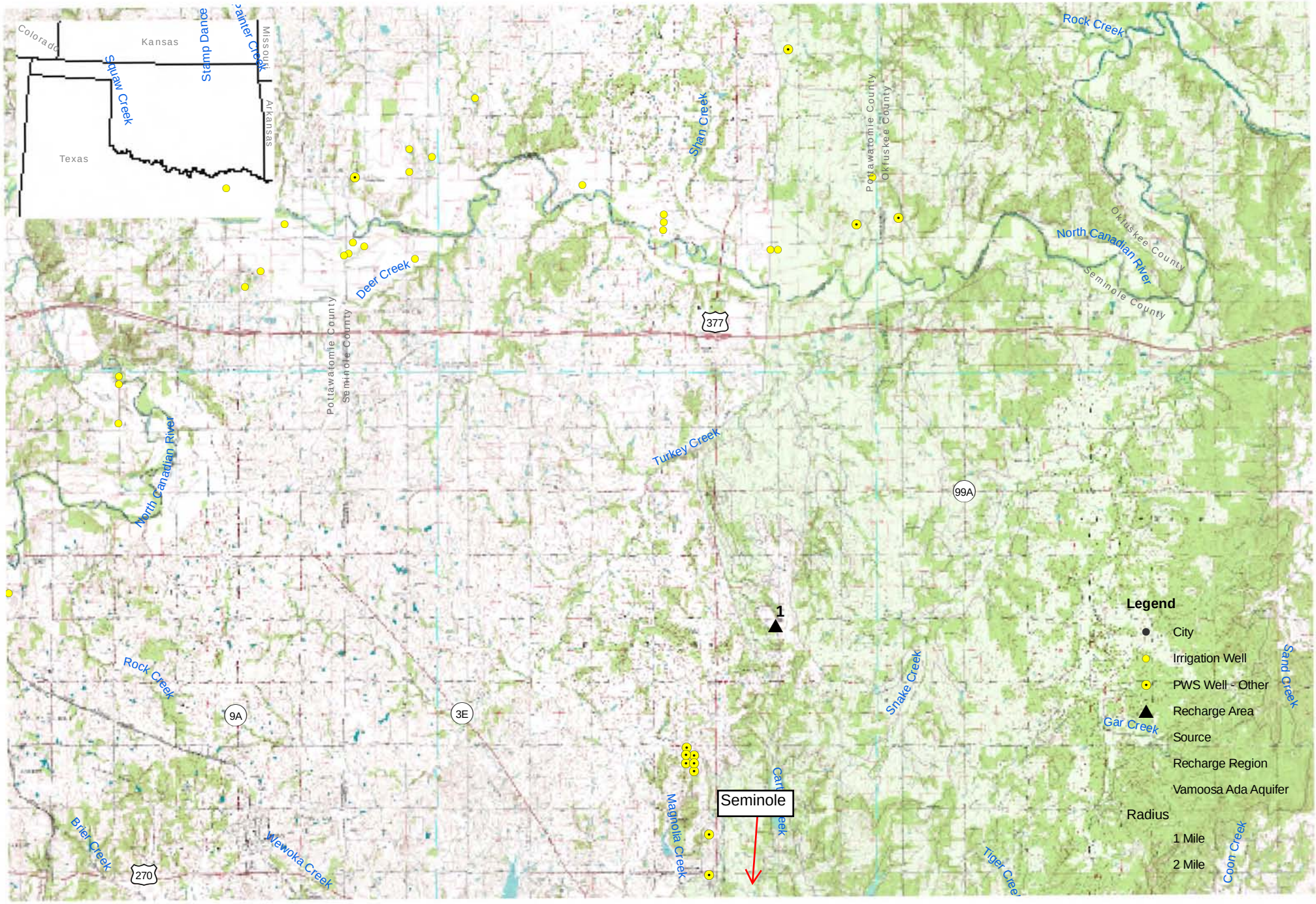
Based on the assumed project size of 1,000 acre-feet, 15 percent of the total demand will be met. Thus, qualitative considerations received a **moderately low** score.

6. Summary

The following table presents a summary of the scores and reasoning for assignment of those scores for Recharge Region 9.

Criterion	Score	Reasoning
Source Availability	Moderately high	Adequate flows; conditional availability of Canton Reservoir
Demand Proximity (distance from recharge area)	Low	Seminole > 2 miles
Source Proximity (distance from recharge area)	Low	North Canadian River > 2 miles
Available Freeboard and Ability to Meet Demand	Low	Not enough volume to meet recharged volume
Demand Density (number of wells)	Low	No wells within 1 mile
Source Quality for Non-degradation	Moderately High	Slightly higher TDS, nitrate in source water
Native Groundwater Quality	Moderately High	Minimal MCL exceedences
Geochemical Interactions of Source and Groundwater	Moderately Low	Langelier's not available for source; slightly higher pH in source water
Transmissivity	Low	Inadequate aquifer properties for AR
Residence Time	Low	87% loss within 180 days, <10 days to 25% loss

Cost (O&M)	Moderate	No pretreatment; operation of AR wells and pipeline
Cost (capital)	Low	Pipeline, install AR wells
Qualitative Considerations	Moderately low	15% of total demand



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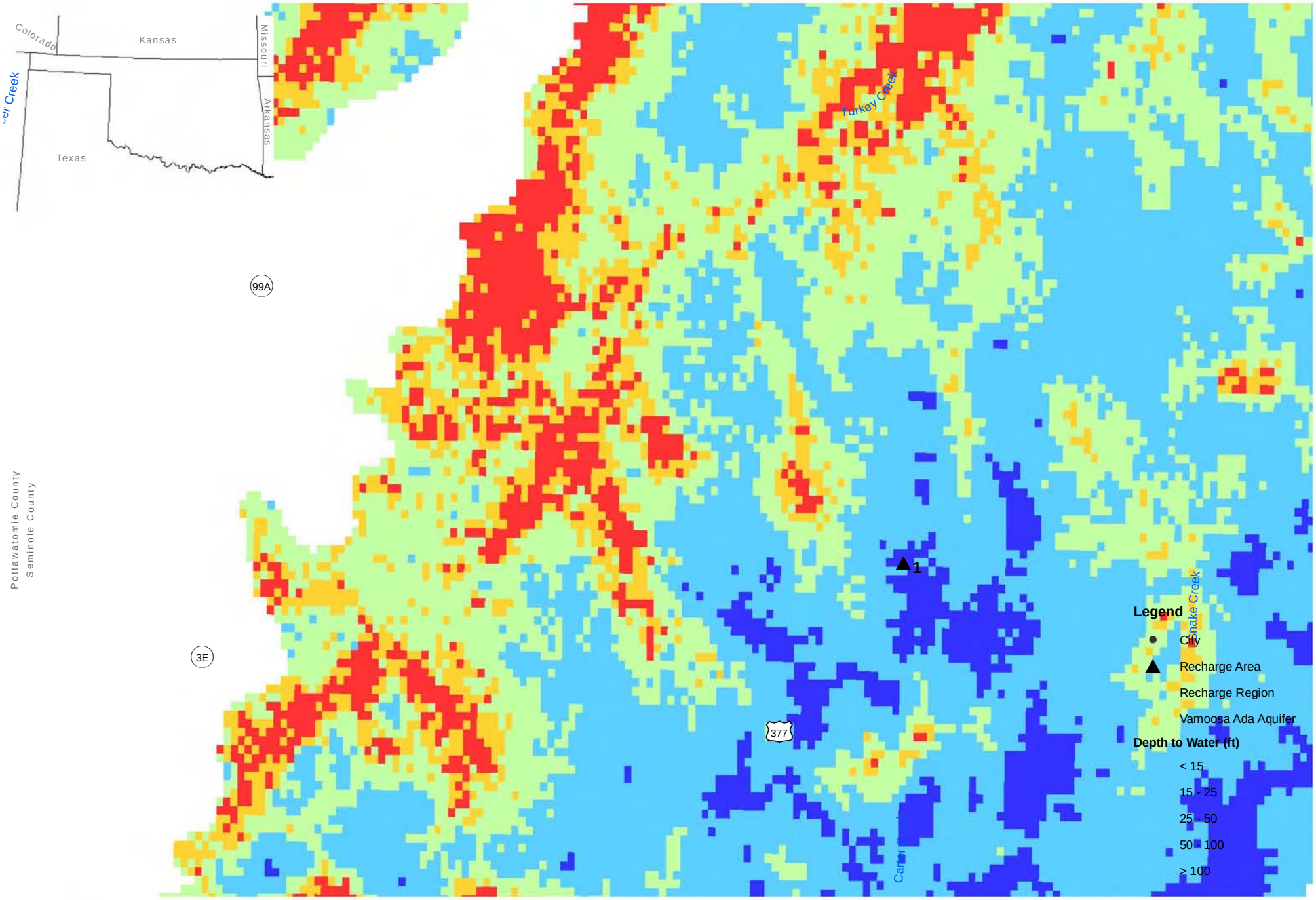
Site 9 Demand and Source Proximity

FIGURE E-1



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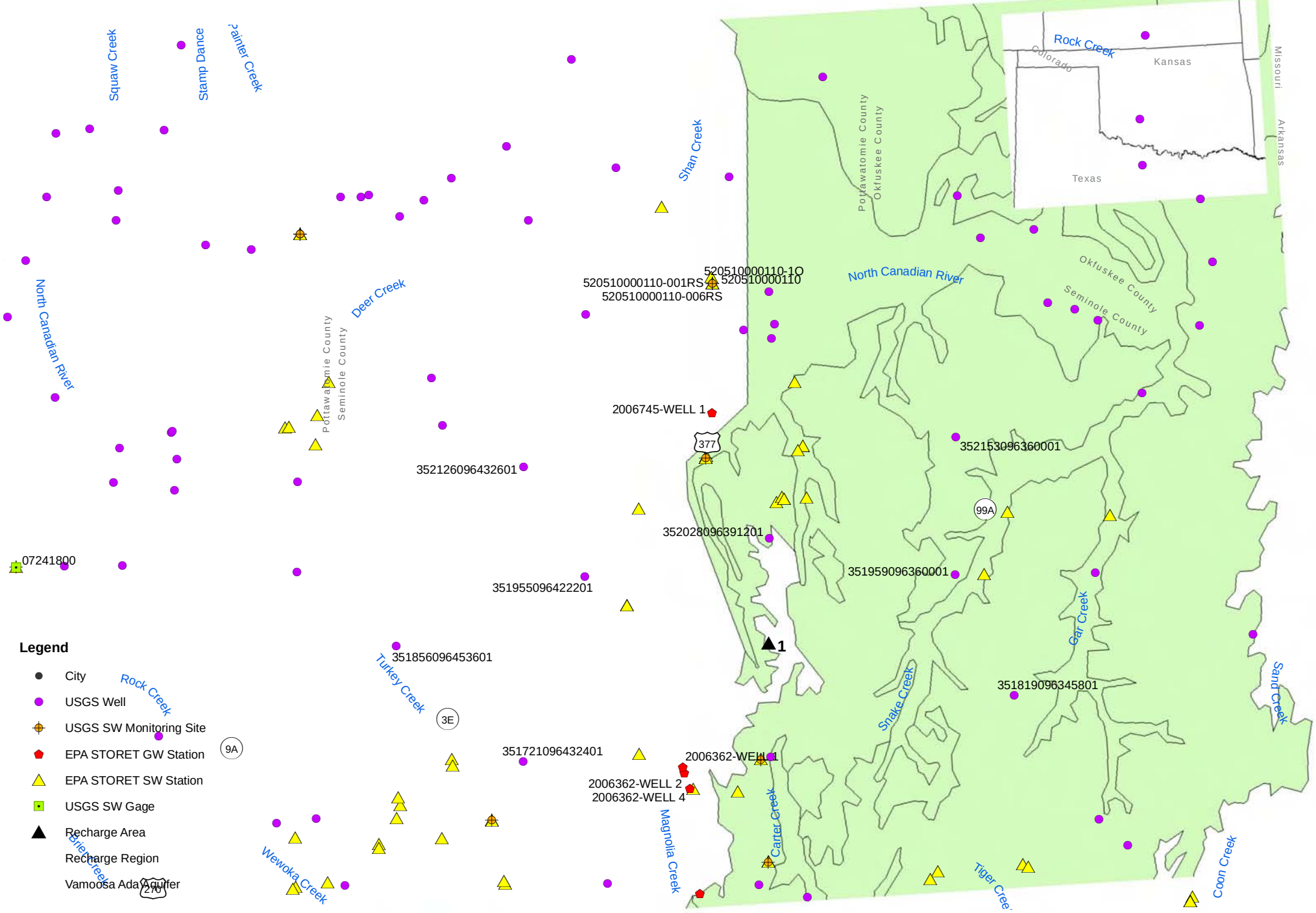
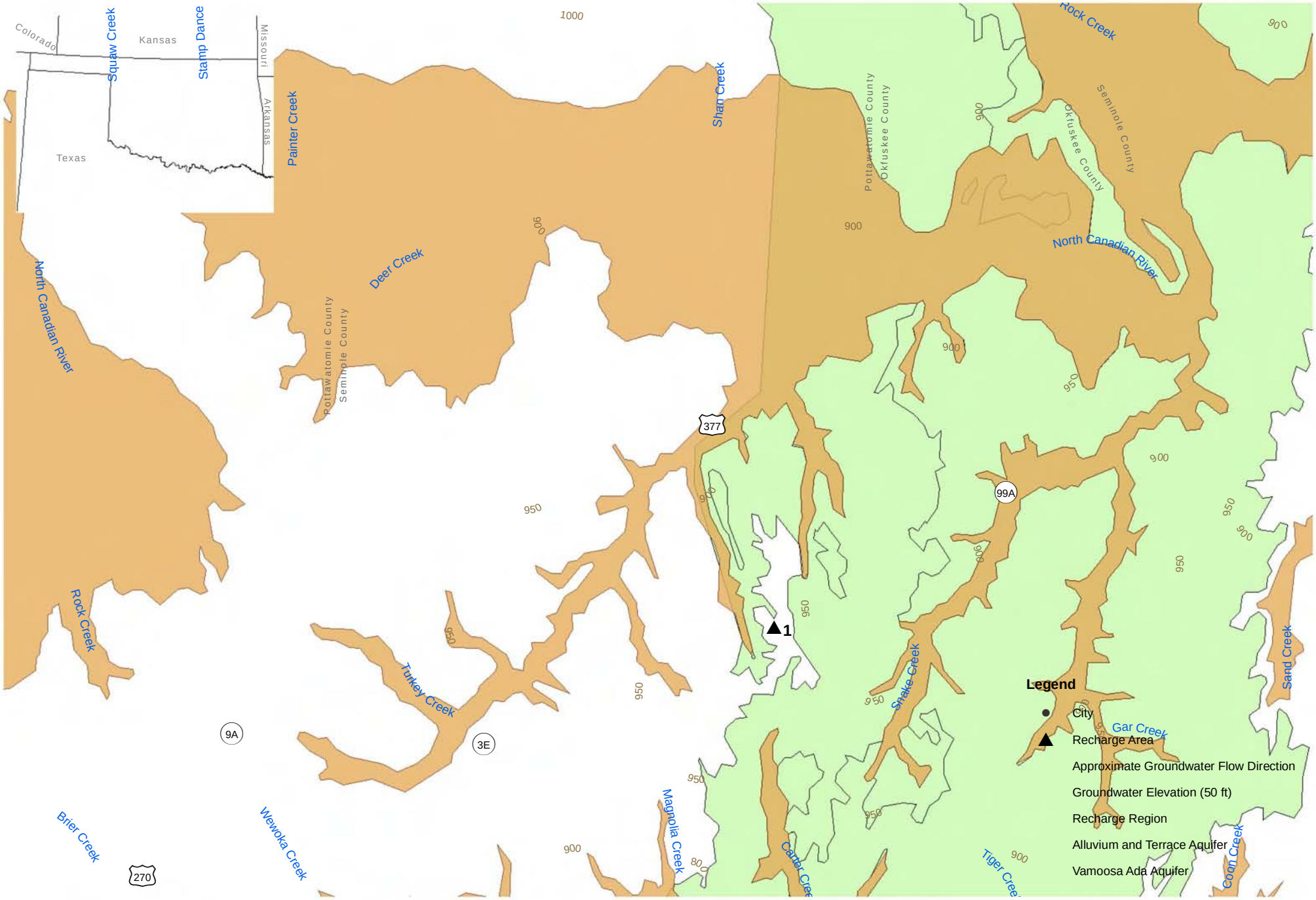
Site 9 Depth to Water

FIGURE E-2



Site 9 Surface and Groundwater Quality Sample Locations

FIGURE E-3



Site 9 Hydrogeology

FIGURE E-4

Appendix F
Detailed Analysis of Recharge Region Number 12, Arbuckle Simpson Aquifer near Ada

Appendix F - Recharge Region 12

Recharge Region 12 is located in the vicinity of the town of Ada, with the Arbuckle Simpson aquifer providing storage for an AR project. According to the U.S. Census Bureau, the town of Ada had an estimated population of approximately 16,729 individuals in 2008; year 2000 census data indicated 15,691 individuals (U.S. Census Bureau). For this recharge region, the demand location was identified as the PWS wells for the town of Ada, and the source for the potential recharge project was identified as Blue River. One potential recharge area was identified based on proximity to the source and demand, and the available freeboard in the aquifer. The recharge area is located in the southeast portion of the recharge region (see Figure F-1).

1. Demand, Source, and Storage Considerations

The following table summarizes several aspects of the recharge area related to source water availability, local demand, ability of the source to meet the demand, and storage capacity. Proximity data is shown on Figure F-1, and available freeboard is shown on Figure F-2.

Source Basin	Basin 10602
Sufficient Legally Available Water for Pilot Project	Yes
Source Stream	Blue River. Probable point of diversion approximately 1 mile northwest of recharge area
Nearest Gage	USGS 07332390, approximately 17 miles downstream of probable point of diversion. Period of record 1976 to 1979; 2003 to 2010. No known major land use changes in the contributing basin since end of the period of record.
Gage POR and below average precipitation	7 years during the gage POR are below average precipitation years. 2005 selected as representative of approximately the 25th percentile of precipitation and occurred within the POR
Representative year flows (source availability)	Annual Flow: 67,400 AF
	Seasonal Distribution: Jan-Feb,Dec 50%; Mar-May 23%; Jun-Aug 15%; Sept-Nov 11%
Local Demand (Ada)	Annual Total 25,000 AFY
Demand Density (PWS Wells)	5 wells within 1 mile radius, 1 well within 2 mile radius. Indicates productive region of aquifer and storage capacity
Source availability as percent of pilot project demand (minimum of local demand or 1,000 AF*)	Annual basis: 100%
	Seasonally: Jan-Feb,Dec 100%; Mar-May 100%; Jun-Aug 100%; Sept-Nov 100%
Aquifer Storage Availability	Specific Yield = 0.2
	0.3 square mile area (radius 0.3 miles) with 25 foot increase in water levels required. Storage capacity is sufficient while maintaining at least 15 feet depth to water

	0.8 square mile area (radius 0.5 miles) with 10 foot increase in water levels. Storage capacity is sufficient while maintaining at least 15 feet depth to water

Based on the availability of flows and the ability of those flows to meet the pilot project demands, the source water availability receives a **moderate** score. This is due to the gage location.

The storage capacity requirement is less than the available storage in the aquifer below the 15 foot threshold; therefore storage availability receives a **high** score.

Based on the location of wells in close proximity to the recharge area, the demand proximity receives a **high** score.

Also, based on the number of wells (five) within one mile of the recharge area, demand density receives a **moderate** score.

The source of water identified for Recharge Region 12 is Blue River. Recharge area 1 is located approximately one mile from the source, and thus receives a **moderately high** score for source proximity.

2. Water Quality

Water quality analysis included the following criteria: source water quality for non-degradation; native groundwater quality; and groundwater geochemical interactions with source water. The following table presents water quality data for those parameters that have an MCL. The MCL was exceeded in at least one recharge area in the State if the parameter is listed. Parameters that did not have any samples collected for the Recharge Region are listed but do not display the min, max, and mean rows. Parameters in **bold** exceed the MCL.

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/Ponds	Gage # 07334200
Aluminum	ug/L	200	#	10	0	1
			min	1.6		1.6
			max	**300**		1.6
			mean*	94		1.6
Antimony	ug/L	6	#	2	0	1
			min	0.20		0.20
			max	0.20		0.20
			mean*	0.20		0.20
Arsenic	ug/L	10	#	3	0	17
			min	0.20		0.45
			max	1.0		1.0
			mean*	0.34		0.95
Beryllium	ug/L	4	#	4	0	16
			min	0.06		0.06

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/Ponds	Gage # 07334200
			max	0.50		0.50
			mean*	0.17		0.44
Cadmium	ug/L	5	**#**	5	0	16
			min	0.03		0.02
			max	2.0		1.0
			mean*	0.30		0.78
Chloride	mg/L	250**	**#**	14	0	18
			min	1.9		3.8
			max	44		47
			mean*	8.0		6.4
Chlorine	mg/L	4	**#**	0	0	0
Chromium	ug/L	100	**#**	4	0	16
			min	0.80		0.13
			max	5.0		6.0
			mean*	2.0		4.0
Fecal Coliform	cfu / 100 ml		**#**	0	0	0
Iron	ug/L	300	**#**	13	0	16
			min	3.0		3.0
			max	63		18
			mean*	16		4.9
Lead	ug/L	15	**#**	4	0	16
			min	0.19		0.08
			max	10		10
			mean*	1.4		7.4
Manganese	ug/L	50	**#**	11	0	16
			min	0.20		0.10
			max	5.0		9.0
			mean*	2.7		1.2
Mercury	ug/L	2	**#**	1	0	16
			min	0.10		0.10
			max	0.10		0.40
			mean*	0.10		0.11
Nitrate / Nitrite+Nitrate (as N)	mg/L	10	**#**	9	0	20
			min	0.05		0.63
			max	3.0		5.7
			mean*	0.73		1.2
pH	SU	6.5-8.5**	**#**	9	54	40
			min	**5.8**	**0**	6.5
			max	7.7	8.3	8.3
			mean*	7.2	7.7	7.3
Selenium	ug/L	50	**#**	2	0	17
			min	0.40		0.40
			max	0.40		2.0
			mean*	0.40		0.99

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/Ponds	Gage # 07334200
Sulfate	mg/L	250**	#	14	0	17
			min	5.5		7.3
			max	51		**940**
			mean*	12		12
Thallium	ug/L	2	#	2	0	1
			min	0.04		0.04
			max	0.04		0.04
			mean*	0.04		0.04
Total dissolved solids	mg/L	500**	#	21	54	32
			min	10	0	216
			max	**628**	382	**1520**
			mean*	266	222	352
Toxaphene	ug/L	3	#	0	0	0
*mean - geometric mean						
** Secondary MCL						

The following table presents the native groundwater quality and the source water quality, including general water quality parameters and water geochemistry factors.

Parameter	Units		Groundwater	Streams/Rivers/Ponds	Gage # 07334200
Alkalinity	mg/L as CaCO3	#	14	0	20
		min	10		254
		max	440		359
		mean*	205		327
Bicarbonate	mg/L	#	3	0	19
		min	390		364
		max	448		438
		mean*	415		404
Calcium	mg/L	#	14	0	18
		min	1.0		58
		max	130		84
		mean*	42		73
Carbonate	mg/L	#	1	0	19
		min	0		0
		max	0		0
		mean*	0		0
Chloride	mg/L	#	14	0	18
		min	1.9		3.8
		max	44		47
		mean*	8.0		6.4
Fluoride	mg/L	#	13	0	12

Parameter	Units		Groundwater	Streams/Rivers/Ponds	Gage # 07334200
		min	0		0.10
		max	0.16		0.20
		mean *	0.10		0.11
Hardness	mg/L as CaCO3	#	7	0	18
		min	310		300
		max	620		340
		mean *	420		328
Magnesium	mg/L	#	14	0	18
		min	1.0		29
		max	78		39
		mean *	26		35
Nitrate / Nitrite+Nitrate (as N)	mg/L as N	#	9	0	20
		min	0.05		0.63
		max	3.0		5.7
		mean *	0.73		1.2
Nitrite (as N)	mg/L as N	#	2	0	14
		min	0.01		0.01
		max	0.01		0.03
		mean *	0.01		0.01
Orthophosphate	mg/L	#	0	0	0
pH	SU	#	9	54	40
		min	5.8	0	6.5
		max	7.7	8.3	8.3
		mean *	7.2	7.7	7.3
Phosphorus	mg/L as P	#	0	0	0
Silica	mg/L as SiO2	#	5	0	16
		min	8.8		10
		max	13		12
		mean *	10		11
Sulfate	mg/L	#	14	0	17
		min	5.5		7.3
		max	51		940
		mean *	12		12
Temperature	deg C	#	4	54	42
		min	10	0	5.0
		max	19	18	22
		mean *	16	10	17
Total dissolved solids	mg/L	#	21	54	32
		min	10	0	216

Parameter	Units		Groundwater	Streams/Rivers/Ponds	Gage # 07334200
		max	628	382	1520
		mean *	266	222	352
Total suspended solids (TSS)	mg/L	#	0	0	0
Langelier's Saturation Index**	LSI	#	7	0	16
		min	-0.48		-0.60
		max	1.3		0.20
		mean *	0.21		-0.10
*mean - geometric mean					
**Langelier's Index (LSI)					

In general, the source water quality appeared to be very good, with similar concentrations as groundwater, and minimal exceedences. TDS concentrations were slightly higher than those in groundwater, but the mean was below MCL. Thus, the source water quality received a **moderately high** score. The groundwater conditions appear to be very good, with only the TDS maximum exceeding the MCL. This resulted in a **high** score for native groundwater quality.

Based on the Langelier's index, the groundwater and source water geochemistry is near neutral for scaling and dissolution, indicating minimal geochemical instability that would impact AR operations. Thus, the geochemical interaction criterion receives a **high** score.

3. Hydrogeologic Suitability

Hydrogeologic suitability of the Arbuckle Simpson aquifer includes an evaluation of transmissivity, residence time, and general aquifer properties. The Arbuckle Simpson aquifer is a carbonate/karst aquifer that is presumably unconfined in the immediate vicinity of the Recharge Region. Groundwater flow in the vicinity of the Recharge Region is anticipated to be generally to the west, toward the local stream system. There are no major nearby alluvial systems, although minor alluvial systems may be located on Blue River.

Parameter	Value	Source
Transmissivity	15,000 ft^2/day	AWI
Specific Yield	0.2	AWI
Well Yield	100 to 500 GPM	AWI
% of Recharge Lost in 180 Days	0	Glover
Number of Days Until 25% Loss	>1,680 days	Glover
Distance to Discharge	3.5 miles	N/A

Based on the aquifer properties, transmissivity received a **high** score.

Based on the Glover calculations, the residence time criterion received a **high** score.

4. Cost: Operation and Maintenance (O&M) and Capital

A table showing the primary cost considerations and whether they apply to a recharge area is presented below.

	Treatment – High TSS	Treatment - Other	Gravity Feed	Forcemain/ Pipeline	Injection Well - Available	Injection Well - Construct	Spreading Basin
Recharge Area 1				X	X		

The relatively good water quality of the source water will require minimal treatment, if any, prior to injection into the aquifer. Due to the topography of the region, a force-main pipeline will be required to deliver water to the recharge project. The depth to water at the Recharge Region is prohibitive of a spreading basin, although the existing PWS wells in the vicinity may be usable for AR. Based on these factors, the Recharge Region received a **moderate** score for capital cost. The O&M cost received a **moderate** score due to maintenance of the force-main and AR well(s).

5. Qualitative Considerations

Based on the assumed project size of 1,000 acre-feet, four percent of the total demand will be met. Thus, qualitative considerations received a **low** score.

6. Summary

The following table presents a summary of the scores and reasoning for assignment of those scores for Recharge Region 12.

Criterion	Score	Reasoning
Source Availability	Moderate	Adequate flows, but gage located 17 miles downstream
Demand Proximity (distance from recharge area)	High	PWS wells within 1 mile
Source Proximity (distance from recharge area)	Moderately high	Blue River = 1 mile

Available Freeboard and Ability to Meet Demand	High	Plentiful volume to meet recharged volume
Demand Density (number of wells)	Moderate	5 wells within 1 mile
Source Quality for Non-degradation	Moderately High	Minimal MCL exceedences, slightly higher TDS
Native Groundwater Quality	High	Low TDS, minimal MCL exceedences
Geochemical Interactions of Source and Groundwater	High	Near neutral Langelier's for source and groundwater
Transmissivity	High	Good aquifer properties for AR
Residence Time	High	No losses within 180 days, >1,680 days to 25% loss
Cost (O&M)	Moderate	No pretreatment; operation of AR wells and pipeline
Cost (capital)	Moderate	Pipeline, retrofit AR wells
Qualitative Considerations	Low	4% of total demand

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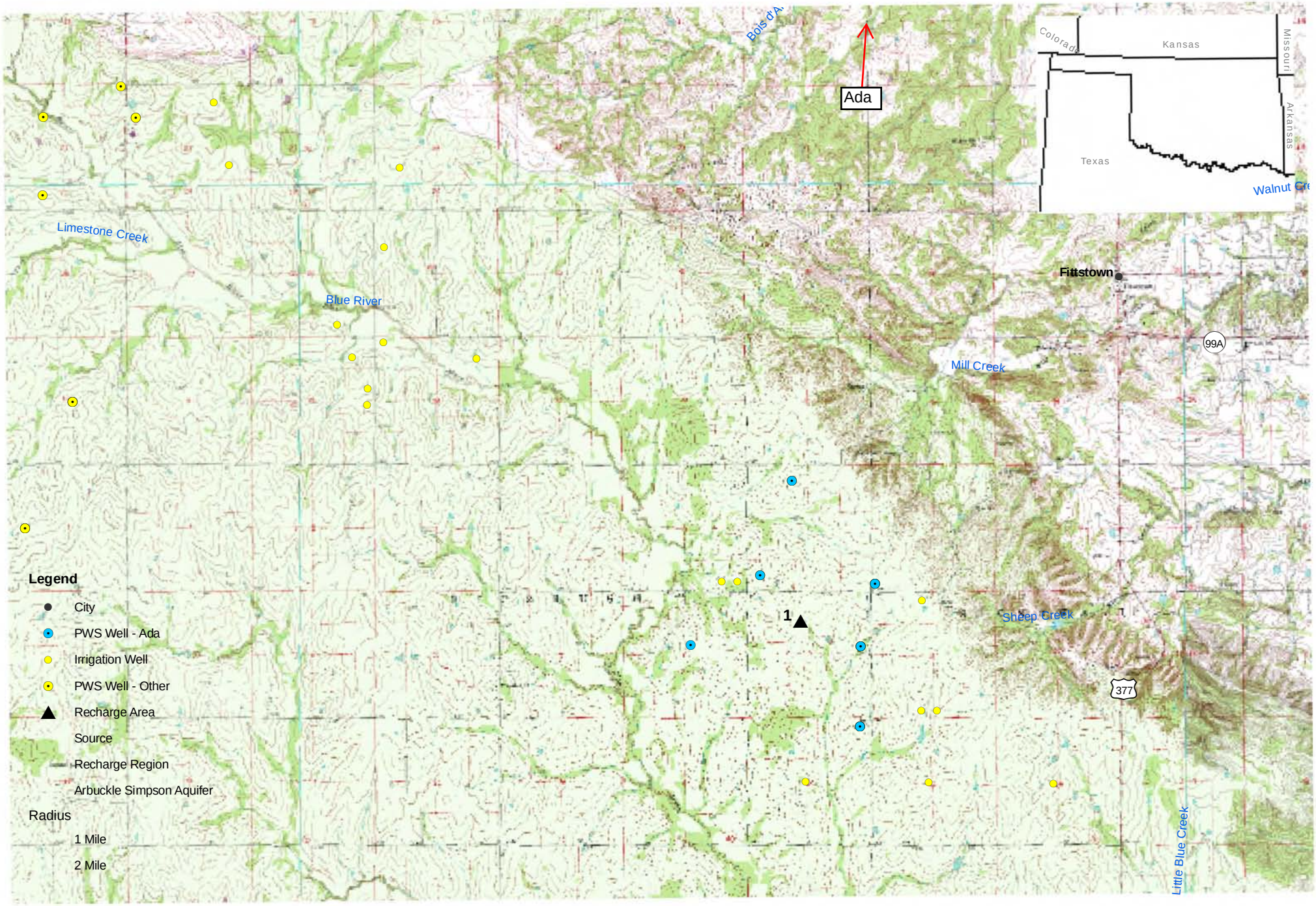

N
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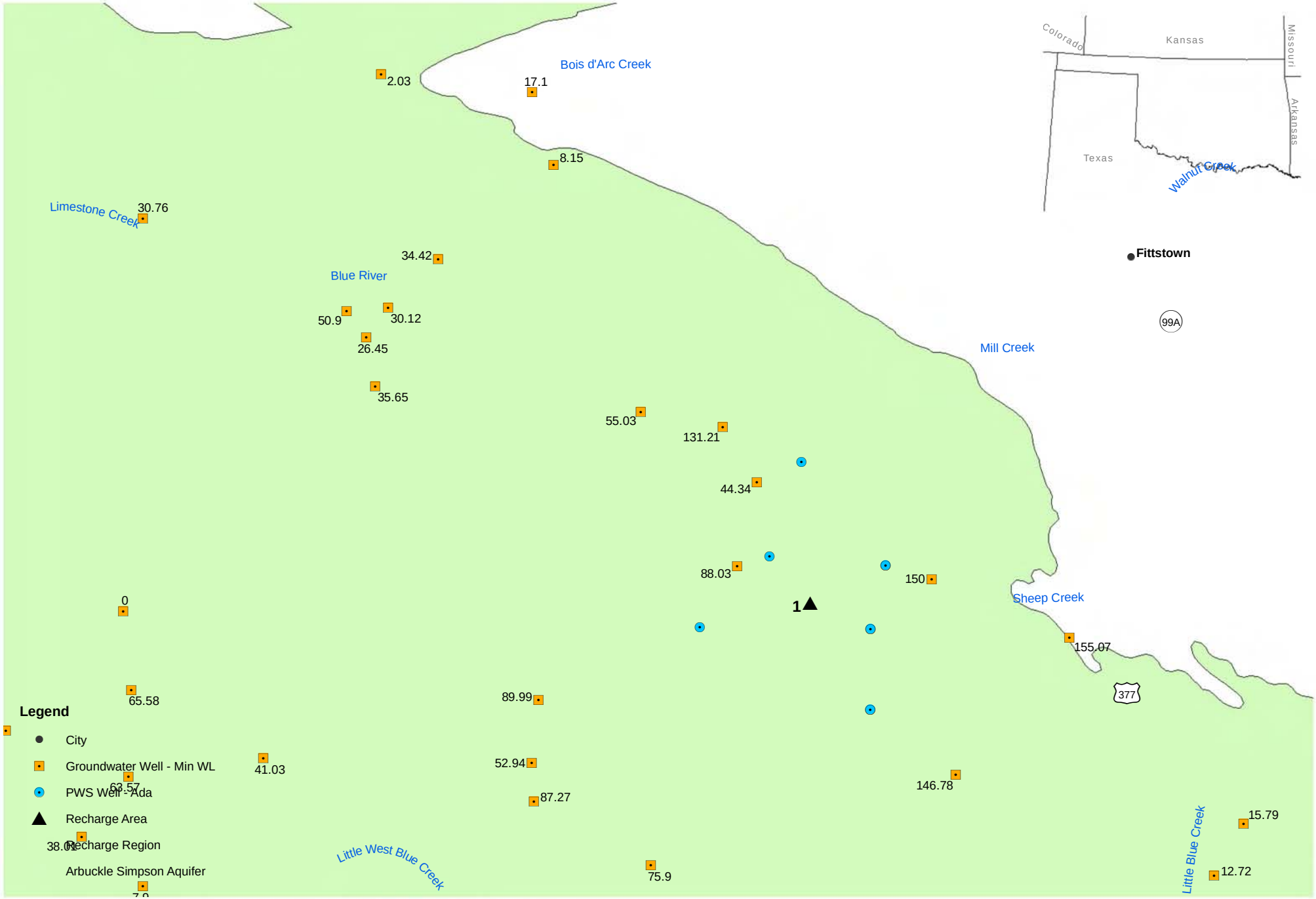
0 0.5 1 2
Miles

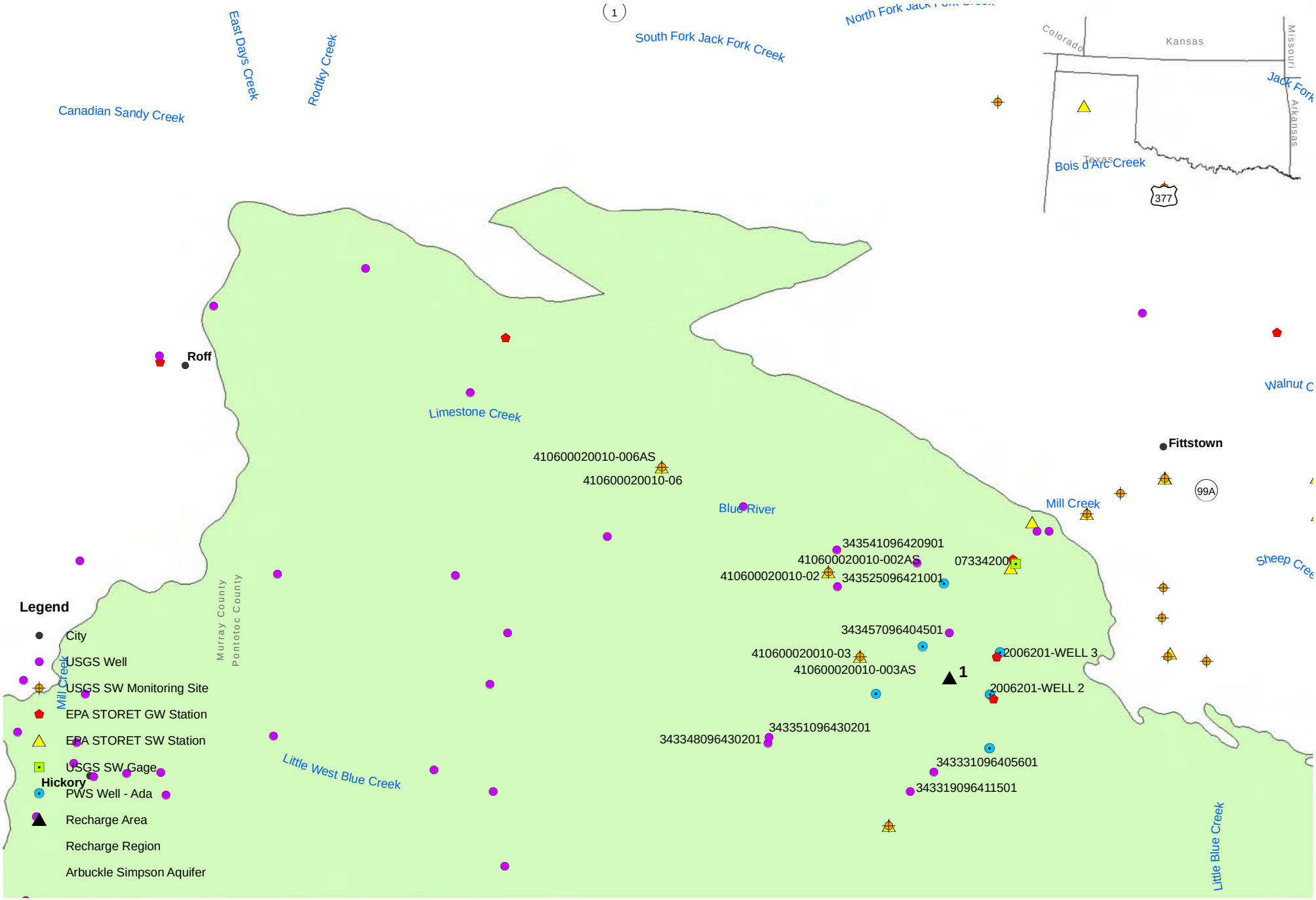
Site 12 Demand and Source Proximity

FIGURE F-1



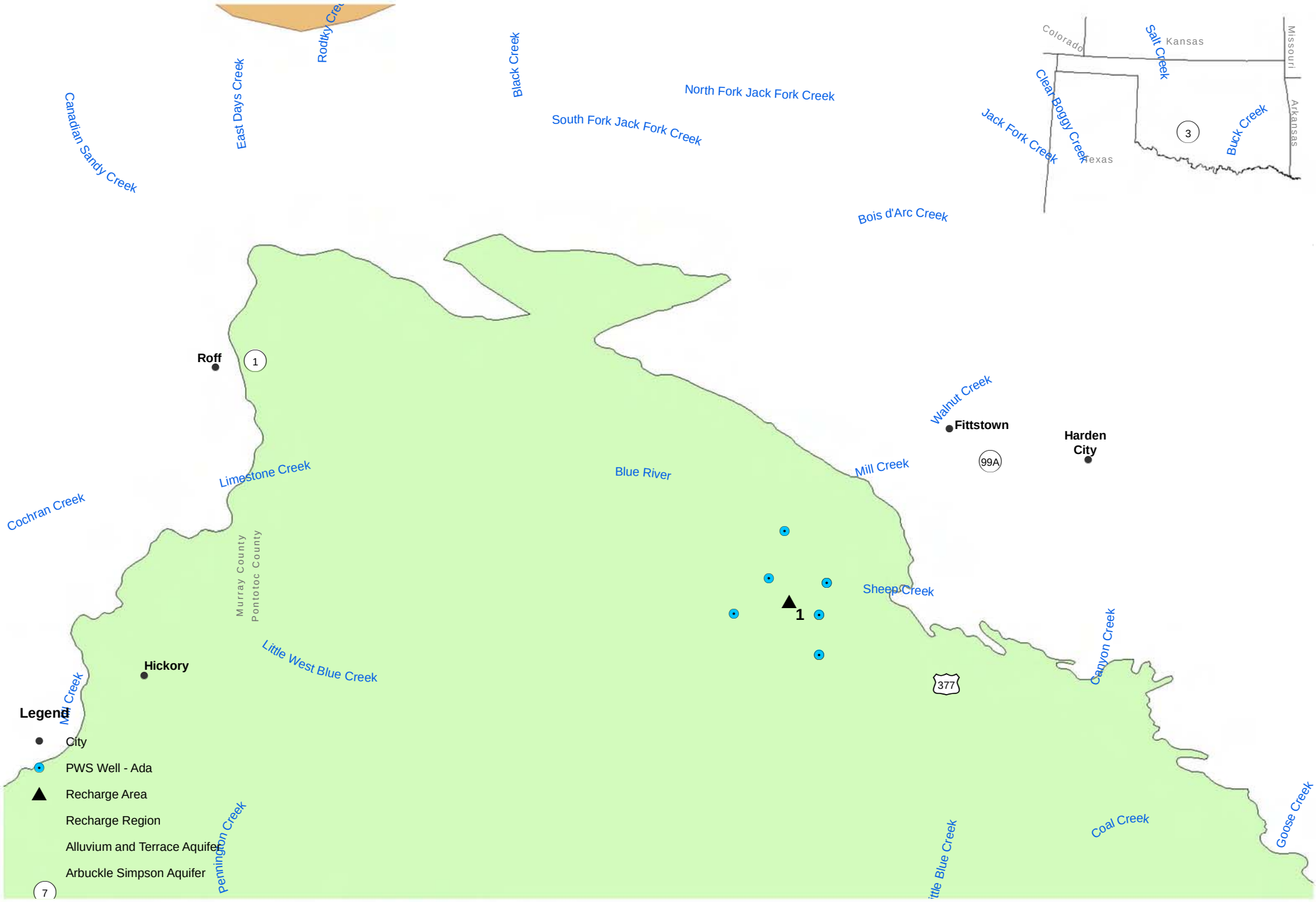
Site 12 Depth to Water

FIGURE F-2



Site 12 Surface and Groundwater Quality Sample Locations

FIGURE F-3



Site 12 Hydrogeology

FIGURE F-4

Appendix G
Detailed Analysis of Recharge Region Number 14, Antlers Aquifer near Durant

Appendix G - Recharge Region 15

Recharge Region 15 is located in the vicinity of the town of Durant, with the Antlers aquifer providing storage for an AR project. This Recharge Region was identified as a possible supplement to the town of Durant, although the town would be required to install wells in the vicinity to recover the stored water. According to the U.S. Census Bureau, the town of Durant had an estimated population of approximately 16,450 individuals in 2008; year 2000 census data indicated 13,549 individuals (U.S. Census Bureau). For this recharge region, the demand location was identified as the town of Durant, and the source for the potential recharge project was identified as Blue River. One potential recharge area was identified within this recharge region based on the available freeboard in the aquifer, and proximity to the source and demand. The potential recharge area is located in the northwestern portion of the recharge region (see Figure G-1).

1. Demand, Source, and Storage Considerations

The following table summarizes several aspects of the recharge area related to source water availability, local demand, ability of the source to meet the demand, and storage capacity. Proximity data is shown on Figure G-1, and available freeboard is shown on Figure G-2.

Source Basin	Basin 10700
Sufficient Legally Available Water for Pilot Project	Yes
Source Stream	Blue River. Probable point of diversion near confluence with Thompson Creek
Nearest Gage	USGS 07332500, approximately 8 miles downstream of probable point of diversion. Period of record 1936 to 2008. No known major land use changes in the contributing basin since end of the period of record. Possible restraints at low flow.
Gage POR and below average precipitation	34 years during the gage POR are below average precipitation years. 2005 selected as representative of approximately the 25th percentile of precipitation and occurred within the POR
Representative year flows (source availability)	Annual Flow: 122,856 AF
	Seasonal Distribution: Jan-Feb,Dec 61%; Mar-May 21%; Jun-Aug 12%; Sept-Nov 5%
Local Demand (Durant)	Annual Total 15,545 AFY
Demand Density (PWS Wells)	0 wells within 1 mile radius, 0 wells within 2 mile radius.
Source availability as percent of pilot project demand (minimum of local demand or 1,000 AF*)	Annual basis: 100%
	Seasonally: Jan-Feb,Dec 100%; Mar-May 100%; Jun-Aug 50%; Sept-Nov 50%

Aquifer Storage Availability	Specific Yield = 0.21
	0.3 square mile area (radius 0.3 miles) with 25 foot increase in water levels required. Storage capacity is sufficient while maintaining at least 15 feet depth to water
	0.7 square mile area (radius 0.5 miles) with 10 foot increase in water levels. Storage capacity is sufficient while maintaining at least 15 feet depth to water

Based on the availability of flows and the ability of those flows to meet the pilot project demands, the source water availability receives a **moderate** score. This is due to the gage location.

The storage capacity requirement is less than the available storage in the aquifer below the 15 foot threshold; therefore storage availability receives a **high** score.

Based on the location of the town of Durant approximately 2 miles from the recharge area, the demand proximity receives a **moderately low** score.

Also, based on the number of wells (none) within one mile of the recharge area, demand density receives a **low** score.

The source of water identified for Recharge Region 15 is Blue River. Recharge area 1 is located approximately two miles from the source, and thus receives a **moderately low** score for source proximity.

2. Water Quality

Water quality analysis included the following criteria: source water quality for non-degradation; native groundwater quality; and groundwater geochemical interactions with source water. The following table presents water quality data for those parameters that have an MCL. The MCL was exceeded in at least one recharge area in the State if the parameter is listed. Parameters that did not have any samples collected for the Recharge Region are listed but do not display the min, max, and mean rows. Parameters in **bold** exceed the MCL.

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/Ponds
Aluminum	ug/L	200	#	2	0
			min	**300**	
			max	**300**	
			mean*	**300**	
Antimony	ug/L	6	#	0	0
Arsenic	ug/L	10	#	2	22
			min	1.0	10
			max	1.0	10
			mean*	1.0	10
Beryllium	ug/L	4	#	0	0

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/Ponds
Cadmium	ug/L	5	#	0	22
			min		1.0
			max		5.0
			mean*		2.8
Chloride	mg/L	250**	#	2	140
			min	35	0
			max	40	63
			mean*	38	6.7
Chlorine	mg/L	4	#	0	1
			min		**14**
			max		**14**
			mean*		**14**
Chromium	ug/L	100	#	0	22
			min		5.0
			max		11
			mean*		7.4
Fecal Coliform	cfu / 100 ml		#	0	36
			min		10
			max		5000
			mean*		94
Iron	ug/L	300	#	4	0
			min	10	
			max	90	
			mean*	27	
Lead	ug/L	15	#	1	28
			min	2.0	3.0
			max	2.0	10
			mean*	2.0	5.8
Manganese	ug/L	50	#	3	0
			min	5.0	
			max	10	
			mean*	6.3	
Mercury	ug/L	2	#	2	22
			min	0.50	0.05
			max	0.50	0.50
			mean*	0.50	0.26
Nitrate / Nitrite+Nitrate (as N)	mg/L	10	#	2	140
			min	0.05	0.05
			max	0.05	0.72
			mean*	0.05	0.11
pH	SU	6.5-8.5**	#	3	135
			min	**9.0**	**0**
			max	**9.3**	**9.2**
			mean*	**9.2**	7.8
Selenium	ug/L	50	#	2	22
			min	1.0	5.0

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/Ponds
			max	1.0	10
			mean*	1.0	5.7
Sulfate	mg/L	250**	#	2	140
			min	41	0
			max	43	82
			mean*	42	17
Thallium	ug/L	2	#	0	22
			min		**3.0**
			max		**10**
			mean*		**4.8**
Total dissolved solids	mg/L	500**	#	2	191
			min	**636**	0
			max	**799**	329
			mean*	**713**	86
Toxaphene	ug/L	3	#	0	0
*mean - geometric mean					
** Secondary MCL					

The following table presents the native groundwater quality and the source water quality, including general water quality parameters and water geochemistry factors.

Parameter	Units		Groundwater	Streams/Rivers/Ponds
Alkalinity	mg/L as CaCO3	#	2	0
		min	554	
		max	600	
		mean*	577	
Bicarbonate	mg/L	#	0	0
Calcium	mg/L	#	2	0
		min	1.0	
		max	1.0	
		mean*	1.0	
Carbonate	mg/L	#	0	138
		min		5.0
		max		335
		mean*		165
Chloride	mg/L	#	2	140
		min	35	0
		max	40	63
		mean*	38	6.7
Fluoride	mg/L	#	4	0
		min	0.30	
		max	1.3	
		mean*	0.71	
Hardness	mg/L as CaCO3	#	0	0

Parameter	Units		Groundwater	Streams/Rivers/Ponds
Magnesium	mg/L	#	2	0
		min	1.0	
		max	1.0	
		mean*	1.0	
Nitrate / Nitrite+Nitrate (as N)	mg/L as N	#	2	140
		min	0.05	0.05
		max	0.05	0.72
		mean*	0.05	0.11
Nitrite (as N)	mg/L as N	#	0	134
		min		0.05
		max		0.26
		mean*		0.05
Orthophosphate	mg/L	#	0	140
		min		0.01
		max		0.36
		mean*		0.03
pH	SU	#	3	135
		min	9.0	0
		max	9.3	9.2
		mean*	9.2	7.8
Phosphorus	mg/L as P	#	0	0
Silica	mg/L as SiO2	#	0	0
Sulfate	mg/L	#	2	140
		min	41	0
		max	43	82
		mean*	42	17
Temperature	deg C	#	3	136
		min	18	0
		max	22	33
		mean*	19	17
Total dissolved solids	mg/L	#	2	191
		min	636	0
		max	799	329
		mean*	713	86
Total suspended solids (TSS)	mg/L	#	0	62
		min		0
		max		292
		mean*		25
Langelier's Saturation Index**	LSI	#	0	0
*mean - geometric mean				
**Langelier's Index (LSI)				

In general, the source water quality appeared to be very good, and may even improve groundwater quality due to lower TDS concentrations. Only thallium exceeded MCLs, likely due to detection limits. Thus, the source water quality received a **high** score. The groundwater conditions appear to be favorable, with the only exceptions being high pH and TDS (aluminum exceeded MCL, but is likely due to detection limits). This resulted in a **moderate** score for native groundwater quality.

The Langelier's index was unable to be calculated for either the groundwater or source water. Hardness concentrations also were not available; pH values were higher in groundwater than source water, suggesting an imbalance. Thus, the geochemical interaction criterion will receive a **moderately low** score, primarily due to the data gap for the Langelier's index, as well as the difference in pH.

3. Hydrogeologic Suitability

Hydrogeologic suitability of the Antlers aquifer includes an evaluation of transmissivity, residence time, and general aquifer properties. The Antlers aquifer is a sandstone aquifer that is unconfined in the immediate vicinity of the Recharge Region. Groundwater flow in the vicinity of the Recharge Region generally travels in an eastern direction, toward the local stream system, as indicated on Figure G-4. Major nearby alluvial systems are located primarily to the south of the Recharge Region at the Red River. The Antlers aquifer likely contributes to the Blue River, as indicated by areas in red on Figure G-2. The following table provides a summary of aquifer properties and approximate residence time.

Parameter	**Value**	**Source**
Transmissivity	80 to 5,700 ft^2/day	AWI
Specific Yield	0.15 to 0.26	AWI
Well Yield	50 to 500 GPM	AWI
% of Recharge Lost in 180 Days	3	Glover
Number of Days Until 25% Loss	660	Glover
Distance to Discharge	1.3 miles	N/A

Based on the aquifer properties, transmissivity received a **high** score.

Based on the Glover calculations, the residence time criterion received a **high** score.

4. Cost: Operation and Maintenance (O&M) and Capital

A table showing the primary cost considerations and whether they apply to the recharge area is presented below.

	Treatment – High TSS	Treatment - Other	Gravity Feed	Forcemain/ Pipeline	Injection Well - Available	Injection Well - Construct	Spreading Basin

Recharge Area 1				X	X		

The relatively good water quality of the source water will require minimal treatment, if any, prior to injection into the aquifer. Due to the topography of the region, a force-main pipeline will be required to deliver water to the recharge project. The depth to water at the Recharge Region is prohibitive of a spreading basin, and there are no existing wells in the vicinity that could be usable for AR. Based on these factors, the Recharge Region received a **low** score for capital cost. The O&M cost received a **moderate** score due to maintenance of the force-main and AR well(s).

5. Qualitative Considerations

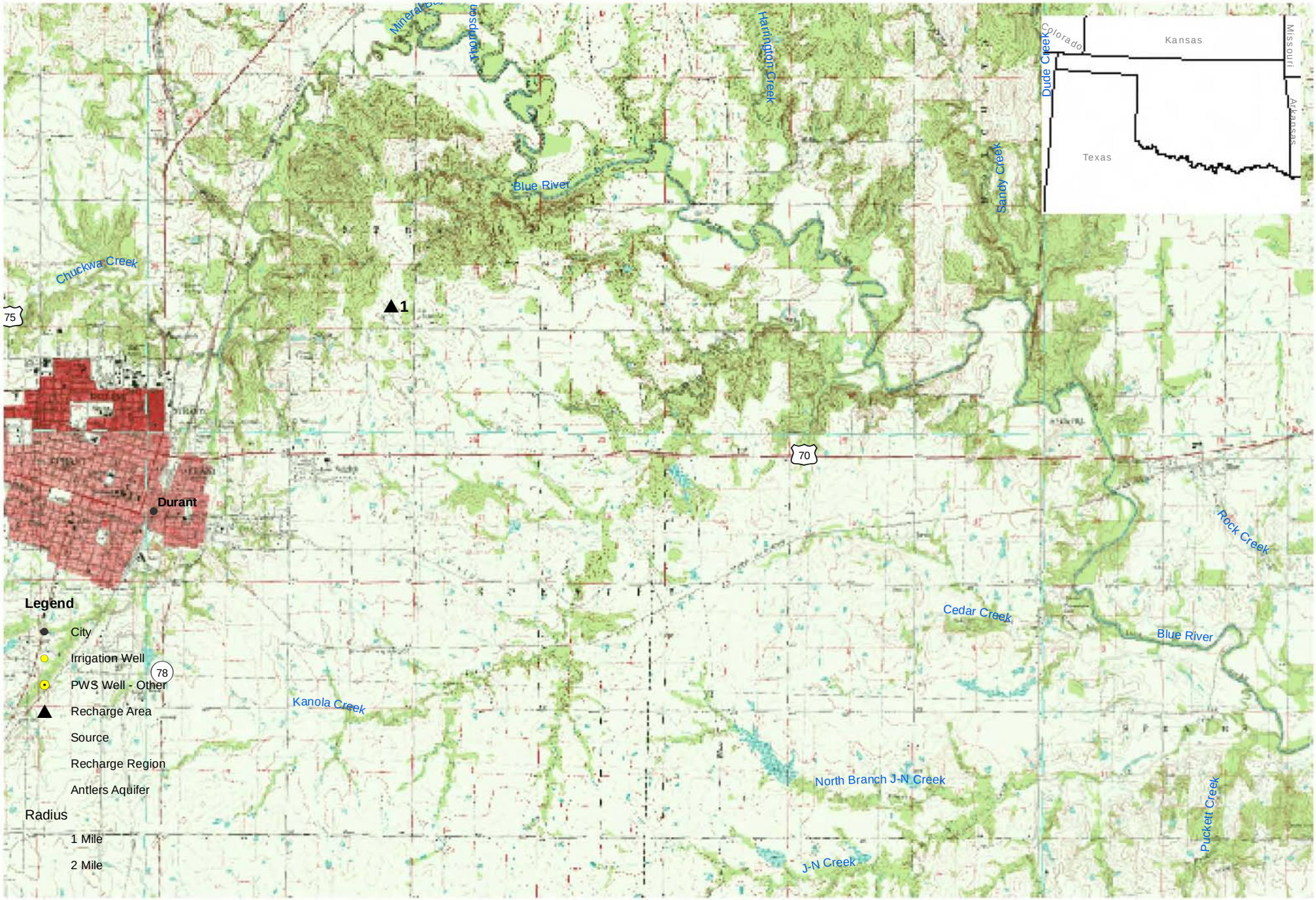
Based on the assumed project size of 1,000 acre-feet, six percent of the total demand will be met. Thus, qualitative considerations received a **moderately low** score.

6. Summary

The following table presents a summary of the scores and reasoning for assignment of those scores for Recharge Region 15.

Criterion	Score	Reasoning
Source Availability	Moderate	Adequate flows, but gage 8 miles downstream; potentially limited during low flow seasons
Demand Proximity (distance from recharge area)	Moderately low	Durant approximately 2 miles
Source Proximity (distance from recharge area)	Moderately low	Blue River = 2 miles
Available Freeboard and Ability to Meet Demand	High	Plentiful volume to meet recharged volume
Demand Density (number of wells)	Low	No wells within 1 mile
Source Quality for Non-degradation	High	Low TDS, minimal MCL exceedences
Native Groundwater Quality	Moderate	High TDS, minimal MCL

		exceedances
Geochemical Interactions of Source and Groundwater	Moderately Low	Langelier's not available for source or groundwater; higher pH in groundwater
Transmissivity	High	Good aquifer properties for AR
Residence Time	High	No losses within 180 days, >1,680 days to 25% loss
Cost (O&M)	Moderate	No pretreatment; operation of AR wells and pipeline
Cost (capital)	Low	Pipeline, install AR wells
Qualitative Considerations	Moderately low	6% of total demand



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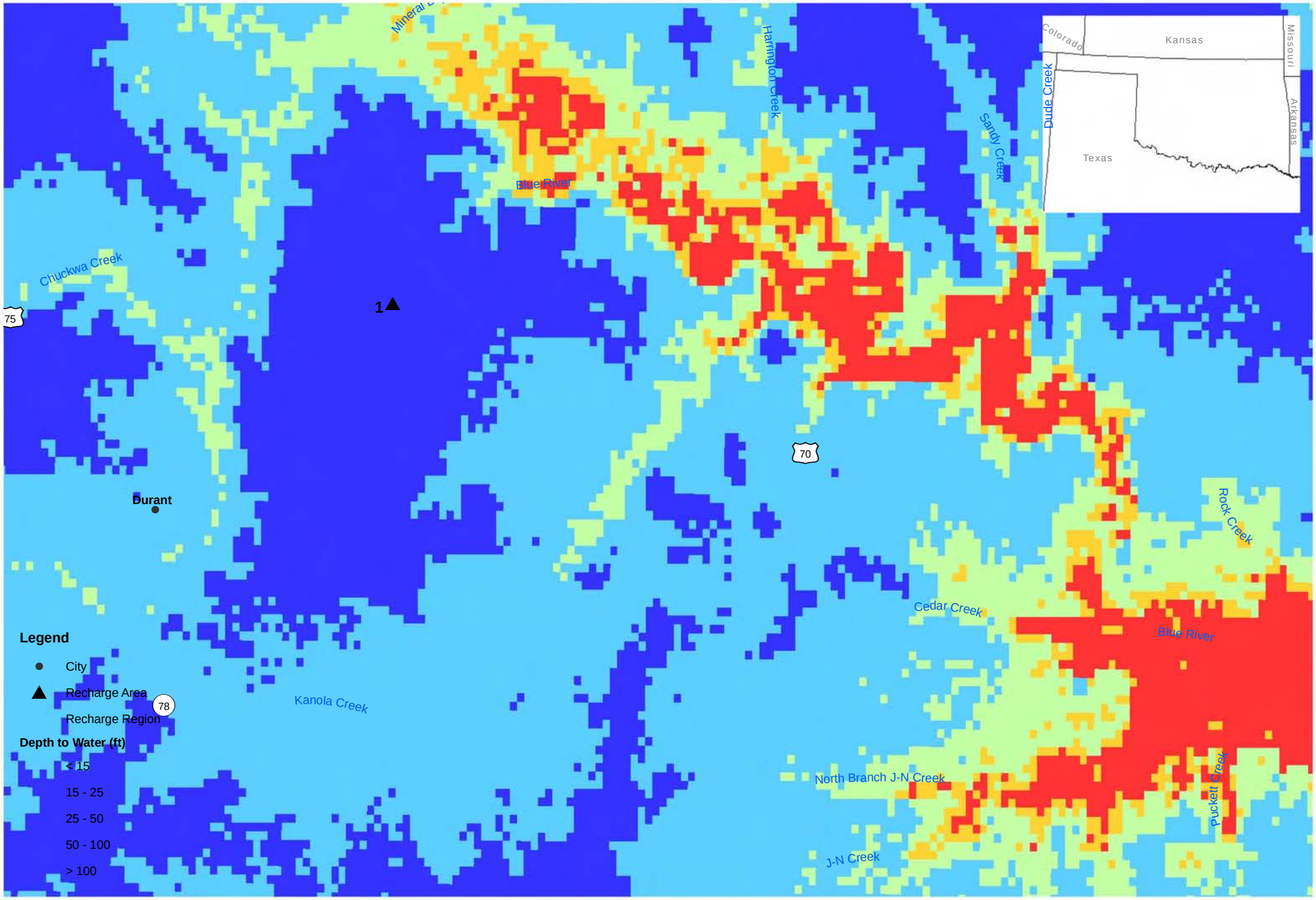
Site 15 Demand and Source Proximity

FIGURE G-1



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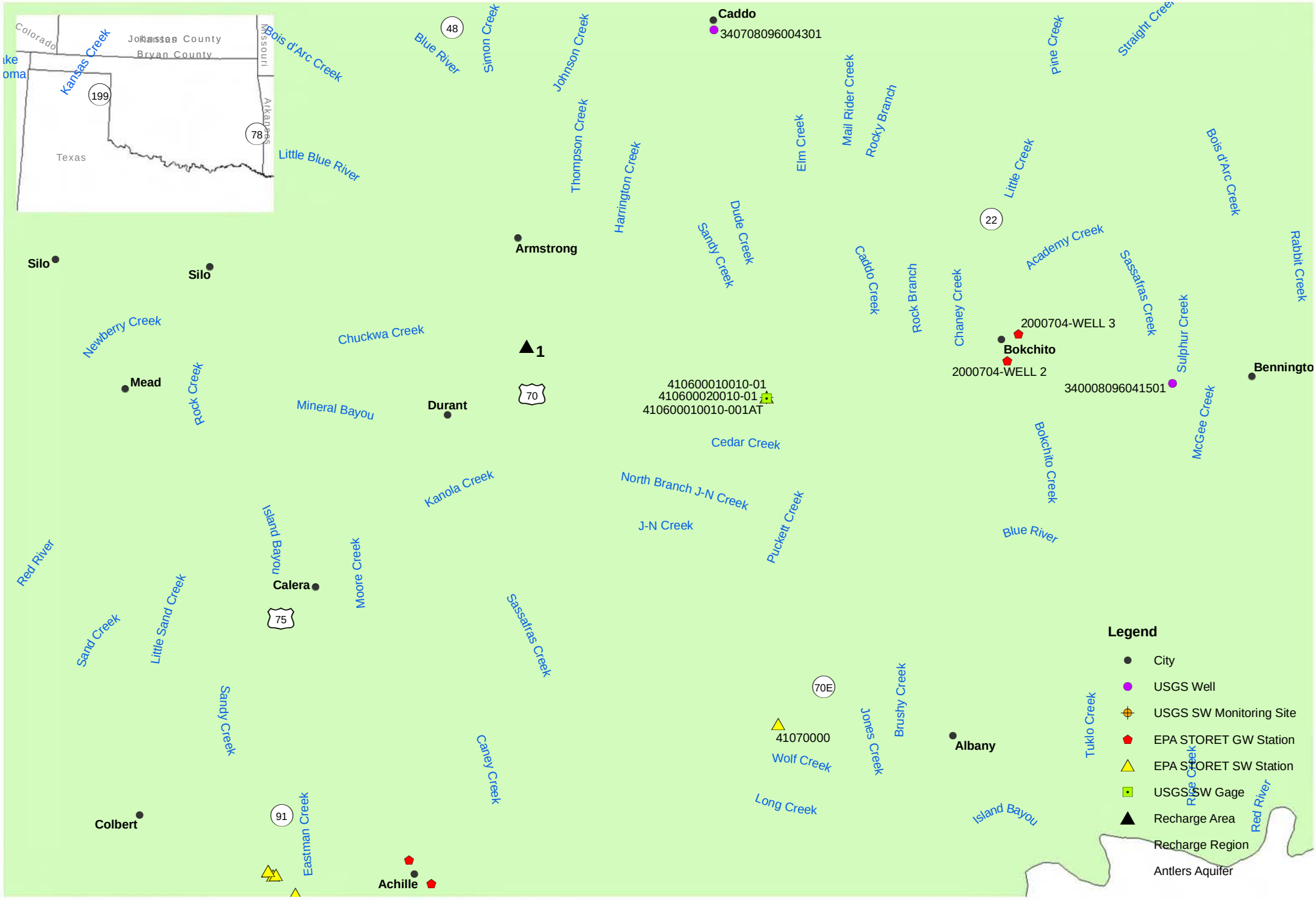
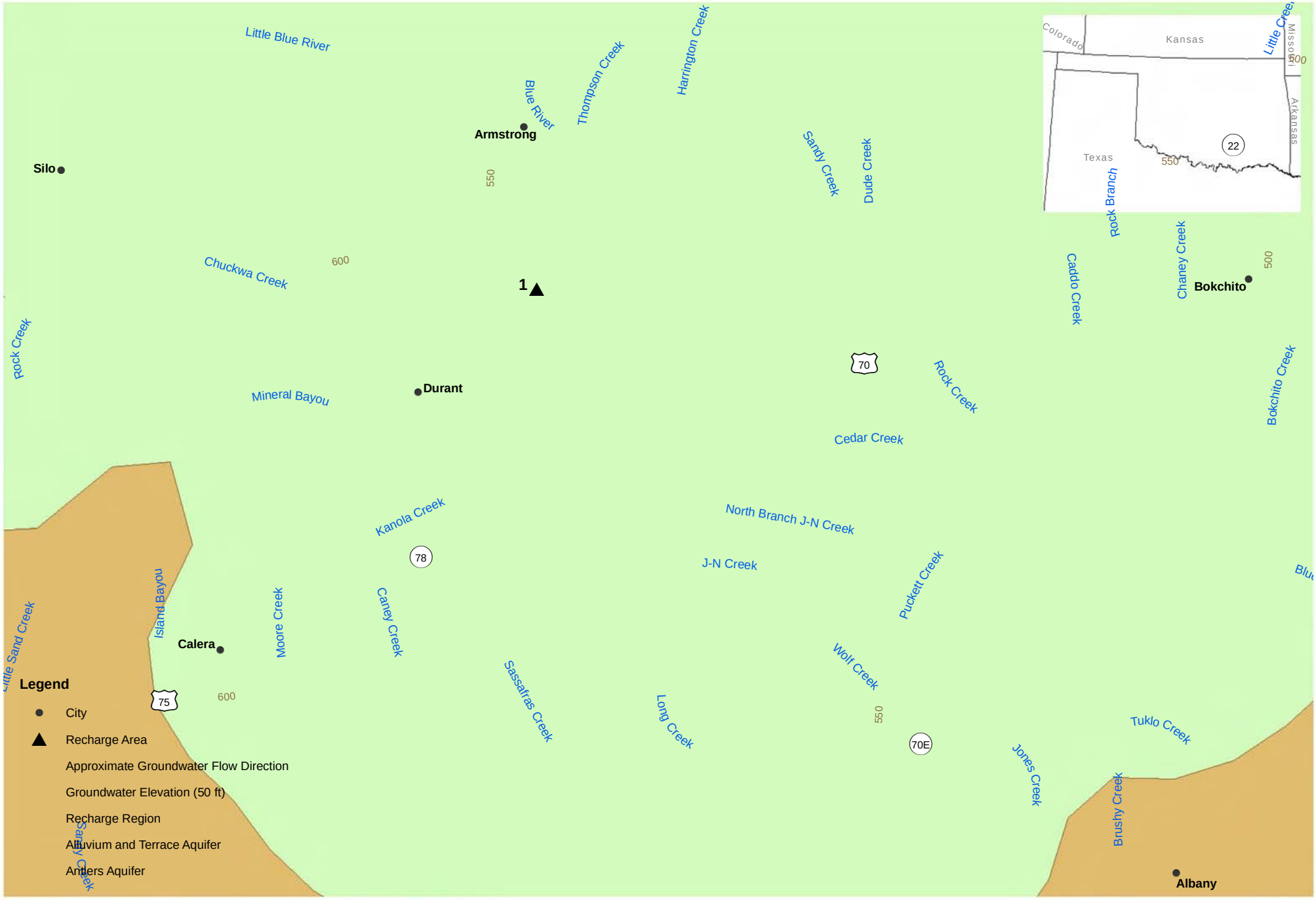
Site 15 Depth to Water

FIGURE G-2



Site 15 Surface and Groundwater Quality Sample Locations

FIGURE G-3



Site 15 Hydrogeology

FIGURE G-4

Appendix H
Detailed Analysis of Recharge Region Number 19, Upper North Canadian River Alluvial Aquifer near Woodward

Appendix H - Recharge Region 19

Recharge Region 19 is located in the vicinity of the town of Woodward, with the North Canadian alluvial terrace aquifer providing storage for an AR project. According to the U.S. Census Bureau, the town of Woodward had an estimated population of approximately 12,299 individuals in 2008; year 2000 census data indicated 11,853 individuals (U.S. Census Bureau). For this recharge region, the demand location was identified as the PWS wells for the town of Woodward, and the source for the potential recharge project was identified as the North Canadian River. Two potential recharge areas were identified based on proximity to the source and demand, the available freeboard in the aquifer, and groundwater flow direction (see Figure H-1). One of the potential recharge areas is located in the northwest portion of the recharge region, and one in the southeast portion of the recharge region. Recharge area 1, in the northwest portion, was selected based on its closer proximity to the source of water. Thus, the following detailed analysis includes only a discussion of recharge area 1.

1. Demand, Source, and Storage Considerations

The following table summarizes several aspects of the recharge area related to source water availability, local demand, ability of the source to meet the demand, and storage capacity. Proximity data is shown on Figure H-1, and available freeboard is shown on Figure H-2.

Source Basin	Basin 20532
Sufficient Legally Available Water for Pilot Project	Yes; conditionally available based on Canton Reservoir yield
Source Stream	North Canadian River. Probable point of diversion approximately 2 miles northwest of recharge area
Nearest Gage	USGS 07237500, approximately 18 miles downstream of probable point of diversion. Period of record 1938 to 2008. No known major land use changes in the contributing basin since end of the period of record.
Gage POR and below average precipitation	30 years during the gage POR are below average precipitation years. 2001 selected as representative of approximately the 25th percentile of precipitation and occurred within the POR
Representative year flows (source availability)	Annual Flow: 91,283 AF
	Seasonal Distribution: Jan-Feb,Dec 26%; Mar-May 53%; Jun-Aug 17%; Sept-Nov 4%
Local Demand (Woodward)	Annual Total 15,000 AFY
Demand Density (PWS Wells)	9 wells within 1 mile radius, 18 wells within 2 mile radius. Indicates productive region of aquifer and storage capacity
Source availability as percent of pilot project demand (minimum of local demand or 1,000 AF*)	Annual basis: 100%
	Seasonally: Jan-Feb,Dec 100%; Mar-May 100%; Jun-Aug 100%; Sept-Nov 100%

Aquifer Storage Availability	Specific Yield = 0.29
	0.2 square mile area (radius 0.3 miles) with 25 foot increase in water levels required. Storage capacity is sufficient while maintaining at least 15 feet depth to water
	0.5 square mile area (radius 0.4 miles) with 10 foot increase in water levels. Storage capacity is sufficient while maintaining at least 15 feet depth to water

Based on the availability of flows and the ability of those flows to meet the pilot project demands, the source water availability receives a **moderate** score. This is due to the gage location and conditional availability from Canton Reservoir.

The storage capacity requirement is less than the available storage in the aquifer below the 15 foot threshold; therefore storage availability receives a **high** score.

Based on the location of wells in close proximity to the recharge area, the demand proximity receives a **high** score.

Also, based on the number of wells (five to ten) within one mile of the recharge area, demand density receives a **moderately high** score.

The source of water identified for Recharge Region 19 is the North Canadian River. Recharge area 1 is located approximately two miles from the North Canadian, and thus receives a **moderately low** score for source proximity.

2. Water Quality

Water quality analysis included the following criteria: source water quality for non-degradation; native groundwater quality; and groundwater geochemical interactions with source water. The following table presents water quality data for those parameters that have an MCL. The MCL was exceeded in at least one recharge area in the State if the parameter is listed. Parameters that did not have any samples collected for the Recharge Region are listed but do not display the min, max, and mean rows. Parameters in **bold** exceed the MCL.

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/ Ponds	Gage # 07237500
Aluminum	ug/L	200	#	0	0	50
			min			10
			max			**300**
			mean*			15
Antimony	ug/L	6	#	0	0	1
			min			**350**
			max			**350**
			mean*			**350**
Arsenic	ug/L	10	#	1	15	95

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/ Ponds	Gage # 07237500
			min	2.0	10	1.0
			max	2.0	10	10
			mean*	2.0	10	3.6
Beryllium	ug/L	4	#	0	0	32
			min			0.50
			max			**10**
			mean*			2.5
Cadmium	ug/L	5	#	0	15	71
			min		1.0	0
			max		5.0	**20**
			mean*		1.7	2.1
Chloride	mg/L	250**	#	7	53	189
			min	6.6	0	70
			max	70	**4237**	**640**
			mean*	11	194	**292**
Chlorine	mg/L	4	#	0	5	0
			min		**136**	
			max		**377**	
			mean*		**237**	
Chromium	ug/L	100	#	0	15	75
			min		5.0	0
			max		6.0	50
			mean*		5.1	4.8
Fecal Coliform	cfu / 100 ml		#	0	13	
			min		10	
			max		13000	
			mean*		145	
Iron	ug/L	300	#	1	0	122
			min	20		3.0
			max	20		**13000**
			mean*	20		66
Lead	ug/L	15	#	0	15	49
			min		5.0	0
			max		10	**200**
			mean*		6.3	6.4
Manganese	ug/L	50	#	1	0	118
			min	10		0
			max	10		**530**
			mean*	10		47
Mercury	ug/L	2	#	1	15	95
			min	0.10	0.05	0
			max	0.10	0.50	**4.0**
			mean*	0.10	0.19	0.17
Nitrate / Nitrite+Nitrate	mg/L	10	#	7	51	276
			min	0.68	0.05	0.02

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/ Ponds	Gage # 07237500
(as N)			**max**	**11**	2.3	**12**
			mean*	3.2	0.46	0.59
pH	SU	6.5-8.5**	#	6	46	247
			min	6.7	6.7	7.3
			max	7.9	**8.6**	**9.4**
			mean*	7.3	8.1	8.3
Selenium	ug/L	50	#	1	15	110
			min	2.0	5.0	0
			max	2.0	10	5.0
			mean*	2.0	6.3	1.0
Sulfate	mg/L	250**	#	7	53	190
			min	4.7	0	75
			max	151	**569**	**930**
			mean*	12	195	**309**
Thallium	ug/L	2	#	0	15	1
			min		**5.0**	**200**
			max		**10**	**200**
			mean*		**7.2**	**200**
Total dissolved solids	mg/L	500**	#	6	48	327
			min	145	**532**	400
			max	449	**1609**	**3110**
			mean*	185	**981**	**1209**
Toxaphene	ug/L	3	#	0	0	1
			min			1.0
			max			1.0
			mean*			1.0
*mean - geometric mean						
** Secondary MCL						

The following table presents the native groundwater quality and the source water quality, including general water quality parameters and water geochemistry factors.

Parameter	Units		Groundwater	Streams/Rivers/ Ponds	Gage # 07237500
Alkalinity	mg/L as CaCO3	#	7	0	206
		min	64		88
		max	236		290
		mean*	99		197
Bicarbonate	mg/L	#	7	5	108
		min	78	195	104
		max	288	322	353
		mean*	121	242	233
Calcium	mg/L	#	3	12	156
		min	13	77	58
		max	30	174	280

Parameter	Units		Groundwater	Streams/Rivers/ Ponds	Gage # 07237500
		mean*	22	116	136
Carbonate	mg/L	**#**	5	41	106
		min	0	188	0
		max	0	3620	30
		mean*		462	9.9
Chloride	mg/L	**#**	7	53	189
		min	6.6	0	70
		max	70	4237	640
		mean*	11	194	292
Fluoride	mg/L	**#**	2	0	158
		min	0.20		0.30
		max	0.40		1.0
		mean*	0.28		0.71
Hardness	mg/L as CaCO3	**#**	7	0	176
		min	74		170
		max	280		970
		mean*	127		485
Magnesium	mg/L	**#**	2	5	157
		min	3.9	31	15
		max	4.4	53	66
		mean*	4.1	40	40
Nitrate / Nitrite+Nitrate (as N)	mg/L as N	**#**	7	51	276
		min	0.68	0.05	0.02
		max	11	2.3	12
		mean*	3.2	0.46	0.59
Nitrite (as N)	mg/L as N	**#**	0	42	55
		min		0.05	0.01
		max		0.60	0.56
		mean*		0.07	0.03
Orthophosphate	mg/L	**#**	0	46	0
		min		0.01	
		max		0.16	
		mean*		0.03	
pH	SU	**#**	6	46	247
		min	6.7	6.7	7.3
		max	7.9	8.6	9.4
		mean*	7.3	8.1	8.3
Phosphorus	mg/L as P	**#**	0	0	124
		min			0.01
		max			2.9
		mean*			0.17
Silica	mg/L as SiO2	**#**	3	0	157
		min	29		7.0
		max	34		54
		mean*	32		21

Parameter	Units		Groundwater	Streams/Rivers/ Ponds	Gage # 07237500
Sulfate	mg/L	#	7	53	190
		min	4.7	0	75
		max	151	569	930
		mean*	12	195	309
Temperature	deg C	#	6	41	231
		min	16	0.32	0
		max	18	31	36
		mean*	17	14	12
Total dissolved solids	mg/L	#	6	48	327
		min	145	532	400
		max	449	1609	3110
		mean*	185	981	1209
Total suspended solids (TSS)	mg/L	#	0	2	0
		min		6.0	
		max		112	
		mean*		26	
Langelier's Saturation Index**	LSI	#	3	0	144
		min	-2.0		-0.54
		max	-1.2		2.1
		mean*	-1.6		0.84
*mean - geometric mean					
**Langelier's Index (LSI)					

In general, the source water quality is poor, with many exceedences of MCLs, and high TDS concentrations. Additionally, the majority of the parameters with exceedences have higher concentrations than the groundwater. Thus, the source water quality received a **low** score. The groundwater conditions appear to be favorable, with only the nitrate maximum exceeding MCL, and low TDS concentrations. This resulted in a **high** score for native groundwater quality.

Based on the Langelier's index, the groundwater geochemistry is negative for scaling and dissolution, indicating geochemical instability that would dissolve the aquifer matrix and potentially impact AR operations. Source water sampling resulted in a positive Langelier's index, suggesting scaling would occur. The positive and negative geochemical indices suggest that reactions may occur, although this could be beneficial for creating a more neutral environment. Overall, the geochemical interaction criterion will receive a **moderate** score, primarily due to the potential for unknown reactions to occur.

3. Hydrogeologic Suitability

Hydrogeologic suitability of the North Canadian alluvial terrace aquifer includes an evaluation of transmissivity, residence time, and general aquifer properties. The North Canadian alluvial terrace aquifer is an unconfined alluvial aquifer. Groundwater flow in the vicinity of the Recharge Region generally travels in a southern direction, toward the North Canadian, as indicated on Figure H-4. The

North Canadian aquifer is in connection with the river, as indicated by areas in red on Figure H-2. The following table provides a summary of aquifer properties and approximate residence time.

Parameter	**Value**	**Source**
Hydraulic Conductivity	20 to 310 ft/day	AWI
Greatest Thickness	110 ft	AWI
Transmissivity (Computed from K, thickness)	2,200 to 34,100 ft2/day	AWI
Specific Yield	0.29	AWI
Well Yield	50 to 600 GPM	AWI
% of Recharge Lost in 180 Days	3	Glover
Number of Days Until 25% Loss	680	Glover
Distance to Discharge	2 miles	N/A

Based on the aquifer properties, transmissivity received a **high** score.

Based on the Glover calculations, the residence time criterion received a **high** score.

4. Cost: Operation and Maintenance (O&M) and Capital

A table showing the primary cost considerations and whether they apply to the recharge area is presented below.

	Treatment – High TSS	Treatment - Other	Gravity Feed	Forcemain/ Pipeline	Injection Well - Available	Injection Well - Construct	Spreading Basin
Recharge area 1		X		X			X

The relatively poor water quality of the source water indicates that treatment will likely be necessary prior to injection into the aquifer. Due to the topography of the region, a force-main pipeline will be required to deliver water to the recharge project. Because the aquifer is alluvial and the depth to water is approximately 50 feet, a spreading basin could be used, although the existing PWS wells in the vicinity may also be usable for AR. Based on these factors, the Recharge Region received a **low** score for capital cost. The O&M cost received a **moderate** score due to maintenance of the force-main and spreading basin, and operation of a treatment facility.

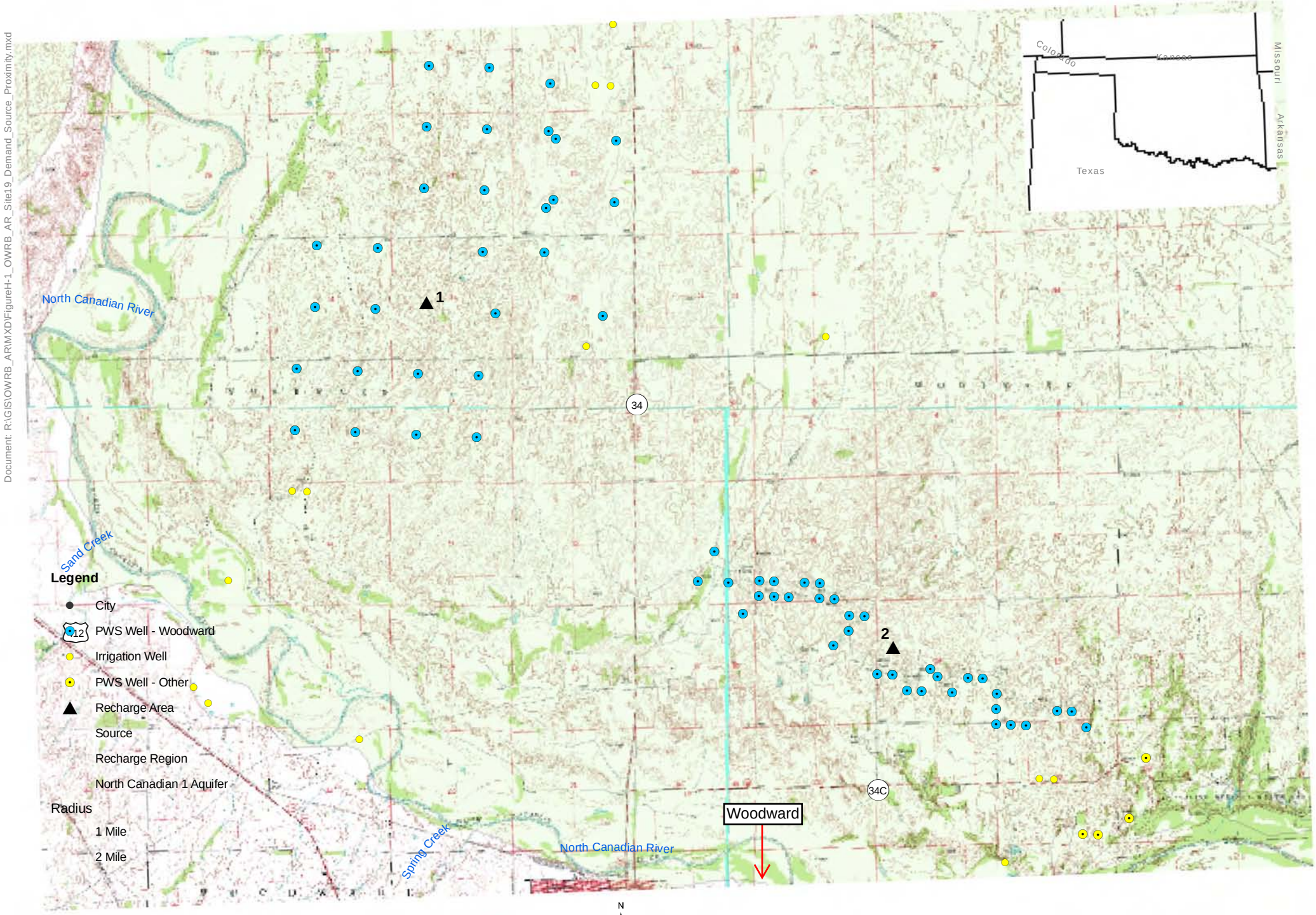
5. Qualitative Considerations

Based on the assumed project size of 1,000 acre-feet, seven percent of the total demand will be met. Thus, qualitative considerations received a **moderately low** score.

6. Summary

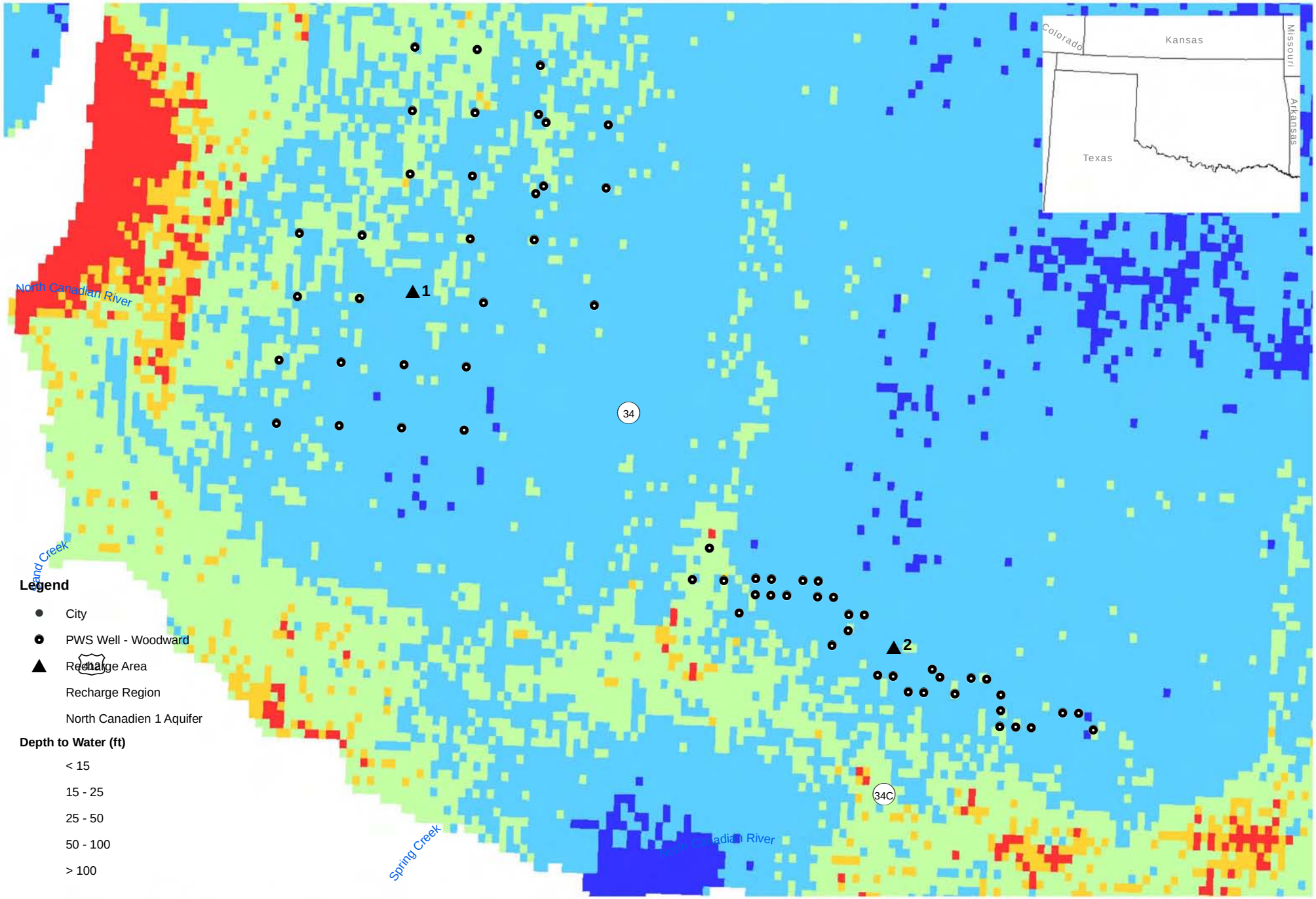
The following table presents a summary of the scores and reasoning for assignment of those scores for Recharge Region 19.

Criterion	Score	Reasoning
Source Availability	Moderate	Adequate flow, but gage 18 miles downstream; conditional availability based on Canton Reservoir
Demand Proximity (distance from recharge area)	High	PWS wells within 1 mile
Source Proximity (distance from recharge area)	Moderately low	North Canadian River = 2 miles
Available Freeboard and Ability to Meet Demand	High	Plentiful volume to meet recharged volume
Demand Density (number of wells)	Moderately high	5 to 10 wells within 1 mile
Source Quality for Non-degradation	Low	Numerous MCL exceedences, high TDS
Native Groundwater Quality	High	Low TDS, minimal MCL exceedences
Geochemical Interactions of Source and Groundwater	Moderate	Offsetting LSI
Transmissivity	High	Good aquifer properties for AR
Residence Time	High	3% loss within 180 days,680 days to 25% loss
Cost (O&M)	Moderate	Operation of spreading basin, pretreatment, and pipeline
Cost (capital)	Low	Pipeline, spreading basin, treatment system
Qualitative Considerations	Moderately low	7% of total demand



Site 19 Demand and Source Proximity

FIGURE H-1



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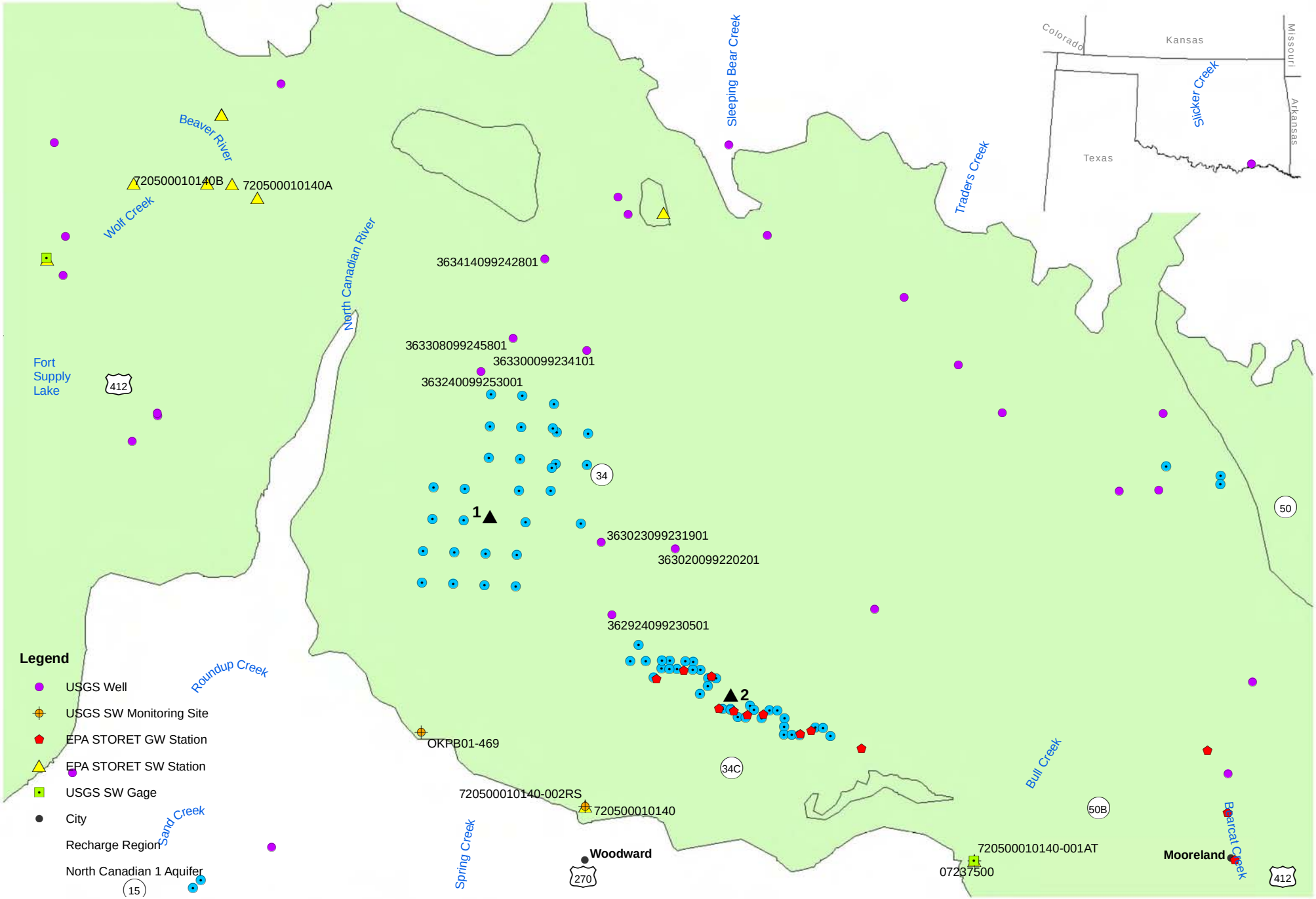
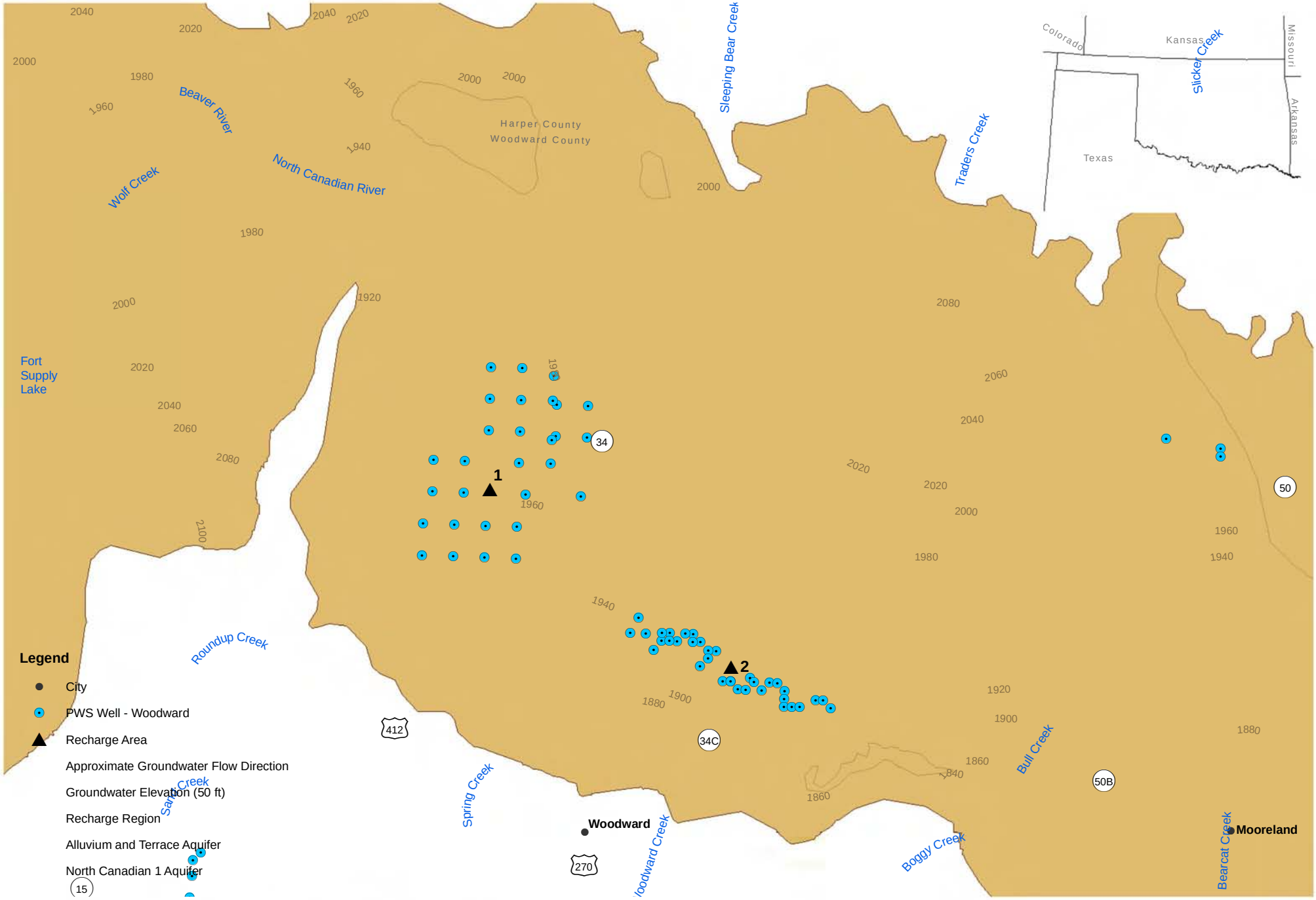
Site 19 Depth to Water

FIGURE H-2



Site 19 Surface and Groundwater Quality Sample Locations

FIGURE H-3



Site 19 Hydrogeology

FIGURE H-4

Appendix I
Detailed Analysis of Recharge Region Number 21, Upper North Fork Red River Alluvial Aquifer near Elk City

Appendix I - Recharge Region 21

Recharge Region 21 is located in the vicinity of the town of Elk City, with the North Fork Red River alluvial terrace aquifer providing storage for an AR project. According to the U.S. Census Bureau, the town of Elk City had an estimated population of approximately 11,311 individuals in 2008; year 2000 census data indicated 10,510 individuals (U.S. Census Bureau). For this recharge region, the demand location was identified as the PWS wells for the town of Elk City, and the source for the potential recharge project was identified as the North Fork Red River. One potential recharge area was identified within this recharge region based on proximity to the source and demand, the available freeboard in the aquifer, and groundwater flow direction. The recharge area is located in the southern portion of the recharge region, based on its proximity to the demand (see Figure I-1).

1. Demand, Source, and Storage Considerations

The following table summarizes several aspects of the recharge area related to source water availability, local demand, ability of the source to meet the demand, and storage capacity. Proximity data is shown on Figure I-1, and available freeboard is shown on Figure I-2.

Source Basin	Basin 11522
Sufficient Legally Available Water for Pilot Project	Yes
Source Stream	North Fork Red River. Probable point of diversion near confluence with Flat Creek
Nearest Gage	USGS 07301481, approximately 10 miles upstream of probable point of diversion. Period of record 1978 to 1984. Substantial well development since the selected year.
Gage POR and below average precipitation	3 years during the gage POR are below average precipitation years. 1980 selected as representative of approximately the 25th percentile of precipitation and occurred within the POR
Representative year flows (source availability)	Annual Flow: 26,870 AF
	Seasonal Distribution: Jan-Feb,Dec 32%; Mar-May 64%; Jun-Aug 3%; Sept-Nov 0%
Local Demand (Elk City)	Annual Total 12,500 AFY
Demand Density (PWS Wells)	2 wells within 1 mile radius, 0 wells within 2 mile radius. Indicates productive region of aquifer and storage capacity
Source availability as percent of pilot project demand (minimum of local demand or 1,000 AF*)	Annual basis: 100%
	Seasonally: Jan-Feb,Dec 100%; Mar-May 100%; Jun-Aug 91%; Sept-Nov 0%
Aquifer Storage Availability	Specific Yield = 0.25
	0.3 square mile area (radius 0.3 miles) with 25 foot increase in water levels required. Storage capacity is insufficient to maintain at least 15 feet depth to water

	0.6 square mile area (radius 0.5 miles) with 10 foot increase in water levels. Storage capacity is insufficient to maintain at least 15 feet depth to water

Based on the availability of flows and the ability of those flows to meet the pilot project demands, the source water availability receives a **moderately low** score. This is due to well development since the period of record and seasonal inability to meet demand.

The storage capacity requirement is greater than the available storage in the aquifer below the 15 foot threshold; therefore storage availability receives a **low** score.

Based on the location of wells in close proximity to the recharge area, the demand proximity receives a **high** score.

Based on the number of wells (less than five) within one mile of the recharge area, demand density receives a **low** score.

The source of water identified for Recharge Region 21 is North Fork Red River. Recharge area 1 is located greater than two miles from the source, and thus receives a **low** score for source proximity.

2. Water Quality

Water quality analysis included the following criteria: source water quality for non-degradation; native groundwater quality; and groundwater geochemical interactions with source water. The following table presents water quality data for those parameters that have an MCL. The MCL was exceeded in at least one recharge area in the State if the parameter is listed. Parameters that did not have any samples collected for the Recharge Region are listed but do not display the min, max, and mean rows. Parameters in **bold** exceed the MCL.

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/ Ponds	Gage # 07301481
Aluminum	ug/L	200	#	12	0	0
			min	**300**		
			max	**300**		
			mean*	**300**		
Antimony	ug/L	6	#	0		0
Arsenic	ug/L	10	#	0	0	0
Beryllium	ug/L	4	#	0	0	0
Cadmium	ug/L	5	#	0	0	0
Chloride	mg/L	250**	#	19	16	1
			min	7.0	10	**336**
			max	98	**718**	**336**
			mean*	16	93	**336**
Chlorine	mg/L	4	#	0	0	0
Chromium	ug/L	100	#	0	0	0

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/ Ponds	Gage # 07301481
Fecal Coliform	cfu / 100 ml		#	0	0	
Iron	ug/L	300	#	12	0	1
			min	20		30
			max	285		30
			mean*	32		30
Lead	ug/L	15	#	0	0	0
Manganese	ug/L	50	#	12	0	1
			min	5.0		5.7
			max	7.0		5.7
			mean*	5.1		5.7
Mercury	ug/L	2	#	0	0	0
Nitrate / Nitrite+Nitrate (as N)	mg/L	10	#	18	0	0
			min	0.36		
			max	9.6		
			mean*	3.6		
pH	SU	6.5-8.5**	#	11	12	12
			min	6.7	7.2	7.3
			max	7.9	7.9	8.4
			mean*	7.5	7.6	8.0
Selenium	ug/L	50	#	0	0	0
Sulfate	mg/L	250**	#	19	16	1
			min	65	10	**503**
			max	**1900**	**911**	**503**
			mean*	169	208	**503**
Thallium	ug/L	2	#	0	0	0
Total dissolved solids	mg/L	500**	#	23	28	2
			min	374	10	**1360**
			max	**3210**	**2890**	**1500**
			mean*	**581**	**697**	**1428**
Toxaphene	ug/L	3	#	0	0	0
*mean - geometric mean						
** Secondary MCL						

The following table presents the native groundwater quality and the source water quality, including general water quality parameters and water geochemistry factors.

Parameter	Units		Groundwater	Streams/Rivers/ Ponds	Gage # 07301481
Alkalinity	mg/L as CaCO3	#	19	0	1
		min	121		121
		max	333		121
		mean*	203		121
Bicarbonate	mg/L	#	7	0	1
		min	148		148

Parameter	Units		Groundwater	Streams/Rivers/ Ponds	Gage # 07301481
		max	406		148
		mean*	271		148
Calcium	mg/L	#	17	16	1
		min	84	1.0	172
		max	231	254	172
		mean*	108	52	172
Carbonate	mg/L	#	7	12	1
		min	0	604	0
		max	0	1048	0
		mean*		794	
Chloride	mg/L	#	19	16	1
		min	7.0	10	336
		max	98	718	336
		mean*	16	93	336
Fluoride	mg/L	#	14	0	1
		min	0.20		0.69
		max	0.35		0.69
		mean*	0.26		0.69
Hardness	mg/L as CaCO3	#	7	0	1
		min	240		630
		max	2000		630
		mean*	472		630
Magnesium	mg/L	#	17	16	1
		min	8.5	1.0	49
		max	49	112	49
		mean*	18	24	49
Nitrate / Nitrite+Nitrate (as N)	mg/L as N	#	18	0	0
		min	0.36		
		max	9.6		
		mean*	3.6		
Nitrite (as N)	mg/L as N	#	0	0	0
Orthophosphate	mg/L	#	0	0	0
pH	SU	#	11	12	12
		min	6.7	7.2	7.3
		max	7.9	7.9	8.4
		mean*	7.5	7.6	8.0
Phosphorus	mg/L as P	#	0	0	0
Silica	mg/L as SiO2	#	2	0	1
		min	25		22
		max	30		22
		mean*	27		21
Sulfate	mg/L	#	19	16	1
		min	65	10	503
		max	1900	911	503
		mean*	169	208	503

Parameter	Units		Groundwater	Streams/Rivers/ Ponds	Gage # 07301481
Temperature	deg C	#	6	12	13
		min	16	4.0	1.5
		max	20	35	36
		mean*	18	13	15
Total dissolved solids	mg/L	#	23	28	2
		min	374	10	1360
		max	3210	2890	1500
		mean*	581	697	1428
Total suspended solids (TSS)	mg/L	#	0	0	0
Langelier's Saturation Index**	LSI	#	8	0	1
		min	-1.0		1.0
		max	1.7		1.0
		mean*	0.38		1.0
*mean - geometric mean					
**Langelier's Index (LSI)					

In general, the source water quality appeared to be somewhat poor, with MCL exceedences for several parameters, and high TDS concentrations. The parameters with exceedences were also greater than the groundwater concentrations. Thus, the source water quality received a **low** score. The groundwater conditions appear to be favorable, with minimal MCL exceedences (aluminum exceedences are likely due to detection limits). However, the TDS concentrations exceeded the MCL for the mean, suggesting that TDS in the aquifer is greater than desired for the project. This resulted in a **moderately low** score for native groundwater quality.

Based on the Langelier's index, the groundwater geochemistry is near neutral for scaling and dissolution, indicating minimal geochemical instability that would impact AR operations. Source water sampling for all but one sample did not include all the parameters necessary to calculate the Langelier's index. The one sample with an LSI had a positive index, suggesting a likelihood of precipitation and scaling. The total hardness also only had one sample; pH samples suggest that source water is slightly more alkaline. Thus, the geochemical interaction criterion will receive a **moderate** score, primarily due to the data gap for the Langelier's index, and slight difference in pH.

3. Hydrogeologic Suitability

Hydrogeologic suitability of the North Fork Red River alluvial terrace aquifer includes an evaluation of transmissivity, residence time, and general aquifer properties. The North Fork Red River alluvial terrace aquifer is an unconfined alluvial aquifer. Groundwater flow in the vicinity of the Recharge Region generally travels in a southern or eastern direction, toward the local stream system. The North Fork Red River aquifer is likely in connection with the local streams, as indicated by wells with less than 10 feet of

freeboard on Figure H-2. The following table provides a summary of aquifer properties and approximate residence time.

Parameter	Value	Source
Transmissivity	3,536 to 4,692 ft^2/day	AWI
Specific Yield	0.25	AWI
Well Yield	200 to 500 GPM	AWI
% of Recharge Lost in 180 Days	52	Glover
Number of Days Until 25% Loss	60	Glover
Distance to Discharge	0.3 miles	N/A

Based on the aquifer properties, transmissivity received a **high** score.

Based on the Glover calculations, the residence time criterion received a **low** score.

4. Cost: Operation and Maintenance (O&M) and Capital

A table showing the primary cost considerations and whether they apply to a recharge area is presented below.

	Treatment – High TSS	Treatment – Other	Gravity Feed	Forcemain/ Pipeline	Injection Well - Available	Injection Well - Construct	Spreading Basin
Recharge area 1		X		X			X

The relatively poor water quality of the source water will require treatment prior to injection into the aquifer. Due to the topography of the region, a force-main pipeline will be required to deliver water to the recharge project. Because the aquifer is alluvial and the depth to water is less than 50 feet, a spreading basin could be used, although the existing PWS wells in the vicinity may also be usable for AR. Based on these factors, the Recharge Region received a **low** score for capital cost. The O&M cost received a **moderate** score due to maintenance of the force-main, spreading basin, and treatment system.

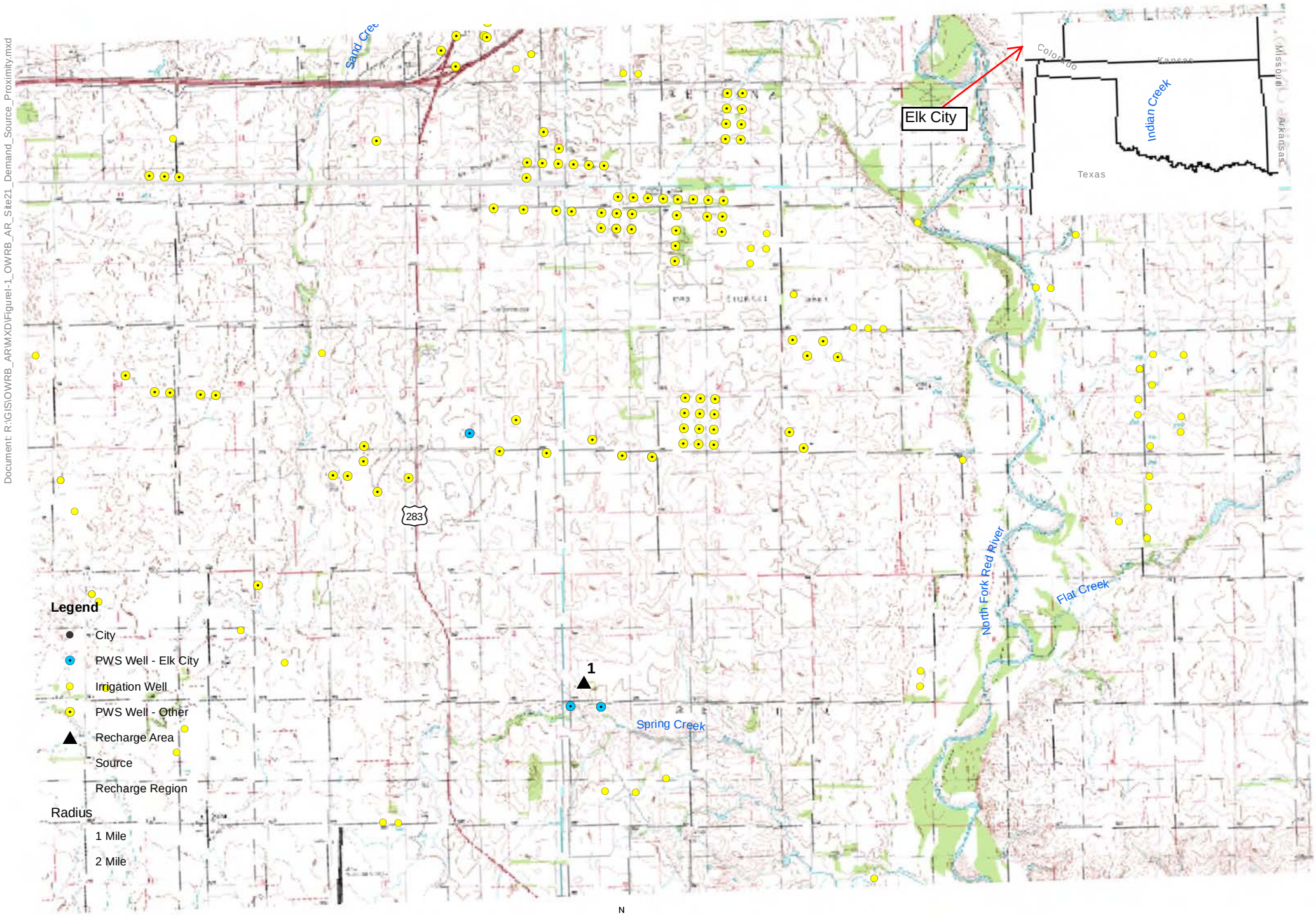
5. Qualitative Considerations

Based on the assumed project size of 1,000 acre-feet, eight percent of the total demand will be met. Thus, qualitative considerations received a **moderately low** score.

6. Summary

The following table presents a summary of the scores and reasoning for assignment of those scores for Recharge Region 21.

Criterion	Score	Reasoning
Source Availability	Moderately low	Unable to meet demand seasonally, gage 10 miles upstream, well development since period of record
Demand Proximity (distance from recharge area)	High	PWS wells within 1 mile
Source Proximity (distance from recharge area)	Low	North Fork Red River > 2 miles
Available Freeboard and Ability to Meet Demand	Low	Not enough volume to meet recharged volume
Demand Density (number of wells)	Low	Less than 5 wells within 1 mile
Source Quality for Non-degradation	Low	Several MCL exceedences, higher TDS
Native Groundwater Quality	Moderately Low	High TDS, minimal MCL exceedances
Geochemical Interactions of Source and Groundwater	moderate	Langelier's not available for source; similar pH and hardness
Transmissivity	High	Good aquifer properties for AR
Residence Time	Low	52% loss within 180 days, 60 days to 25% loss
Cost (O&M)	Moderate	Pretreatment; operation of spreading basin and pipeline
Cost (capital)	Low	Pipeline, spreading basin, treatment system
Qualitative Considerations	Moderately low	8% of total demand

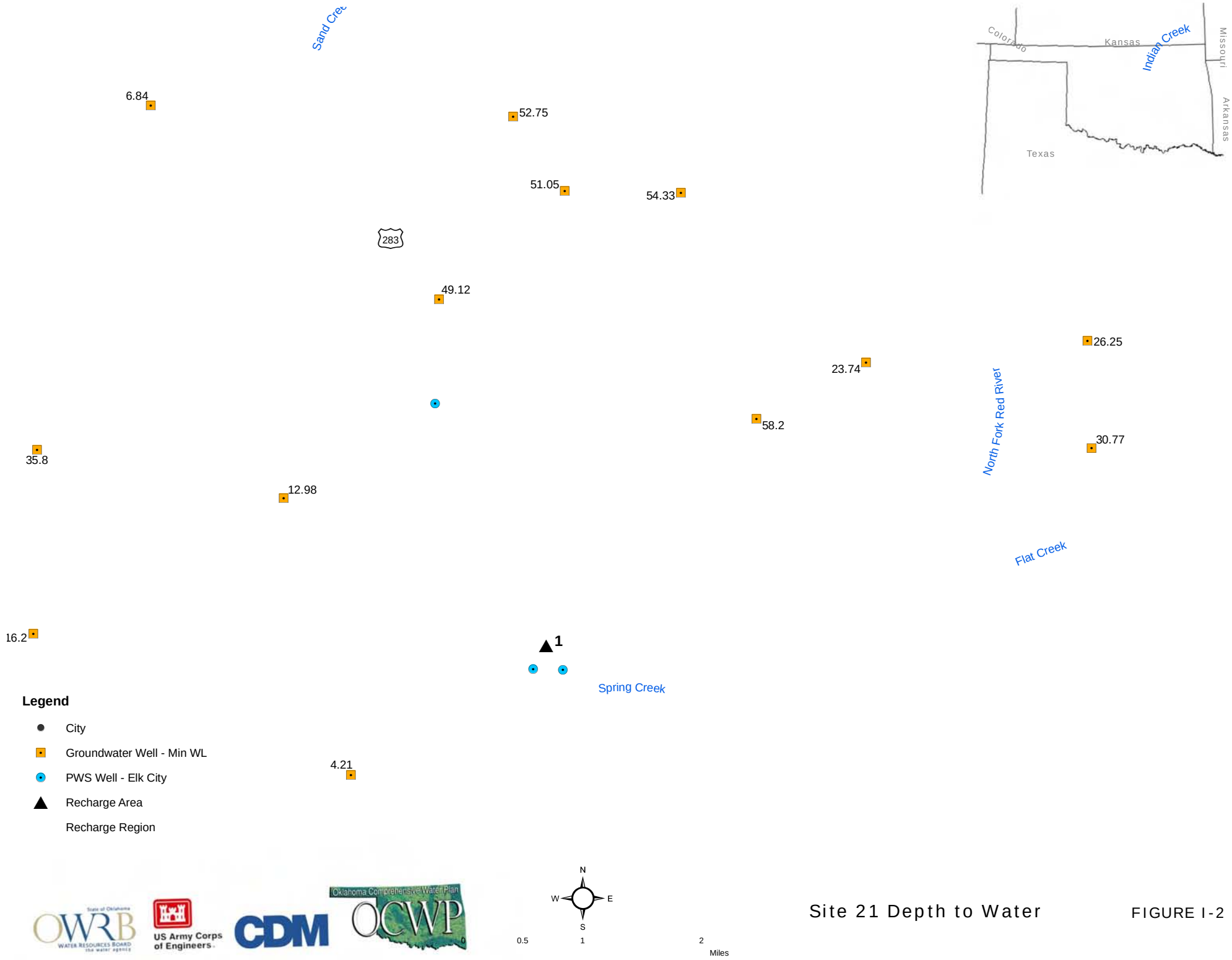


N
W E
S

0 0.5 1 2
Miles

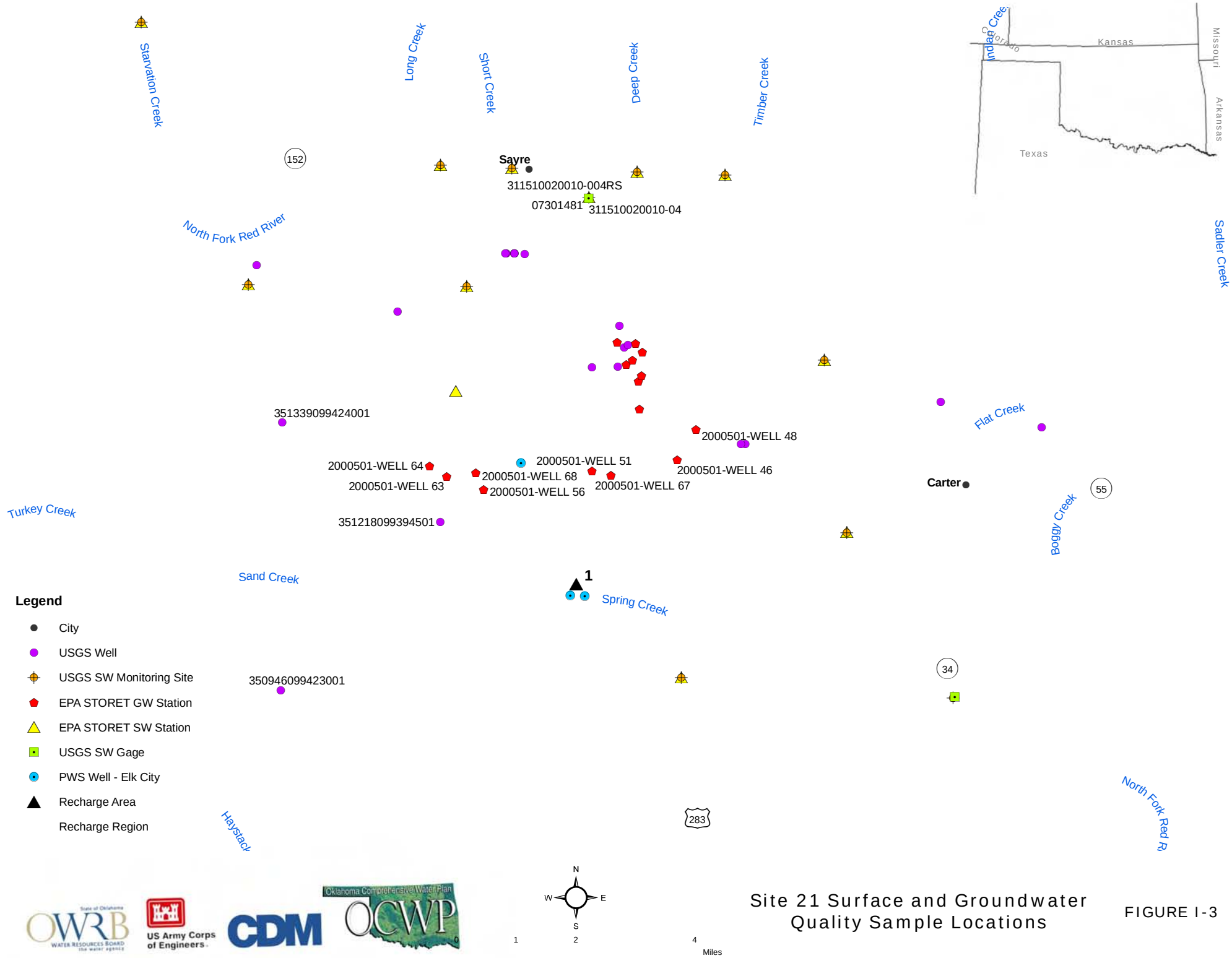
Site 21 Demand and Source Proximity

FIGURE I-1



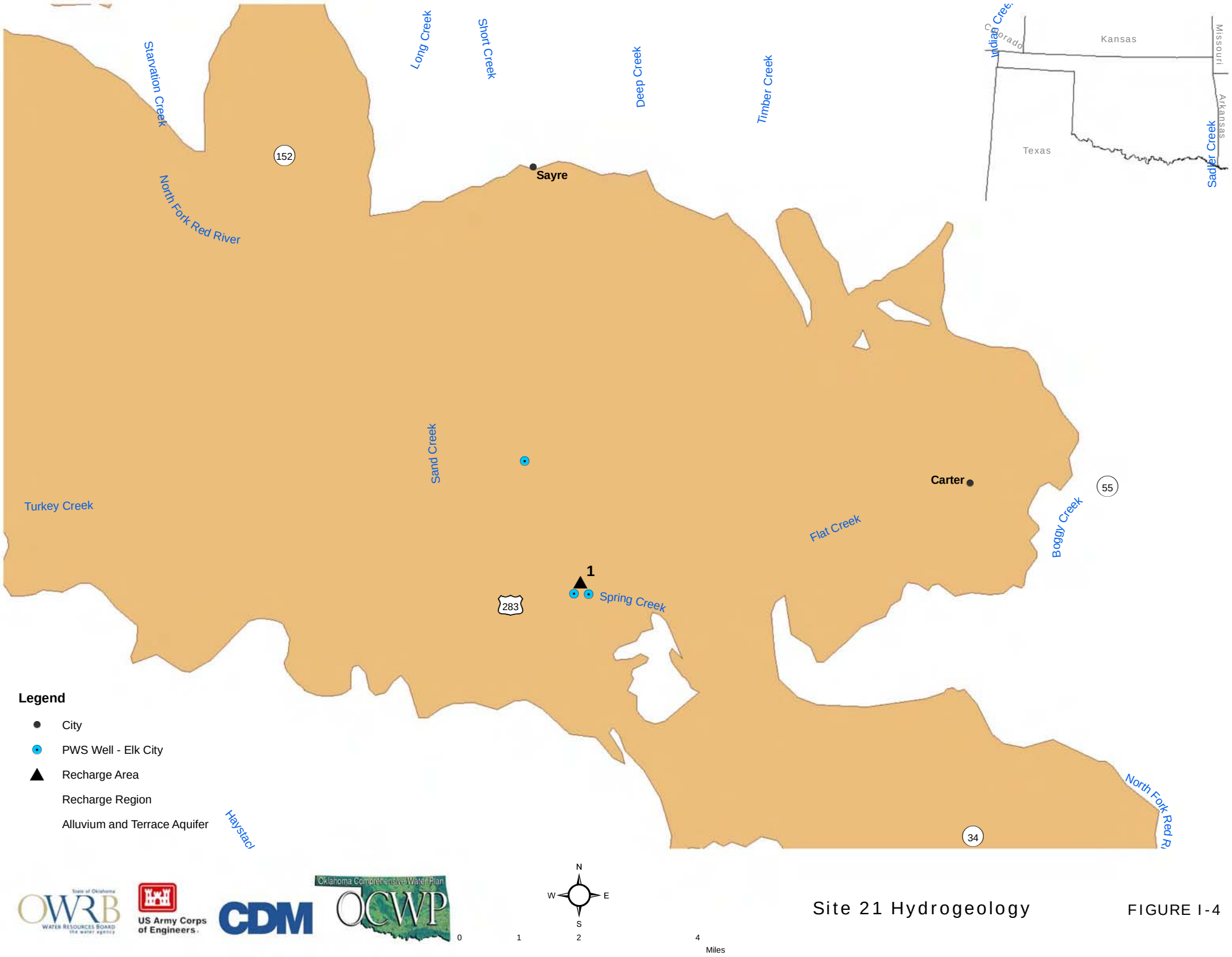
Site 21 Depth to Water

FIGURE I-2



Site 21 Surface and Groundwater Quality Sample Locations

FIGURE I-3



Site 21 Hydrogeology

FIGURE I-4

Appendix J
Detailed Analysis of Recharge Region Number 27, Middle North Canadian River Alluvial Aquifer near El Reno

Appendix J - Recharge Region 27

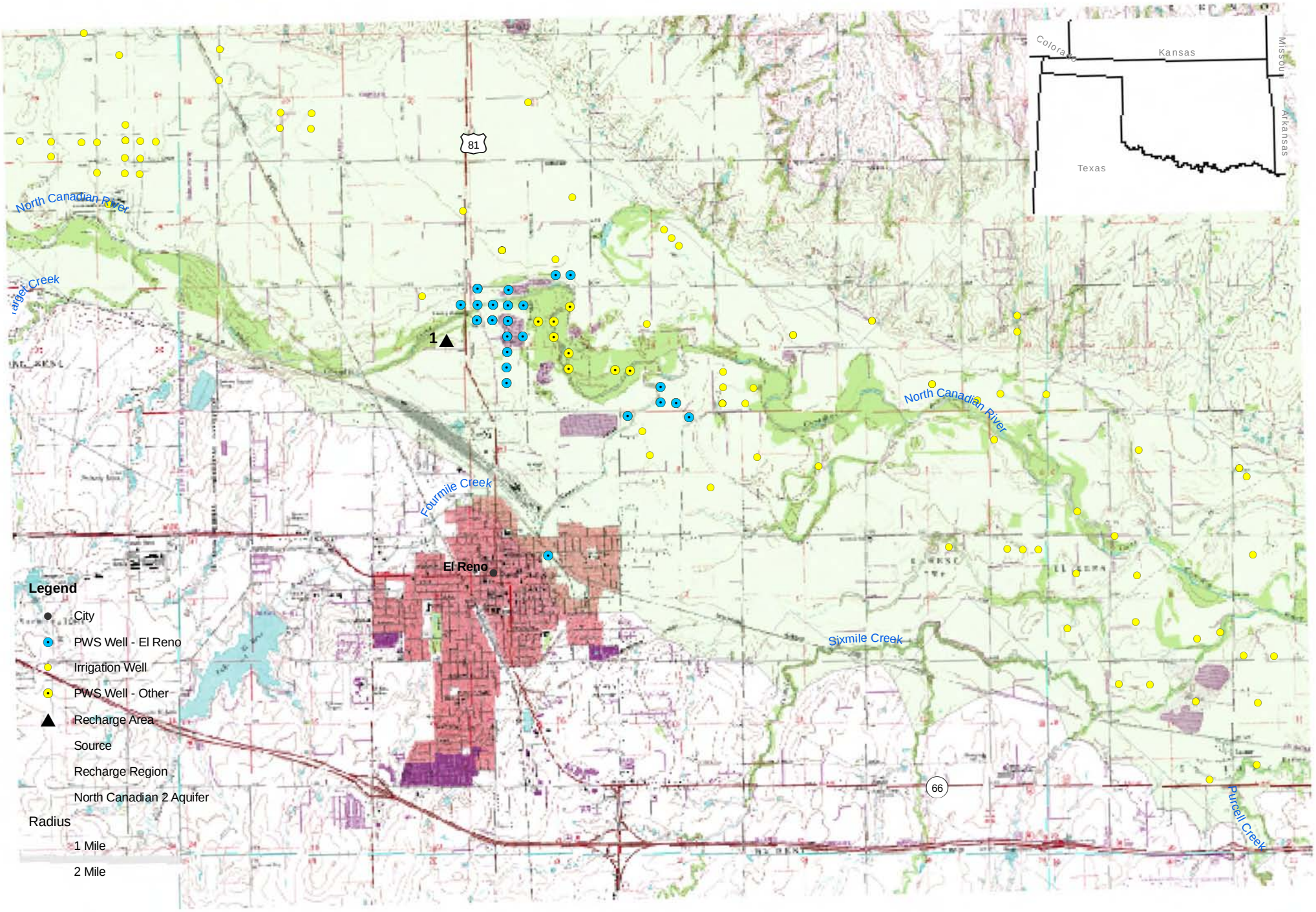
Recharge Region 27 is located in the vicinity of the town of El Reno, with the North Canadian alluvial terrace aquifer providing storage for an AR project. According to the U.S. Census Bureau, the town of El Reno had an estimated population of approximately 16,545 individuals in 2008; year 2000 census data indicated 16,212 individuals (U.S. Census Bureau). For this recharge region, the demand location was identified as the PWS wells for the town of El Reno, and the source for the potential recharge project was identified as the North Canadian River. One potential recharge area was identified based on the available freeboard, and proximity to the source and demand (see Figure J-1). The recharge area is located in the northwest portion of the recharge region.

1. Demand, Source, and Storage Considerations

The following table summarizes several aspects of the recharge area related to source water availability, local demand, ability of the source to meet the demand, and storage capacity. Proximity data is shown on Figure J-1, and available freeboard is shown on Figure J-2.

Source Basin	Basin 20520
Sufficient Legally Available Water for Pilot Project	No
Source Stream	N/A
Nearest Gage	N/A
Gage POR and below average precipitation	N/A
Representative year flows (source availability)	N/A
	N/A
Local Demand (Woodward)	N/A
Demand Density (PWS Wells)	N/A
Source availability as percent of pilot project demand (minimum of local demand or 1,000 AF*)	N/A
	N/A
Aquifer Storage Availability	N/A
	N/A
	N/A

As indicated in the table, there is not sufficient, legally-available source water for this recharge region. Thus, this recharge region has been dropped from the detailed analysis.



N
W E
S

0 0.5 1 2
Miles

Site 27 Demand and Source Proximity

FIGURE J-1

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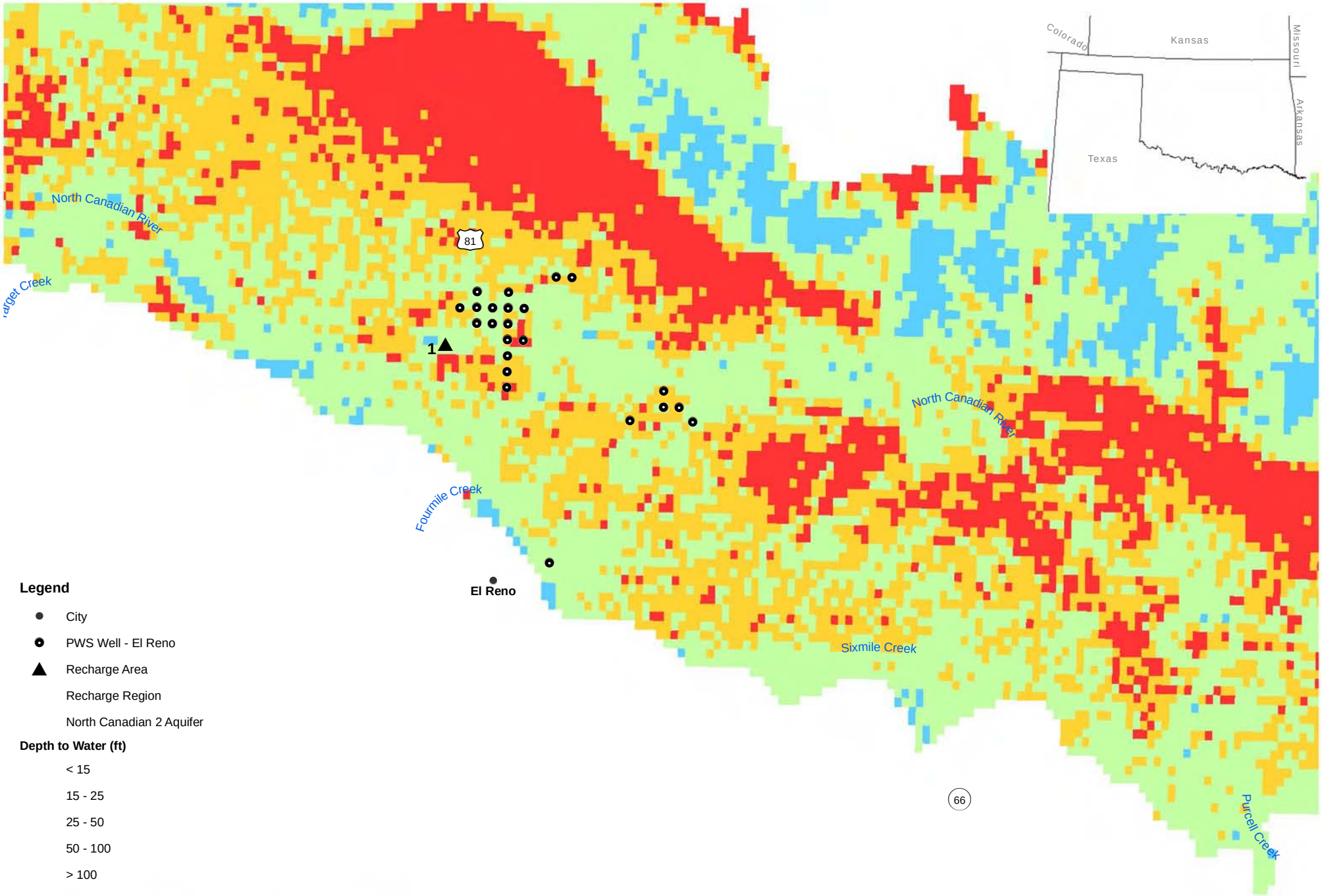


Legend

- City
- PWS Well - El Reno
- Recharge Area
- Recharge Region
- North Canadian 2 Aquifer

Depth to Water (ft)

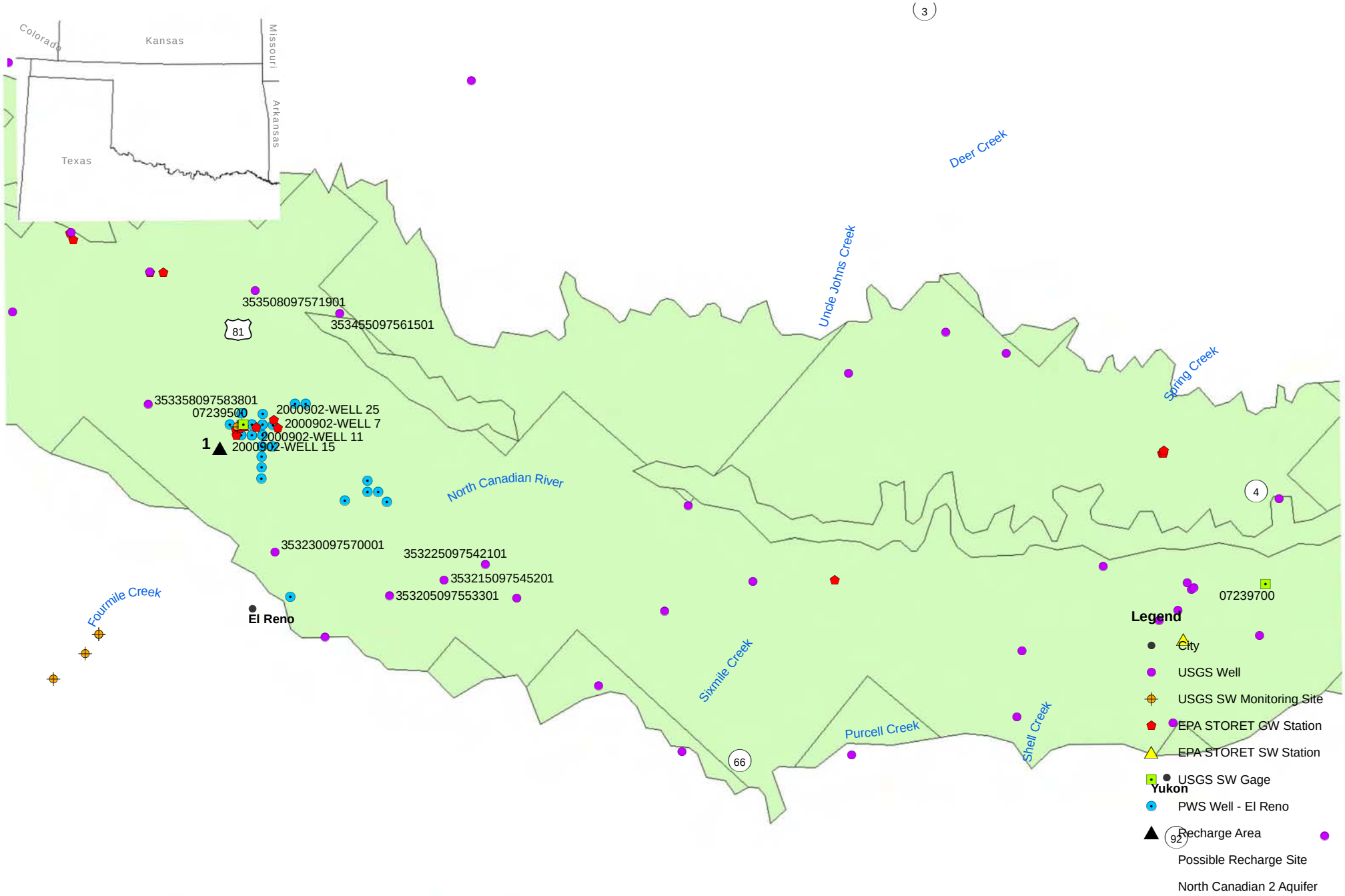
- < 15
- 15 - 25
- 25 - 50
- 50 - 100
- > 100

N
W E
S

0 0.5 1 2
Miles

Site 27 Depth to Water

FIGURE J-2

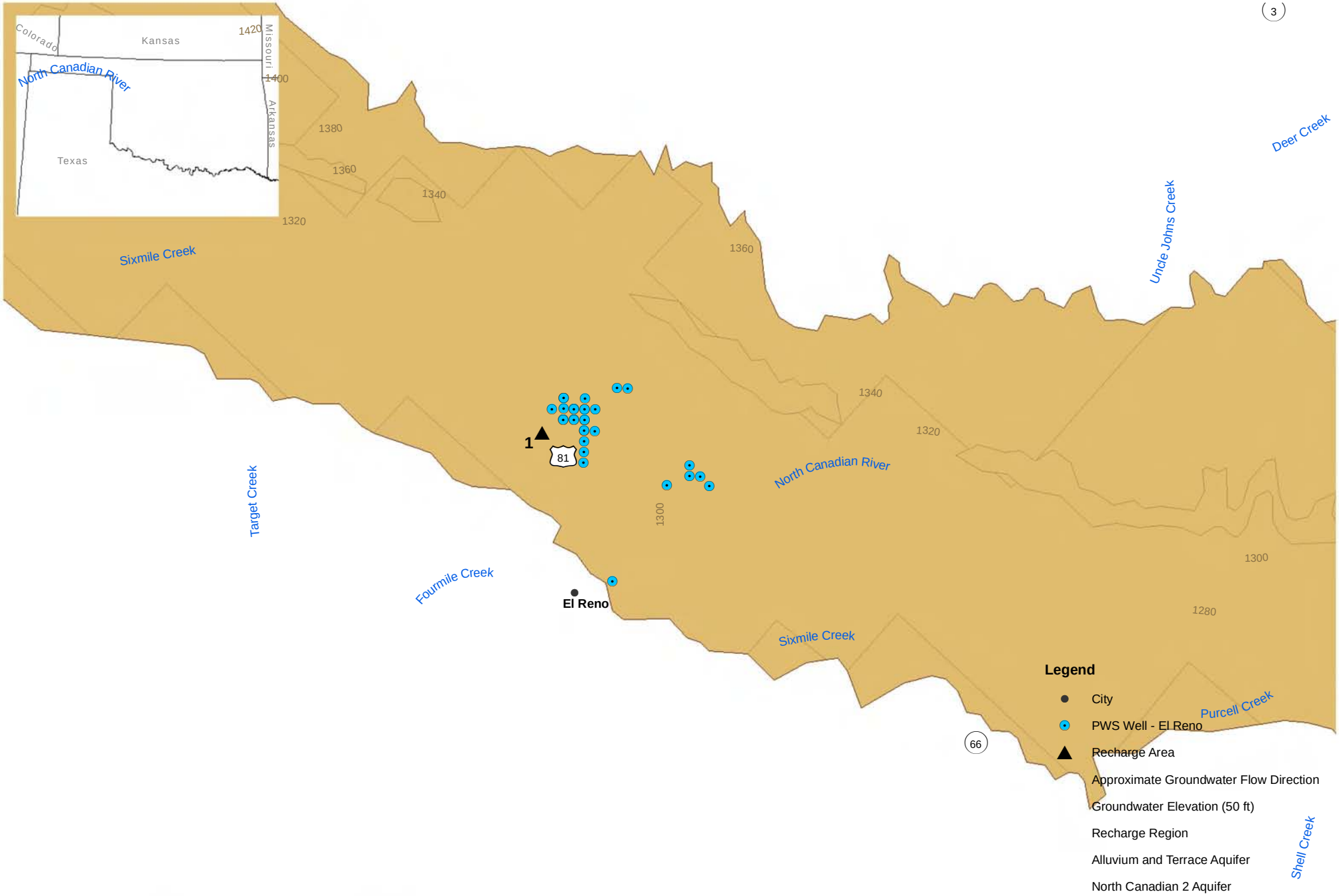


N
W E
S

0 0.75 1.5 3
Miles

Site 27 Surface and Groundwater Quality Sample Locations

FIGURE J-3



N
W E
S

0 0.75 1.5 3
Miles

Site 27 Hydrogeology

FIGURE J-4

Appendix K
Detailed Analysis of Recharge Region Number 28, Middle Cimarron River Alluvial Aquifer near Kingfisher and Hennessey

Appendix K - Recharge Region 28

Recharge Region 28 is located in the vicinity of the town of Kingfisher, with the Cimarron River alluvial terrace aquifer providing storage for an AR project. According to the U.S. Census Bureau, the town of Kingfisher had an estimated population of approximately 4,343 individuals in 2008; year 2000 census data indicated 4,380 individuals (U.S. Census Bureau). For this recharge region, the demand location was identified as the PWS wells for the town of Kingfisher, and the source for the potential recharge project was identified as the Cimarron River. One potential recharge area was identified within this recharge region based on the available freeboard in the aquifer, and proximity to the source and demand. The potential recharge area is located in the northwest portion of the recharge region (see Figure K-1).

1. Demand, Source, and Storage Considerations

The following table summarizes several aspects of the recharge area related to source water availability, local demand, ability of the source to meet the demand, and storage capacity. Proximity data is shown on Figure K-1, and available freeboard is shown on Figure K-2.

Source Basin	Basin 20920
Sufficient Legally Available Water for Pilot Project	Yes
Source Stream	Cimarron River. Probable point of diversion approximately 1 mile west of recharge area
Nearest Gage	USGS 07159100, approximately 6 miles downstream of probable point of diversion. Period of record 1973 to 2008. No known major land use changes in the contributing basin since end of the period of record.
Gage POR and below average precipitation	12 years during the gage POR are below average precipitation years. 2001 selected as representative of approximately the 25th percentile of precipitation and occurred within the POR
Representative year flows (source availability)	Annual Flow: 509,718 AF
	Seasonal Distribution: Jan-Feb,Dec 32%; Mar-May 51%; Jun-Aug 12%; Sept-Nov 5%
Local Demand (Kingfisher)	Annual Total 4,560 AFY
Demand Density (PWS Wells)	3 wells within 1 mile radius, 5 wells within 2 mile radius. Indicates productive region of aquifer and storage capacity
Source availability as percent of pilot project demand (minimum of local demand or 1,000 AF*)	Annual basis: 100%
	Seasonally: Jan-Feb,Dec 100%; Mar-May 100%; Jun-Aug 100%; Sept-Nov 100%
Aquifer Storage Availability	Specific Yield = 0.2 (assumed)

	0.3 square mile area (radius 0.3 miles) with 25 foot increase in water levels required. Storage capacity is insufficient to maintain at least 15 feet depth to water
	0.8 square mile area (radius 0.5 miles) with 10 foot increase in water levels. Storage capacity is insufficient to maintain at least 15 feet depth to water

Based on the availability of flows and the ability of those flows to meet the pilot project demands, the source water availability receives a **moderately high** score. This is due to the gage location.

The storage capacity requirement is greater than the available storage in the aquifer below the 15 foot threshold; therefore storage availability receives a **low** score.

Based on the location of wells in close proximity to the recharge area, the demand proximity receives a **high** score.

Also, based on the number of wells (less than five) within one mile of the recharge area, demand density receives a **moderately low** score.

The source of water identified for Recharge Region 28 is the Cimarron River. Recharge area 1 is located less than one mile from the Cimarron River, and thus receives a **high** score for source proximity.

2. Water Quality

Water quality analysis included the following criteria: source water quality for non-degradation; native groundwater quality; and groundwater geochemical interactions with source water. The following table presents water quality data for those parameters that have an MCL. The MCL was exceeded in at least one recharge area in the State if the parameter is listed. Parameters that did not have any samples collected for the Recharge Region are listed but do not display the min, max, and mean rows. Parameters in **bold** exceed the MCL.

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/ Ponds	Gage # 07159100
Aluminum	ug/L	200	#	16	0	1
			min	**300**		140
			max	**300**		140
			mean*	**300**		140
Antimony	ug/L	6	#	0		0
Arsenic	ug/L	10	#	0	0	13
			min			1.0
			max			**19**
			mean*			5.3
Beryllium	ug/L	4	#	0	0	0
Cadmium	ug/L	5	#	0	0	6

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/ Ponds	Gage # 07159100
			min			2.0
			max			**20**
			mean*			**7.4**
Chloride	mg/L	250**	#	21	0	216
			min	4.0		140
			max	**2450**		**13000**
			mean*	25		**3320**
Chlorine	mg/L	4	#	0	1	0
			min		**164**	
			max		**164**	
			mean*		**164**	
Chromium	ug/L	100	#	0	0	14
			min			7.0
			max			**310**
			mean*			28
Fecal Coliform	cfu / 100 ml		#	24	0	
			min	1.0		
			max	1.0		
			mean*	1.0		
Iron	ug/L	300	#	16	0	36
			min	20		10
			max	141		**24000**
			mean*	28		**689**
Lead	ug/L	15	#	0	0	3
			min			**20**
			max			**200**
			mean*			**74**
Manganese	ug/L	50	#	16	0	38
			min	5.0		10
			max	5.0		**2900**
			mean*	5.0		**168**
Mercury	ug/L	2	#	0	0	11
			min			0.50
			max			0.70
			mean*			0.52
Nitrate / Nitrite+Nitrate (as N)	mg/L	10	#	22	1	174
			min	0.05	1.0	0.05
			max	**12**	1.0	6.0
			mean*	3.4	1.0	0.62
pH	SU	6.5-8.5**	#	109	1	287
			min	**6.2**	7.9	6.7
			max	8.4	7.9	**9.2**
			mean*	7.1	7.9	7.9
Selenium	ug/L	50	#	0	0	10
			min			2.0

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/ Ponds	Gage # 07159100
			max			8.0
			mean*			3.7
Sulfate	mg/L	250**	#	21	0	215
			min	14		34
			max	**830**		**890**
			mean*	34		**458**
Thallium	ug/L	2	#	0	0	0
Total dissolved solids	mg/L	500**	#	21	1	369
			min	202	**710**	356
			max	**5890**	**710**	**21600**
			mean*	370	**710**	**6639**
Toxaphene	ug/L	3	#	0	0	0
*mean - geometric mean						
** Secondary MCL						

The following table presents the native groundwater quality and the source water quality, including general water quality parameters and water geochemistry factors.

Parameter	Units		Groundwater	Streams/Rivers/ Ponds	Gage # 07159100
Alkalinity	mg/L as CaCO3	#	22	0	215
		min	96		1.0
		max	453		305
		mean*	168		158
Bicarbonate	mg/L	#	3	1	186
		min	117	303	0
		max	552	303	372
		mean*	199	303	199
Calcium	mg/L	#	17	1	227
		min	35	62	9.7
		max	72	62	550
		mean*	55	62	175
Carbonate	mg/L	#	3	0	188
		min	0		0
		max	0		10
		mean*			4.5
Chloride	mg/L	#	21	0	216
		min	4.0		140
		max	2450		13000
		mean*	25		3320
Fluoride	mg/L	#	18	0	51
		min	0.15		0.10
		max	0.74		0.80
		mean*	0.25		0.42
Hardness	mg/L as	#	5	0	213

Parameter	Units		Groundwater	Streams/Rivers/ Ponds	Gage # 07159100
	CaCO3	**min**	120		90
		max	1000		1300
		mean*	278		665
Magnesium	mg/L	#	17	1	226
		min	9.1	30	6.2
		max	19	30	190
		mean*	14	30	56
Nitrate / Nitrite+Nitrate (as N)	mg/L as N	#	22	1	174
		min	0.05	1.0	0.05
		max	12	1.0	6.0
		mean*	3.4	1.0	0.62
Nitrite (as N)	mg/L as N	#	1	0	21
		min	0.03		0.01
		max	0.03		0.81
		mean*	0.03		0.02
Orthophosphate	mg/L	#	0	0	0
pH	SU	#	109	1	287
		min	6.2	7.9	6.7
		max	8.4	7.9	9.2
		mean*	7.1	7.9	7.9
Phosphorus	mg/L as P	#	1	0	0
		min	0.04		
		max	0.04		
		mean*	0.04		
Silica	mg/L as SiO2	#	0	0	1
		min			5.1
		max			5.1
		mean*			5.1
Sulfate	mg/L	#	21	0	215
		min	14		34
		max	830		890
		mean*	34		458
Temperature	deg C	#	5	0	156
		min	17		-1.0
		max	19		35
		mean*	18		16
Total dissolved solids	mg/L	#	21	1	369
		min	202	710	356
		max	5890	710	21600
		mean*	370	710	6639
Total suspended solids (TSS)	mg/L	#	0	0	0
Langelier's Saturation Index**	LSI	#	3	0	86
		min	0.50		-1.4
		max	1.1		1.1
		mean*	0.74		0.32

Parameter	Units		Groundwater	Streams/Rivers/ Ponds	Gage # 07159100
*mean - geometric mean					
**Langelier's Index (LSI)					

In general, the source water quality appeared to be very poor, with many exceedences of MCLs and high TDS concentrations. The majority of concentrations were greater than that of the groundwater. Thus, the source water quality received a **low** score. The groundwater conditions appear to be somewhat favorable, with a few exceedences of the MCL. This resulted in a **moderate** score for native groundwater quality.

Based on the Langelier's index, the groundwater geochemistry is slightly positive for scaling and dissolution, indicating a chance for scaling that would impact AR operations. Source water sampling had a near neutral Langelier's index, suggesting minimal chance for scaling. This suggests that the source water has a potential to improve the groundwater geochemistry. Thus, the geochemical interaction criterion will receive a **moderately high** score.

3. Hydrogeologic Suitability

Hydrogeologic suitability of the Cimarron River alluvial terrace aquifer includes an evaluation of transmissivity, residence time, and general aquifer properties. The Cimarron River aquifer is an unconfined alluvial aquifer. Groundwater flow in the vicinity of the Recharge Region generally travels in a southeast direction, along the Cimarron River, as indicated on Figure K-4. The Cimarron River aquifer is in communication with the river, as indicated by areas in red on Figure K-2. The following table provides a summary of aquifer properties and approximate residence time.

Parameter	Value	Source
Hydraulic Conductivity	47.5 to 104.5 ft/day	AWI
Greatest Thickness	120 ft	AWI
Transmissivity (Computed from K, thickness)	5,700 to 12,540 ft2/day	AWI
Specific Yield	Unknown	AWI
Well Yield	100 to 600 GPM	AWI
% of Recharge Lost in 180 Days	70	Glover
Number of Days Until 25% Loss	20	Glover
Distance to Discharge	0.3 miles	N/A

Based on the aquifer properties, transmissivity received a **high** score.

Based on the Glover calculations, the residence time criterion received a **low** score.

4. Cost: Operation and Maintenance (O&M) and Capital

A table showing the primary cost considerations and whether they apply to a recharge area is presented below.

	Treatment – High TSS	Treatment - Other	Gravity Feed	Forcemain/ Pipeline	Injection Well - Available	Injection Well – Construct	Spreading Basin
Recharge area 1		X		X			X

The relatively poor water quality of the source water will require treatment prior to injection into the aquifer. Due to the topography of the region, a force-main pipeline will be required to deliver water to the recharge project. Because the aquifer is alluvial and the depth to water is less than 50 feet, a spreading basin could be used. Based on these factors, the Recharge Region received a **low** score for capital cost. The O&M cost received a **moderate** score due to maintenance of the force-main, treatment system, and spreading basin.

5. Qualitative Considerations

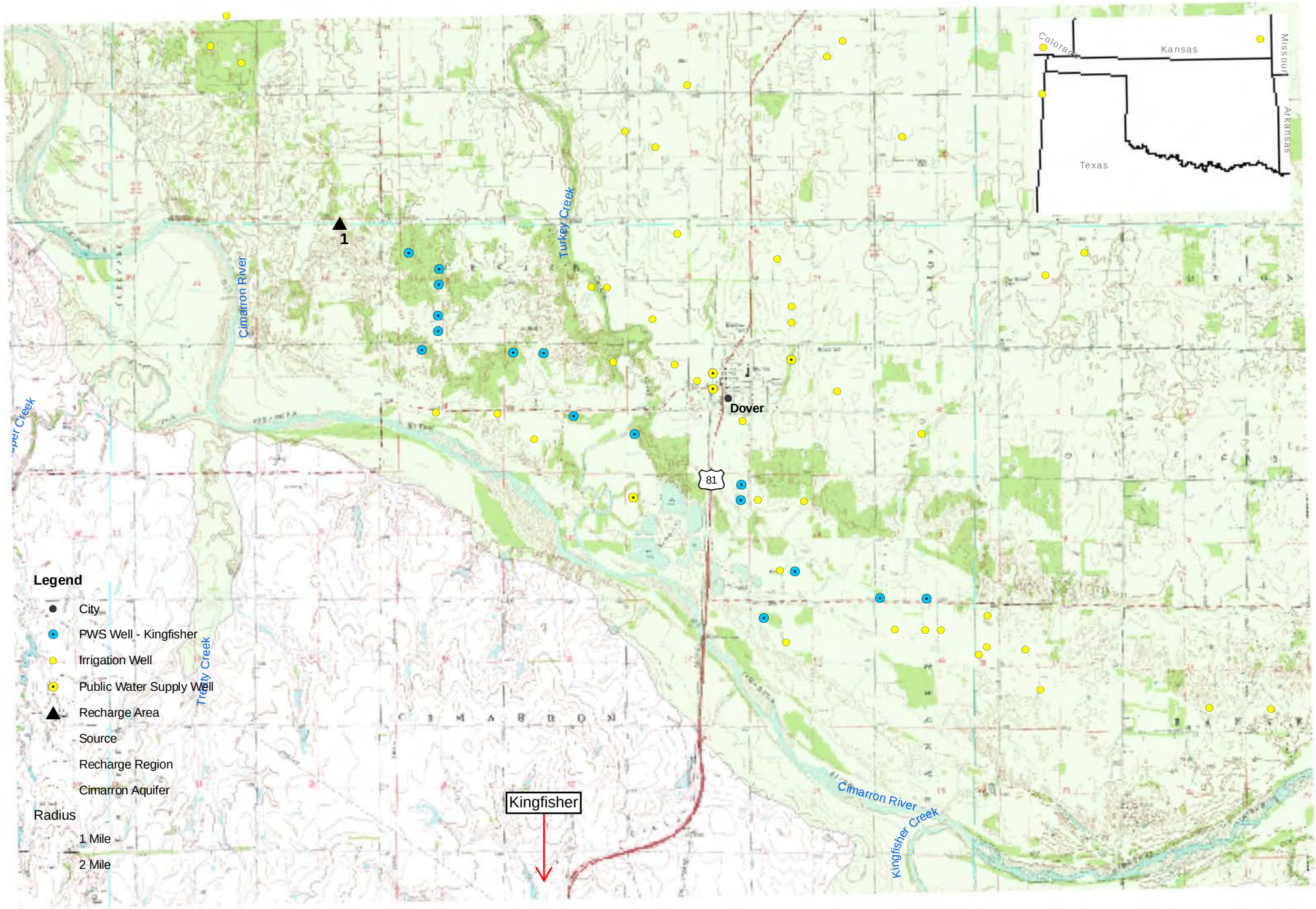
Based on the assumed project size of 1,000 acre-feet, 22 percent of the total demand will be met. Thus, qualitative considerations received a **moderately high** score.

6. Summary

The following table presents a summary of the scores and reasoning for assignment of those scores for Recharge Region 28.

Criterion	Score	Reasoning
Source Availability	Moderately high	Adequate flow, but gage located 6 miles downstream
Demand Proximity (distance from recharge area)	High	PWS wells within 1 mile
Source Proximity (distance from recharge area)	High	Cimarron River < 1 mile
Available Freeboard and Ability to Meet Demand	Low	Not enough volume to meet recharged volume

Demand Density (number of wells)	Moderately low	Less than 5 wells within 1 mile
Source Quality for Non-degradation	Low	Many MCL exceedences, high TDS
Native Groundwater Quality	Moderate	Some MCL exceedances
Geochemical Interactions of Source and Groundwater	Moderately high	Minimal difference in Langelier's; source may improve groundwater
Transmissivity	High	Good aquifer properties for AR
Residence Time	Low	70% loss within 180 days, 20 days to 25% loss
Cost (O&M)	Moderate	Pretreatment; operation of spreading basin and pipeline
Cost (capital)	Low	Pipeline, spreading basin, treatment system
Qualitative Considerations	Moderately high	22% of total demand



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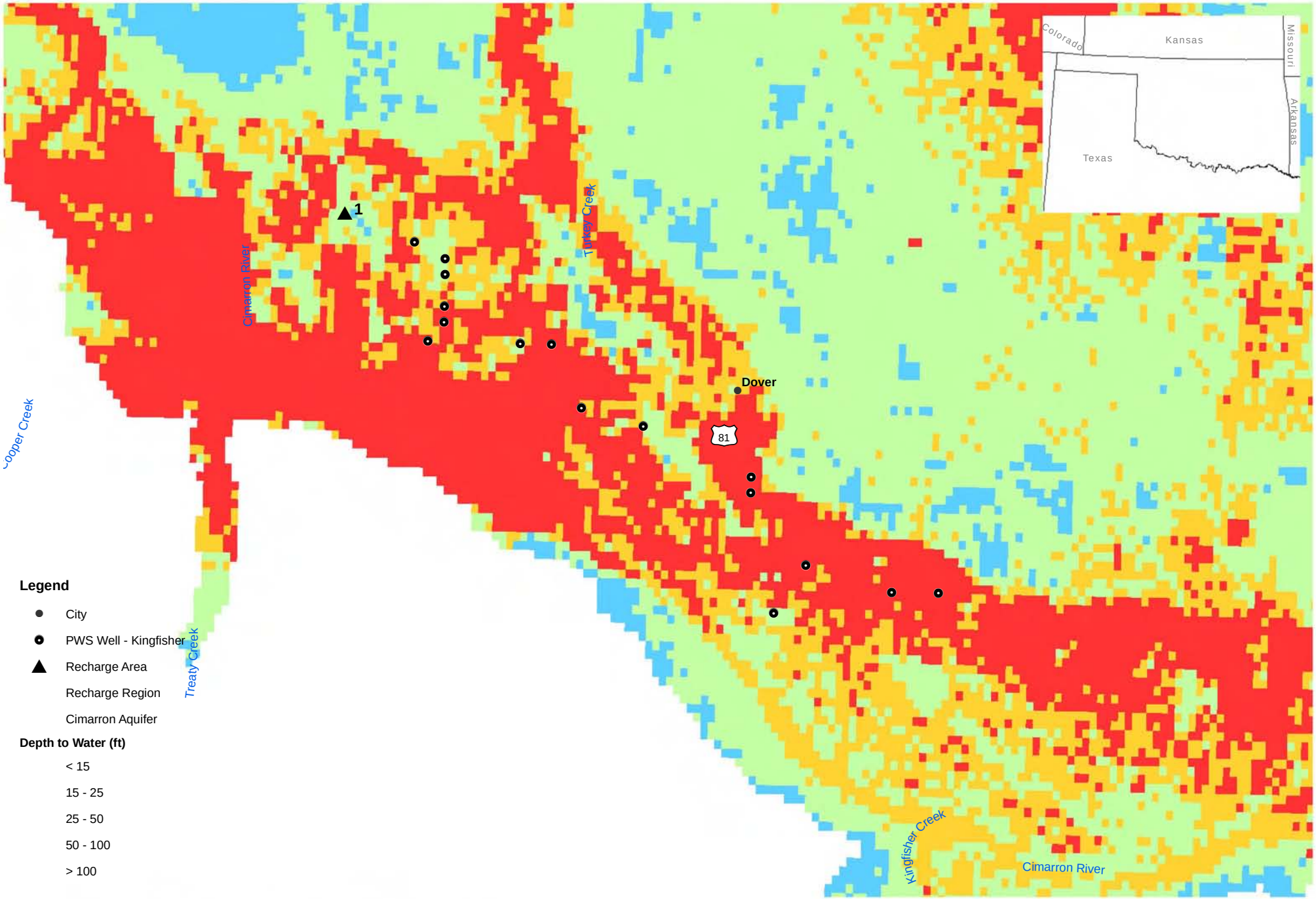
Miles

Site 28 Demand and Source Proximity

FIGURE K-1



OWRB State of Oklahoma Water Resources Board the water agency

US Army Corps of Engineers

CDM

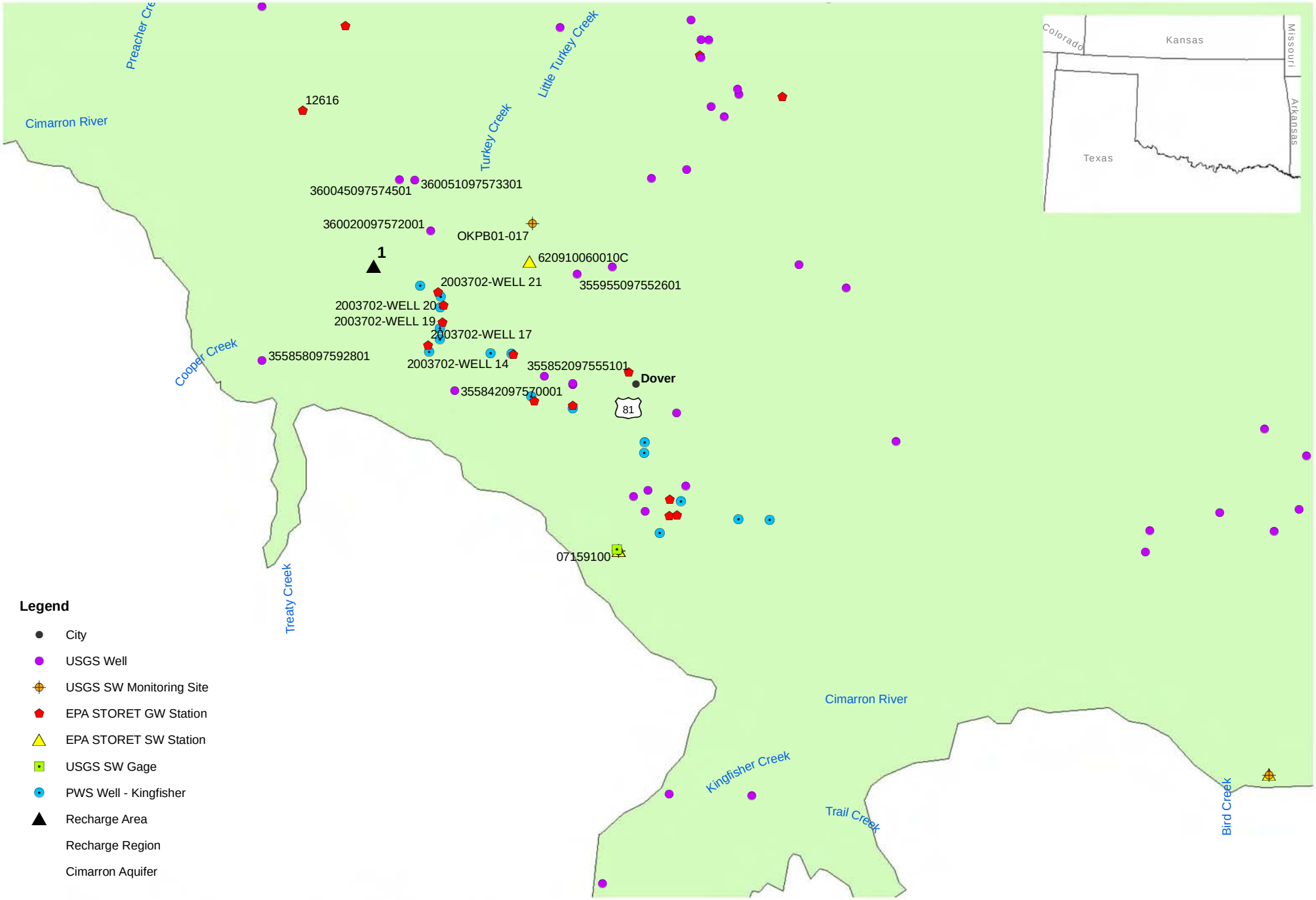
Oklahoma Comprehensive Water Plan OCWP

N W E S

0 0.5 1 2 Miles

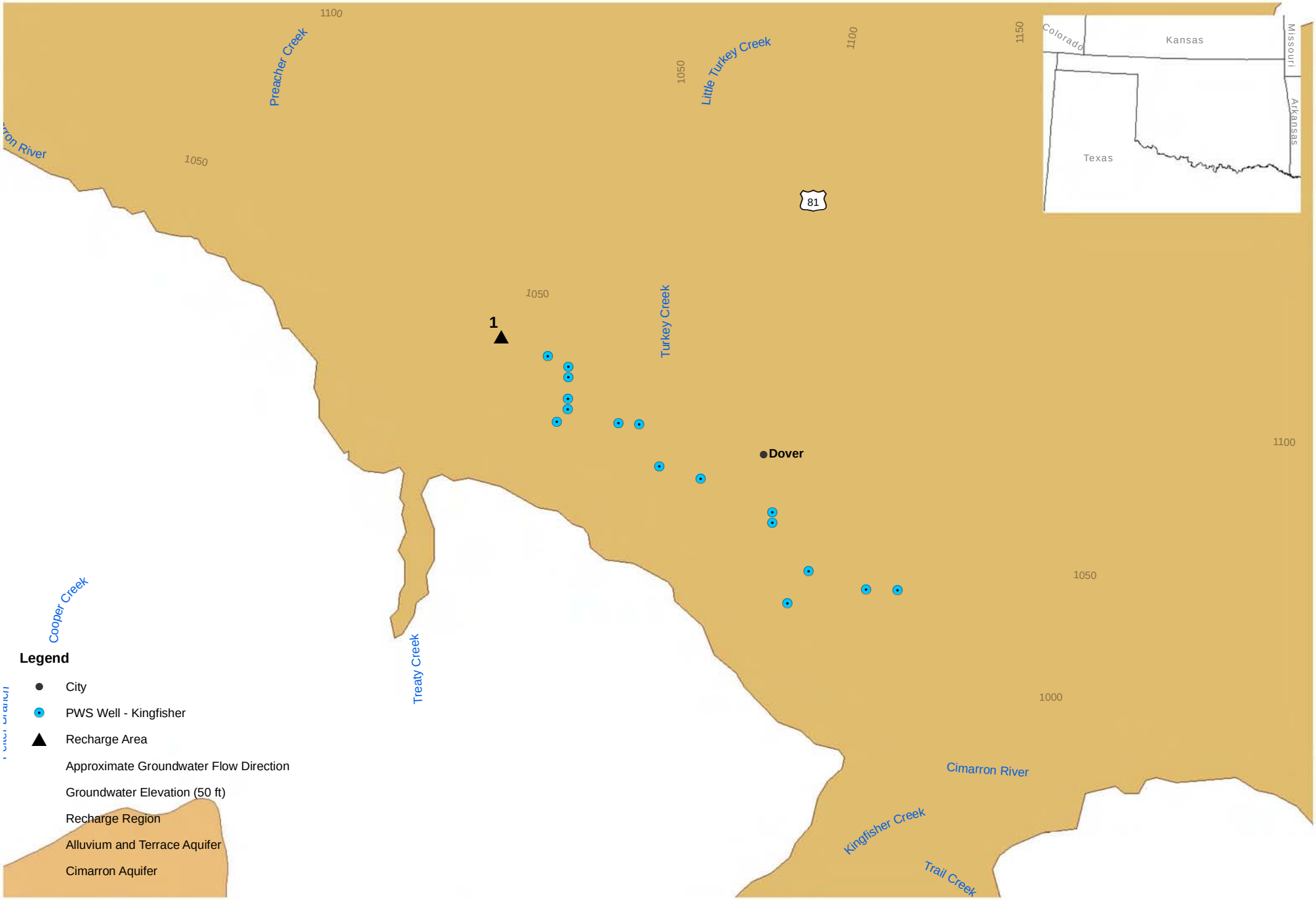
Site 28 Depth to Water

FIGURE K-2



Site 28 Surface and Groundwater Quality Sample Locations

FIGURE K-3



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Site 28 Hydrogeology

FIGURE K-4

Appendix L
Detailed Analysis of Recharge Region Number 30, Lower Cimarron River Alluvial Aquifer near Enid

Appendix L - Recharge Region 30

Recharge Region 30 is located in the vicinity of the town of Enid, with the Enid isolated terrace aquifer providing storage for an AR project. According to the U.S. Census Bureau, the town of Enid had an estimated population of approximately 47,396 individuals in 2008; year 2000 census data indicated 47,045 individuals (U.S. Census Bureau). For this recharge region, the demand location was identified as the PWS wells for the town of Enid, and the source for the potential recharge project was identified as Skeleton Creek. One potential recharge area was identified based on the available freeboard in the aquifer, and proximity to the source and demand. The potential recharge area is located in the northeast portion of the recharge region (see Figure L-1).

1. Demand, Source, and Storage Considerations

The following table summarizes several aspects of the recharge area related to source water availability, local demand, ability of the source to meet the demand, and storage capacity. Proximity data is shown on Figure L-1, and available freeboard is shown on Figure L-2.

Source Basin	Basin 20910
Sufficient Legally Available Water for Pilot Project	Yes
Source Stream	Skeleton Creek. Probable point of diversion approximately 1 mile north of recharge area
Nearest Gage	USGS 07160350, approximately 7 miles downstream of probable point of diversion. Period of record 1996 to 2008. No known major land use changes in the contributing basin since end of the period of record. Low flows regulated by Enid wastewater discharge.
Gage POR and below average precipitation	3 years during the gage POR are below average precipitation years. 2001 selected as representative of approximately the 25th percentile of precipitation and occurred within the POR
Representative year flows (source availability)	Annual Flow: 15,835 AF
	Seasonal Distribution: Jan-Feb,Dec 33%; Mar-May 40%; Jun-Aug 13%; Sept-Nov 14%
Local Demand (Enid)	Annual Total 47,600 AFY
Demand Density (PWS Wells)	7 wells within 1 mile radius, 2 wells within 2 mile radius. Indicates productive region of aquifer and storage capacity
Source availability as percent of pilot project demand (minimum of local demand or 1,000 AF*)	Annual basis: 100%
	Seasonally: Jan-Feb,Dec 100%; Mar-May 100%; Jun-Aug 50%; Sept-Nov 50%
Aquifer Storage Availability	Specific Yield = 0.295

	0.2 square mile area (radius 0.3 miles) with 25 foot increase in water levels required. Storage capacity is sufficient while maintaining at least 15 feet depth to water
	0.5 square mile area (radius 0.4 miles) with 10 foot increase in water levels. Storage capacity is sufficient while maintaining at least 15 feet depth to water

Based on the availability of flows and the ability of those flows to meet the pilot project demands, the source water availability receives a **moderate** score. This is due to the gage location and likely lack of flows seasonally.

The storage capacity requirement is less than the available storage in the aquifer below the 15 foot threshold; therefore storage availability receives a **high** score.

Based on the location of wells in close proximity to the recharge area, the demand proximity receives a **high** score.

Also, based on the number of wells (five to ten) within one mile of the recharge area, demand density receives a **moderately high** score.

The source of water identified for Recharge Region 30 is Skeleton Creek. Recharge area 1 is located greater than two miles from Skeleton Creek, and thus receives a **low** score for source proximity.

2. Water Quality

Water quality analysis included the following criteria: source water quality for non-degradation; native groundwater quality; and groundwater geochemical interactions with source water. The following table presents water quality data for those parameters that have an MCL. The MCL was exceeded in at least one recharge area in the State if the parameter is listed. Parameters that did not have any samples collected for the Recharge Region are listed but do not display the min, max, and mean rows. Parameters in **bold** exceed the MCL.

Parameter	Units	EPA MCL		Groundwater	Gage # 07160350
Aluminum	ug/L	200	#	15	0
			min	**300**	
			max	**300**	
			mean*	**300**	
Antimony	ug/L	6	#	0	0
Arsenic	ug/L	10	#	0	0
Beryllium	ug/L	4	#	0	0
Cadmium	ug/L	5	#	0	0
Chloride	mg/L	250**	#	22	0
			min	12	
			max	**260**	
			mean*	39	

Parameter	Units	EPA MCL		Groundwater	Gage # 07160350
Chlorine	mg/L	4	#	0	0
Chromium	ug/L	100	#	0	0
Fecal Coliform	cfu / 100 ml		#	0	
Iron	ug/L	300	#	15	0
			min	18	
			max	81	
			mean*	23	
Lead	ug/L	15	#	0	0
Manganese	ug/L	50	#	15	0
			min	5.0	
			max	18	
			mean*	5.4	
Mercury	ug/L	2	#	0	0
Nitrate / Nitrite+Nitrate (as N)	mg/L	10	#	23	0
			min	0.05	
			max	**15**	
			mean*	4.2	
pH	SU	6.5-8.5**	#	10	0
			min	6.7	
			max	7.5	
			mean*	7.0	
Selenium	ug/L	50	#	0	0
Sulfate	mg/L	250**	#	22	0
			min	7.9	
			max	63	
			mean*	22	
Thallium	ug/L	2	#	0	0
Total dissolved solids	mg/L	500**	#	18	0
			min	170	
			max	**612**	
			mean*	355	
Toxaphene	ug/L	3	#	0	0
*mean - geometric mean					
** Secondary MCL					

The following table presents the native groundwater quality and the source water quality, including general water quality parameters and water geochemistry factors.

Parameter	Units		Groundwater	Gage # 07160350
Alkalinity	mg/L as CaCO3	#	19	0
		min	119	
		max	319	
		mean*	193	
Bicarbonate	mg/L	#	6	0

Parameter	Units		Groundwater	Gage # 07160350
		min	145	
		max	266	
		mean*	197	
Calcium	mg/L	#	21	0
		min	7.5	
		max	95	
		mean*	52	
Carbonate	mg/L	#	6	0
		min	0	
		max	0	
		mean*		
Chloride	mg/L	#	22	0
		min	12	
		max	260	
		mean*	39	
Fluoride	mg/L	#	18	0
		min	0.05	
		max	0.30	
		mean*	0.18	
Hardness	mg/L as CaCO3	#	6	0
		min	100	
		max	230	
		mean*	155	
Magnesium	mg/L	#	19	0
		min	9.0	
		max	30	
		mean*	11	
Nitrate / Nitrite+Nitrate (as N)	mg/L as N	#	23	0
		min	0.05	
		max	15	
		mean*	4.2	
Nitrite (as N)	mg/L as N	#	0	0
Orthophosphate	mg/L	#	0	0
pH	SU	#	10	0
		min	6.7	
		max	7.5	
		mean*	7.0	
Phosphorus	mg/L as P	#	0	0
Silica	mg/L as SiO2	#	3	0
		min	23	
		max	26	
		mean*	24	
Sulfate	mg/L	#	22	0
		min	7.9	
		max	63	
		mean*	22	

Parameter	Units		Groundwater	Gage # 07160350
Temperature	deg C	#	2	5
		min	16	9.9
		max	17	26
		mean*	16	16
Total dissolved solids	mg/L	#	18	0
		min	170	
		max	612	
		mean*	355	
Total suspended solids (TSS)	mg/L	#	0	0
Langelier's Saturation Index**	LSI	#	8	0
		min	-0.29	
		max	0.92	
		mean*	0.44	
*mean - geometric mean				
**Langelier's Index (LSI)				

There is no surface water quality data available for the vicinity of the recharge region. Thus, the source water quality received a **low** score due to the data gap. The groundwater conditions appear to be favorable, although a few maximum concentrations exceeded the MCL. This resulted in a **moderate** score for native groundwater quality.

Based on the Langelier's index, the groundwater geochemistry is near neutral for scaling and dissolution, indicating minimal geochemical instability that would impact AR operations. There was not enough source water data to make a determination of geochemical stability. Thus, the geochemical interaction criterion will receive a **moderately low** score, due to the data gap for the source water.

3. Hydrogeologic Suitability

Hydrogeologic suitability of the Enid isolated terrace aquifer includes an evaluation of transmissivity, residence time, and general aquifer properties. The Enid isolated terrace aquifer is an unconfined alluvial aquifer. Groundwater flow in the vicinity of the Recharge Region generally travels in a southeastern direction, toward Skeleton Creek, as indicated on Figure L-4. The Enid isolated terrace aquifer discharges to Skeleton Creek, as indicated by areas in red on Figure L-2. The following table provides a summary of aquifer properties and approximate residence time.

Parameter	Value	Source
Transmissivity	1,270 ft^2/day	AWI
Specific Yield	0.298	AWI
Well Yield	20 to 400 GPM	AWI
% of Recharge Lost in 180 Days	0	N/A
Number of Days Until 25% Loss	>1,680 days	N/A

Distance to Discharge	2.4 miles	N/A

Based on the aquifer properties, transmissivity received a **high** score.

Based on the Glover calculations, the residence time criterion received a **high** score.

4. Cost: Operation and Maintenance (O&M) and Capital

A table showing the primary cost considerations and whether it applies to a recharge area is presented below.

	Treatment – High TSS	Treatment - Other	Gravity Feed	Forcemain/ Pipeline	Injection Well - Available	Injection Well - Construct	Spreading Basin
Recharge Area 1			X		X		X

The surface water quality is unknown, so a treatment system may be required. This recharge region would likely be able to utilize gravity flow to deliver water to the project. Because the aquifer is alluvial and the depth to water is approximately 50 feet, a spreading basin could be used, although the existing PWS wells in the vicinity may also be usable for AR. Based on these factors, the Recharge Region received a **moderate** score for capital cost. The O&M cost received a **high** score due to maintenance of the spreading basin.

5. Qualitative Considerations

Based on the assumed project size of 1,000 acre-feet, two percent of the total demand will be met. Thus, qualitative considerations received a **low** score.

6. Summary

The following table presents a summary of the scores and reasoning for assignment of those scores for Recharge Region 30.

Criterion	Score	Reasoning
Source Availability	Moderate	Flows adequate seasonally, gage located 7 miles downstream
Demand Proximity (distance from recharge area)	High	PWS wells within 1 mile

Source Proximity (distance from recharge area)	Low	Skeleton Creek > 2 miles
Available Freeboard and Ability to Meet Demand	High	Plentiful volume to meet recharged volume
Demand Density (number of wells)	Moderately high	5 to 10 wells within 1 mile
Source Quality for Non-degradation	Low	No data available
Native Groundwater Quality	Moderate	Some MCL exceedences
Geochemical Interactions of Source and Groundwater	Moderately Low	Langelier's not available for source
Transmissivity	High	Good aquifer properties for AR
Residence Time	High	No losses within 180 days, >1,680 days to 25% loss
Cost (O&M)	High	Operation of spreading basin
Cost (capital)	Moderate	Gravity feed, spreading basin; possible pretreatment
Qualitative Considerations	Low	2% of total demand

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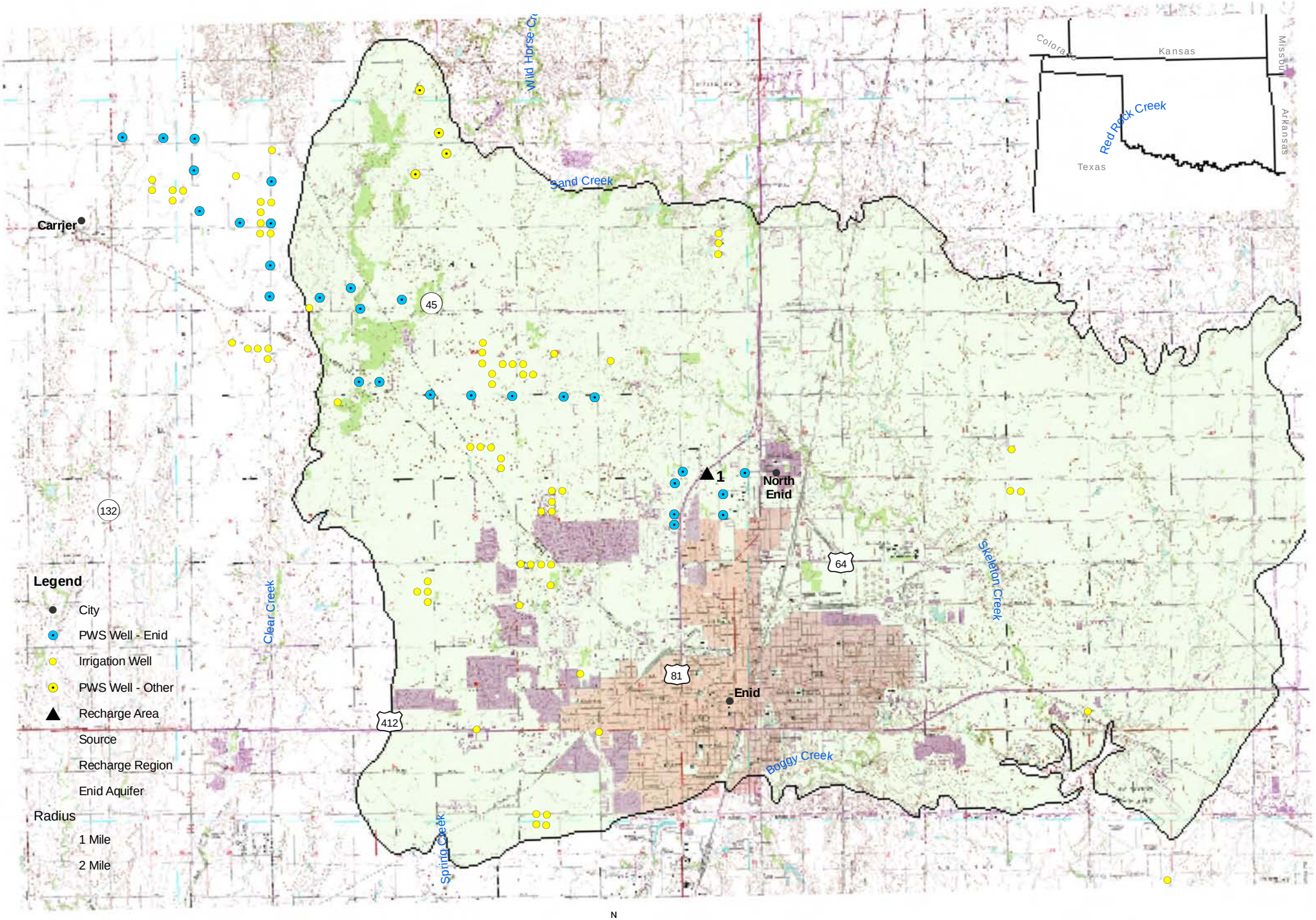

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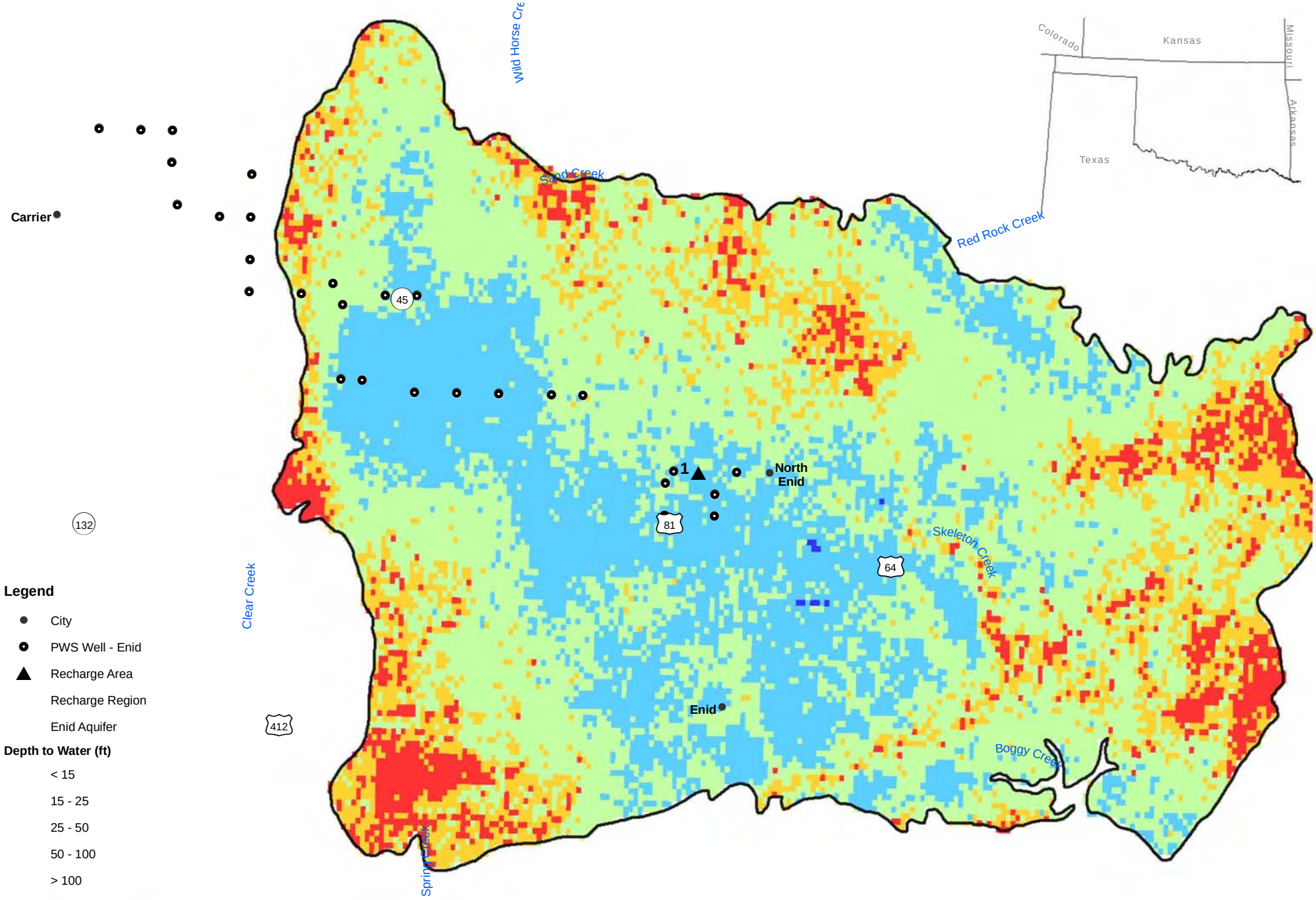
Miles

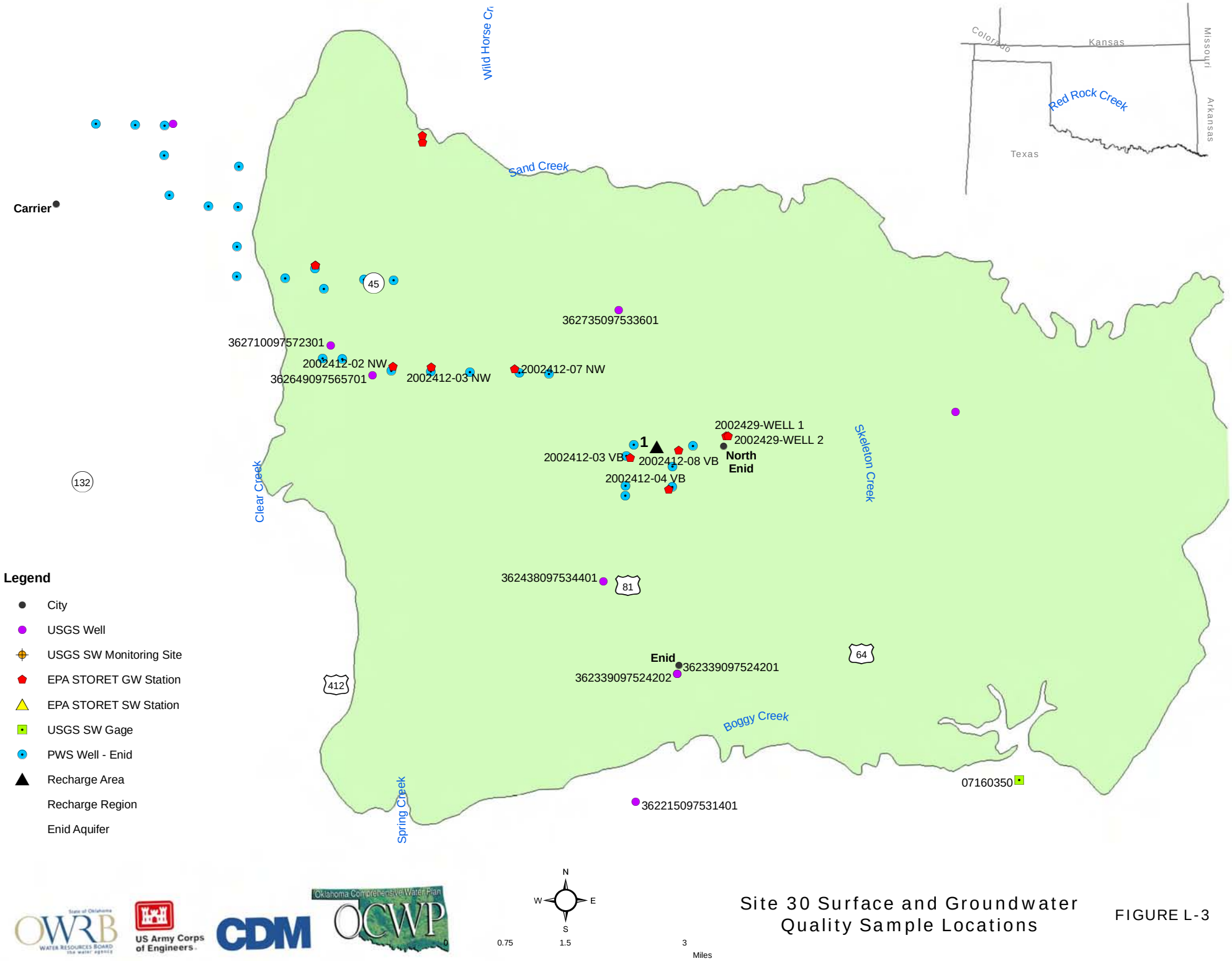
Site 30 Demand and Source Proximity

FIGURE L-1



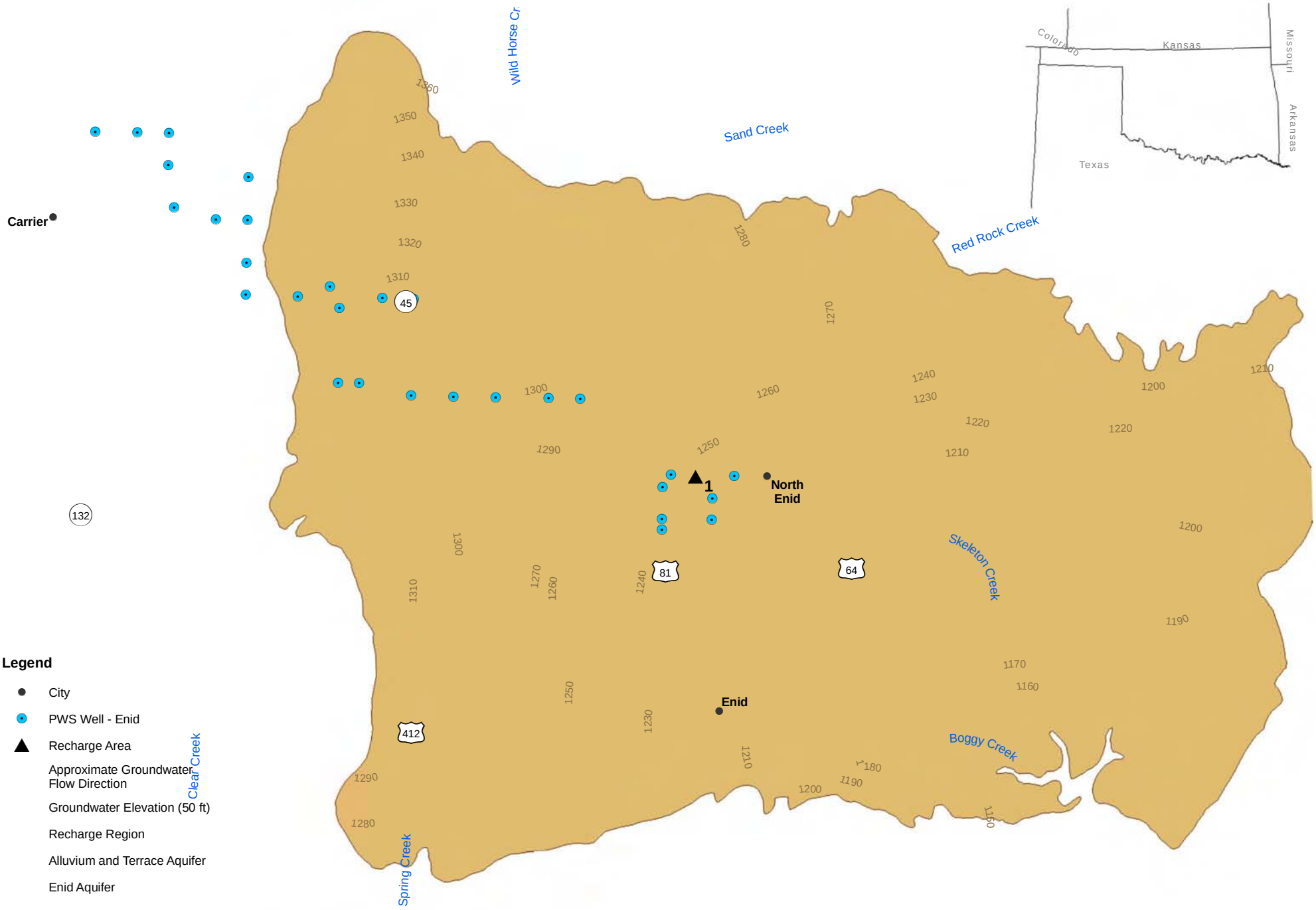
Site 30 Depth to Water

FIGURE L-2



Site 30 Surface and Groundwater Quality Sample Locations

FIGURE L-3



Site 30 Hydrogeology

FIGURE L-4

Appendix M
Detailed Analysis of Recharge Region Number 31, Upper Salt Fork of Arkansas River Alluvial Aquifer near Cherokee

Appendix M - Recharge Region 31

Recharge Region 31 is located in the vicinity of the town of Cherokee, with the Salt Fork Arkansas River alluvial terrace aquifer providing storage for an AR project. According to the U.S. Census Bureau, the town of Cherokee had an estimated population of approximately 1,437 individuals in 2008; year 2000 census data indicated 1,630 individuals (U.S. Census Bureau). For this recharge region, the demand location was identified as the PWS wells for the town of Cherokee, and the source for the potential recharge project was identified as the Salt Fork Arkansas River. One potential recharge area was identified based on the available freeboard in the aquifer, and proximity to the source and demand. The potential recharge area is located in the southwest portion of the recharge region (see Figure M-1).

1. Demand, Source, and Storage Considerations

The following table summarizes several aspects of the recharge area related to source water availability, local demand, ability of the source to meet the demand, and storage capacity. Proximity data is shown on Figure M-1, and available freeboard is shown on Figure M-2.

Source Basin	Basin 21021
Sufficient Legally Available Water for Pilot Project	Yes
Source Stream	Salt Fork Arkansas River. Probable point of diversion approximately 3.5 miles north of recharge area
Nearest Gage	USGS 07148450, approximately 2 miles downstream of probable point of diversion. Period of record 1961 to 1962; 1973 to 1979. No known major land use changes in the contributing basin since end of the period of record. Part of basin in Kansas; unknown development. Only use high flows.
Gage POR and below average precipitation	4 years during the gage POR are below average precipitation years. 1976 selected as representative of approximately the 25th percentile of precipitation and occurred within the POR
Representative year flows (source availability)	Annual Flow: 51,881 AF
	Seasonal Distribution: Jan-Feb,Dec 8%; Mar-May 85%; Jun-Aug 7%; Sept-Nov 0%
Local Demand (Cherokee)	Annual Total 1,650 AFY
Demand Density (PWS Wells)	3 wells within 1 mile radius, 2 wells within 2 mile radius. Indicates productive region of aquifer and storage capacity
Source availability as percent of pilot project demand (minimum of local demand or 1,000 AF*)	Annual basis: 100%
	Seasonally: Jan-Feb,Dec 100%; Mar-May 100%; Jun-Aug 50%; Sept-Nov 50%
Aquifer Storage Availability	Specific Yield = 0.2

	0.3 square mile area (radius 0.3 miles) with 25 foot increase in water levels required. Storage capacity is insufficient to maintain at least 15 feet depth to water
	0.8 square mile area (radius 0.5 miles) with 10 foot increase in water levels. Storage capacity is insufficient to maintain at least 15 feet depth to water

Based on the availability of flows and the ability of those flows to meet the pilot project demands, the source water availability receives a **moderate** score. This is due to the period of record and unknown irrigation well impact.

The storage capacity requirement is greater than the available storage in the aquifer below the 15 foot threshold; therefore storage availability receives a **low** score.

Based on the location of wells in close proximity to the recharge area, the demand proximity receives a **high** score.

Also, based on the number of wells (less than five) within one mile of the recharge area, demand density receives a **moderately low** score.

The source of water identified for Recharge Region 31 is Salt Fork Arkansas River. Recharge area 1 is located greater than two miles from Salt Fork Arkansas River, and thus receives a **low** score for source proximity.

2. Water Quality

Water quality analysis included the following criteria: source water quality for non-degradation; native groundwater quality; and groundwater geochemical interactions with source water. The following table presents water quality data for those parameters that have an MCL. The MCL was exceeded in at least one recharge area in the State if the parameter is listed. Parameters that did not have any samples collected for the Recharge Region are listed but do not display the min, max, and mean rows. Parameters in **bold** exceed the MCL.

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/Ponds
Aluminum	ug/L	200	#	7	0
			min	**300**	
			max	**300**	
			mean*	**300**	
Antimony	ug/L	6	#	0	
Arsenic	ug/L	10	#	0	28
			min		10
			max		10
			mean*		10
Beryllium	ug/L	4	#	0	0
Cadmium	ug/L	5	#	0	28

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/Ponds
			min		1.0
			max		5.0
			mean*		2.0
Chloride	mg/L	250**	#	11	172
			min	10	5.0
			max	**1380**	**1438**
			mean*	165	130
Chlorine	mg/L	4	#	0	10
			min		**59**
			max		**205**
			mean*		**111**
Chromium	ug/L	100	#	0	28
			min		5.0
			max		10
			mean*		5.8
Fecal Coliform	cfu / 100 ml		#	0	100
			min		10
			max		7000
			mean*		331
Iron	ug/L	300	#	7	0
			min	20	
			max	20	
			mean*	20	
Lead	ug/L	15	#	0	28
			min		3.0
			max		10
			mean*		5.2
Manganese	ug/L	50	#	7	0
			min	5.0	
			max	5.0	
			mean*	5.0	
Mercury	ug/L	2	#	0	28
			min		0.05
			max		0.50
			mean*		0.24
Nitrate / Nitrite+Nitrate (as N)	mg/L	10	#	11	198
			min	0.02	0.05
			max	7.0	0.69
			mean*	1.1	0.26
pH	SU	6.5-8.5**	#	11	176
			min	6.6	**6.4**
			max	7.8	8.4
			mean*	7.4	7.9
Selenium	ug/L	50	#	0	44
			min		5.0
			max		11

Parameter	Units	EPA MCL		Groundwater	Streams/Rivers/Ponds
			mean*		7.4
Sulfate	mg/L	250**	#	11	172
			min	10	5.0
			max	**1420**	**1051**
			mean*	**401**	**616**
Thallium	ug/L	2	#	0	28
			min		**3.0**
			max		**10**
			mean*		**5.8**
Total dissolved solids	mg/L	500**	#	11	204
			min	19	1.1
			max	**4800**	**2528**
			mean*	**1142**	**686**
Toxaphene	ug/L	3	#	0	28
			min		0.03
			max		0.03
			mean*		0.03
*mean - geometric mean					
** Secondary MCL					

The following table presents the native groundwater quality and the source water quality, including general water quality parameters and water geochemistry factors.

Parameter	Units		Groundwater	Streams/Rivers/Ponds
Alkalinity	mg/L as CaCO3	#	11	0
		min	10	
		max	455	
		mean*	234	
Bicarbonate	mg/L	#	4	0
		min	222	
		max	342	
		mean*	273	
Calcium	mg/L	#	8	7
		min	1.0	259
		max	492	316
		mean*	75	293
Carbonate	mg/L	#	4	166
		min	0	0
		max	0	1195
		mean*		872
Chloride	mg/L	#	11	172
		min	10	5.0
		max	1380	1438
		mean*	165	130
Fluoride	mg/L	#	7	0

Parameter	Units		Groundwater	Streams/Rivers/Ponds
		min	0.10	
		max	0.39	
		mean*	0.27	
Hardness	mg/L as CaCO3	#	4	0
		min	300	
		max	1700	
		mean*	1030	
Magnesium	mg/L	#	8	7
		min	1.0	65
		max	110	84
		mean*	51	75
Nitrate / Nitrite+Nitrate (as N)	mg/L as N	#	11	198
		min	0.02	0.05
		max	7.0	0.69
		mean*	1.1	0.26
Nitrite (as N)	mg/L as N	#	1	190
		min	0.01	0.04
		max	0.01	0.19
		mean*	0.01	0.05
Orthophosphate	mg/L	#	0	196
		min		0.01
		max		0.43
		mean*		0.02
pH	SU	#	11	176
		min	6.6	6.4
		max	7.8	8.4
		mean*	7.4	7.9
Phosphorus	mg/L as P	#	1	0
		min	0.01	
		max	0.01	
		mean*	0.01	
Silica	mg/L as SiO2	#	0	0
Sulfate	mg/L	#	11	172
		min	10	5.0
		max	1420	1051
		mean*	401	616
Temperature	deg C	#	3	170
		min	13	1.9
		max	16	37
		mean*	15	15
Total dissolved solids	mg/L	#	11	204
		min	19	1.1
		max	4800	2528
		mean*	1142	686
Total suspended solids	mg/L	#	0	40

Parameter	Units		Groundwater	Streams/Rivers/Ponds
(TSS)		**min**		0
		max		2650
		mean*		93
Langelier's Saturation Index**	LSI	#	5	0
		min	0.60	
		max	1.9	
		mean*	1.2	
*mean - geometric mean				
**Langelier's Index (LSI)				

In general, the source water quality appeared to be somewhat poor, with various MCL exceedences, and high TDS. However, many of the source water parameter concentrations were less than that of the groundwater, including TDS, suggesting that an improvement to groundwater quality could occur. overall, the source water quality received a **moderately low** score due to the MCL exceedences. The groundwater conditions appear to be somewhat poor, primarily due to high TDS concentrations. This resulted in a **low** score for native groundwater quality.

Based on the Langelier's index, the groundwater geochemistry is positive for scaling and dissolution, indicating that scaling would be likely and could impact AR operations. Source water sampling did not include all the parameters necessary to calculate the Langelier's index, and did not include sampling for hardness. However, the pH values are only slightly higher than groundwater, suggesting that the geochemical conditions are of the source water are comparable to that of the groundwater. Thus, the geochemical interaction criterion will receive a **moderately low** score due to the data gap for the Langelier's index and potential for scaling.

3. Hydrogeologic Suitability

Hydrogeologic suitability of the Salt Fork Arkansas alluvial aquifer includes an evaluation of transmissivity, residence time, and general aquifer properties. The Salt Fork Arkansas alluvial aquifer is unconfined. Groundwater flow in the vicinity of the Recharge Region is anticipated to travel in an eastern direction, toward the Great Salt Plains Reservoir. The Salt Fork Arkansas alluvial aquifer is likely in communication with the river, as indicated by freeboard values shown on Figure M-2. The following table provides a summary of aquifer properties and approximate residence time.

Parameter	Value	Source
Transmissivity	716 to 4,252 ft^2/day	USGS
Specific Yield	Unknown	AWI
Well Yield	300 to 500 GPM	AWI
% of Recharge Lost in 180 Days	32	Glover
Number of Days Until 25% Loss	140	Glover
Distance to Discharge	0.4 miles	N/A

Based on the aquifer properties, transmissivity received a **high** score.

Based on the Glover calculations, the residence time criterion received a **moderate** score.

4. Cost: Operation and Maintenance (O&M) and Capital

A table showing the primary cost considerations and whether they apply to a recharge area is presented below.

	Treatment – High TSS	Treatment - Other	Gravity Feed	Forcemain/ Pipeline	Injection Well - Available	Injection Well - Construct	Spreading Basin
Recharge area 1		X	X		X		X

The relatively poor water quality of the source water will require treatment prior to injection into the aquifer. This recharge region would likely be able to utilize gravity flow to deliver water to the project. Because the aquifer is alluvial and the depth to water is approximately 50 feet, a spreading basin could be used, although the existing PWS wells in the vicinity may also be usable for AR. Based on these factors, the Recharge Region received a **moderate** score for capital cost. The O&M cost received a **moderately high** score due to maintenance of the spreading basin and operation of the treatment system.

5. Qualitative Considerations

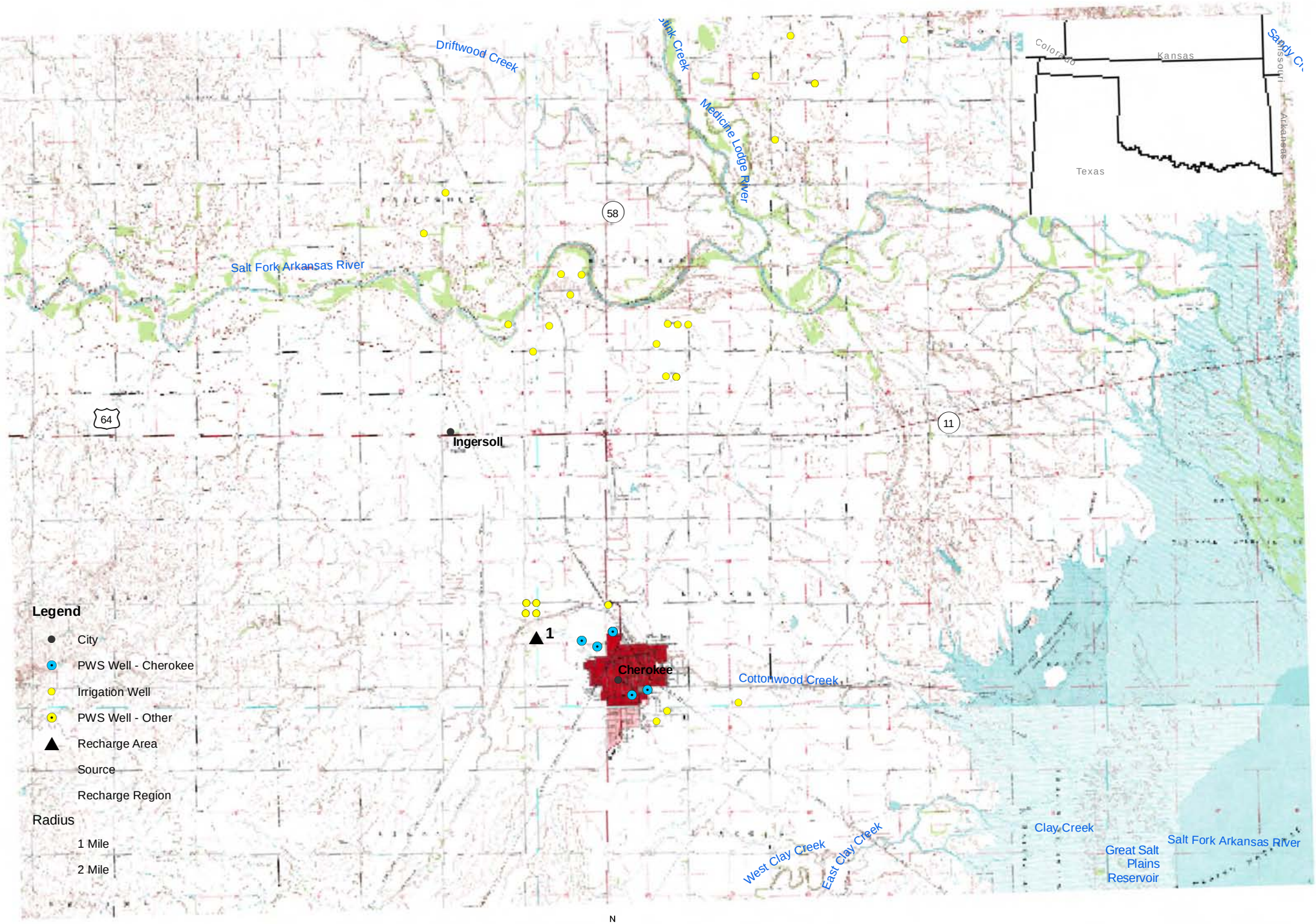
Based on the assumed project size of 1,000 acre-feet, 61 percent of the total demand will be met. Thus, qualitative considerations received a **high** score.

6. Summary

The following table presents a summary of the scores and reasoning for assignment of those scores for Recharge Region 31.

Criterion	Score	Reasoning
Source Availability	Moderate	Adequate flows seasonally, gage located 2 miles downstream, unknown well impact
Demand Proximity (distance	High	PWS wells within 1 mile

from recharge area)		
Source Proximity (distance from recharge area)	Low	Salt Fork Arkansas River > 2 miles
Available Freeboard and Ability to Meet Demand	Low	Not enough volume to meet recharged volume
Demand Density (number of wells)	Moderately low	Less than 5 wells within 1 mile
Source Quality for Non-degradation	Moderately Low	MCL exceedences
Native Groundwater Quality	Low	High TDS, some MCL exceedances
Geochemical Interactions of Source and Groundwater	Moderately Low	Langelier's not available for source; similar pH; groundwater scaling
Transmissivity	High	Good aquifer properties for AR
Residence Time	Moderate	32% loss within 180 days, 140 days to 25% loss
Cost (O&M)	Moderately High	Pretreatment; operation of spreading basin
Cost (capital)	Moderate	Gravity feed, spreading basin; treatment system
Qualitative Considerations	High	61% of total demand



Site 31 Demand and Source Proximity

FIGURE M-1

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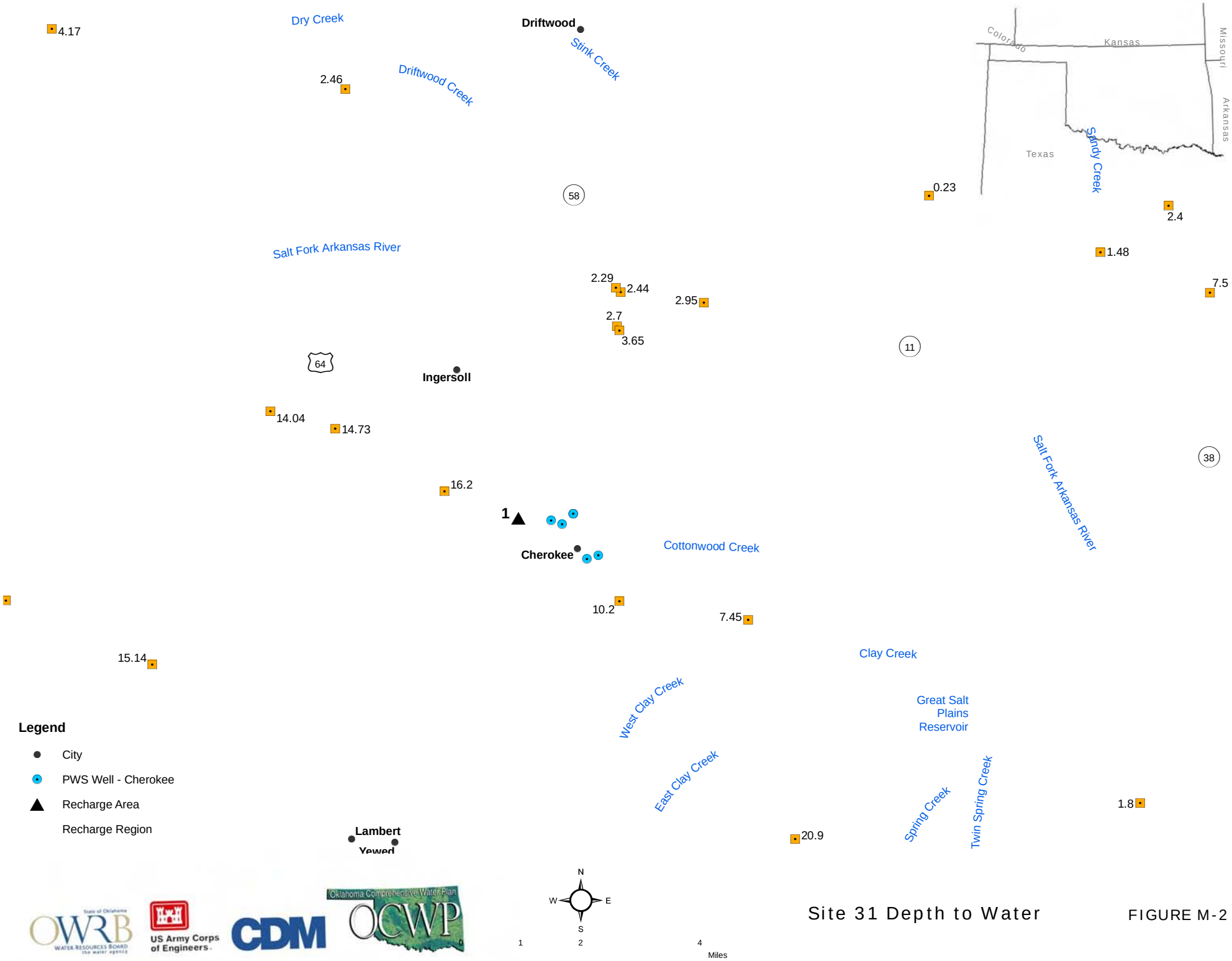
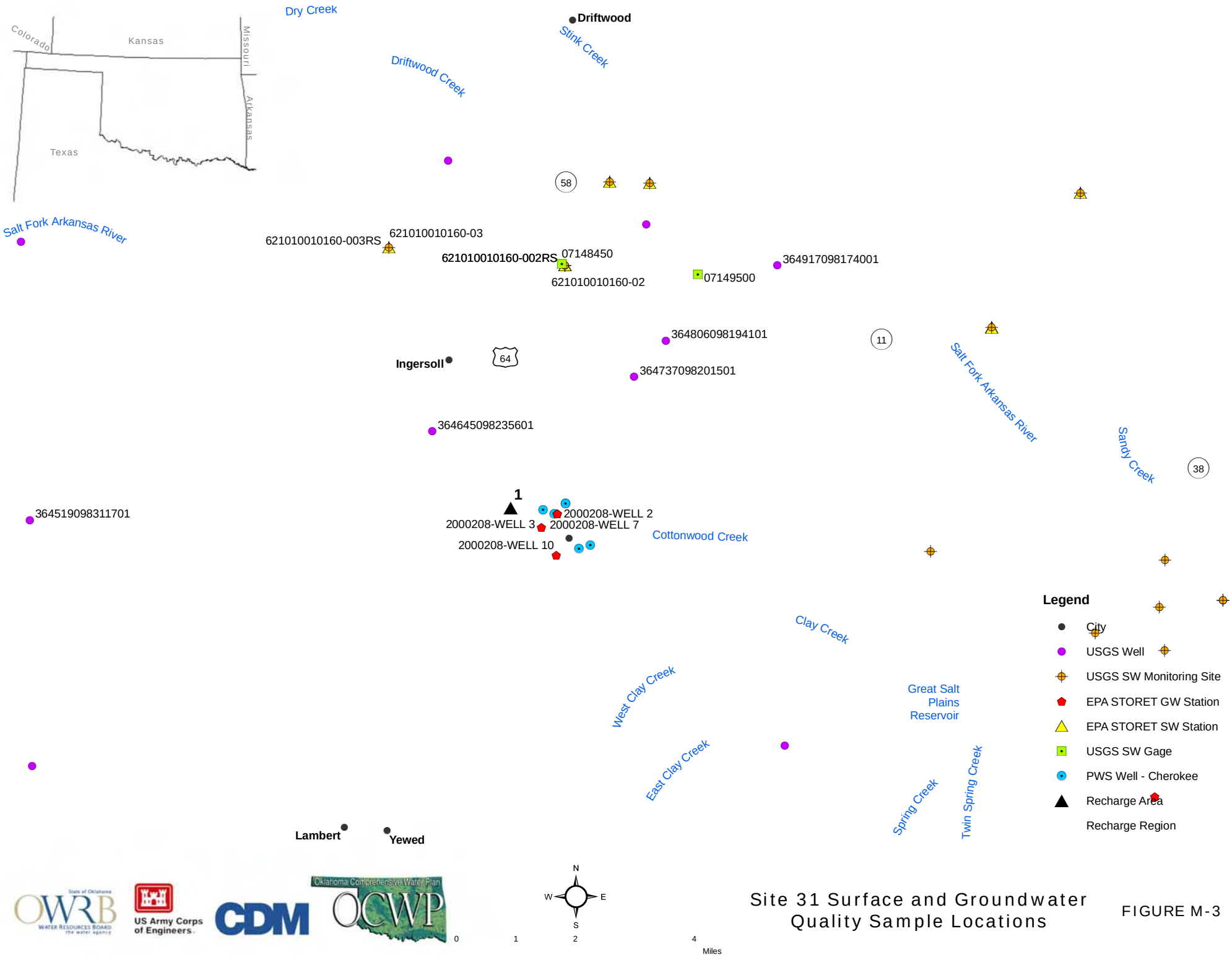


Site 31 Depth to Water

FIGURE M-2



Site 31 Surface and Groundwater Quality Sample Locations

FIGURE M-3

N
W E
S

0 1 2 4
Miles

Site 31 Hydrogeology

FIGURE M-4

Appendix N
Detailed Analysis of Recharge Region Number 40, High Plains Aquifer near Reyden

Appendix N - Recharge Region 40

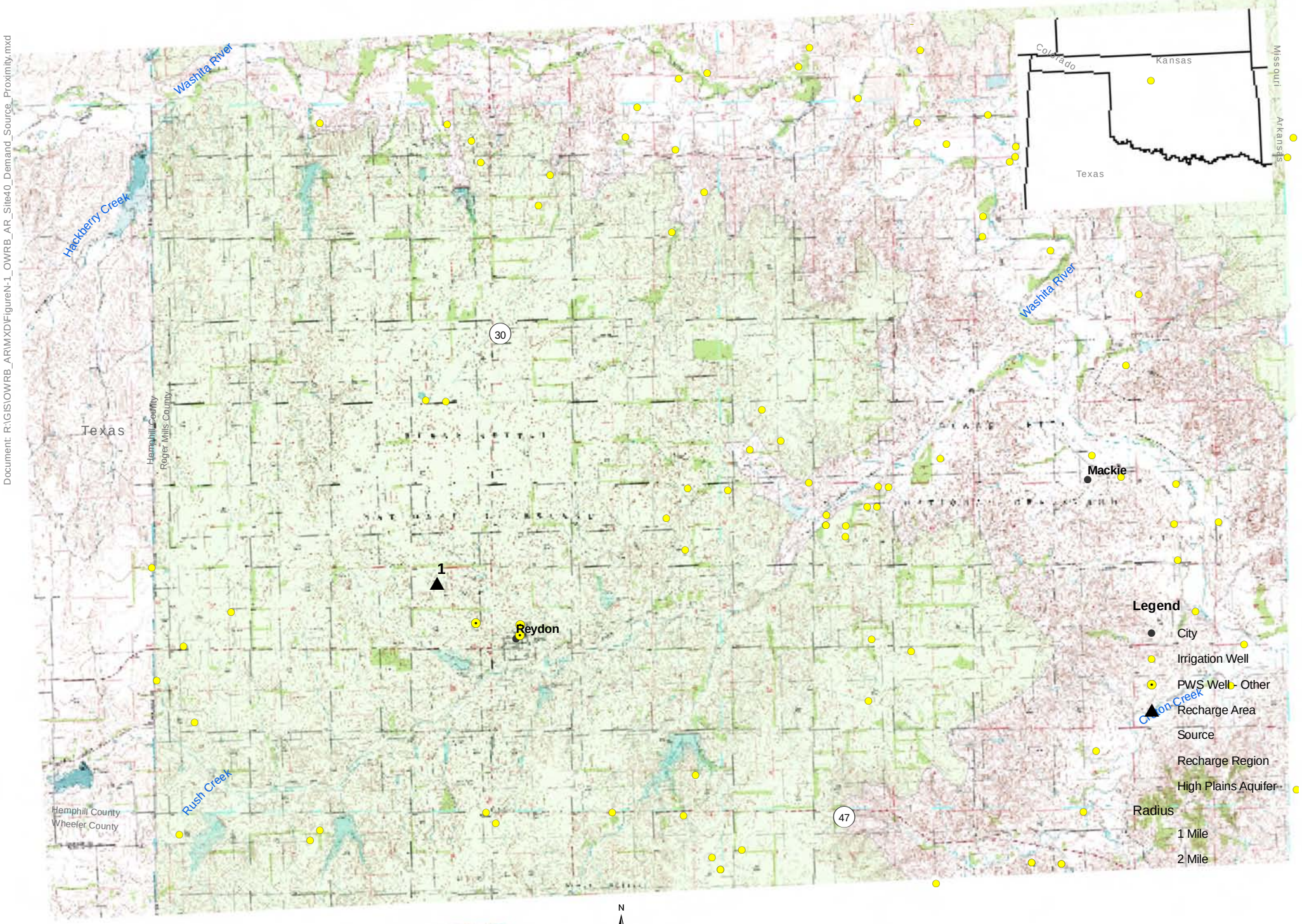
Recharge Region 40 is located in the vicinity of the town of Reydon, with the Ogallala/High Plains aquifer providing storage for an AR project. According to the U.S. Census Bureau, the town of Reydon had an estimated population of approximately 176 individuals in 2008; year 2000 census data indicated 177 individuals (U.S. Census Bureau). For this recharge region, the demand location was identified as the PWS wells for the town of Reydon, and the source for the potential recharge project was identified as the Washita River. One potential recharge area was identified based on proximity of demand and source, the available freeboard in the aquifer, and groundwater flow direction. The potential recharge area is located in the west central portion of the recharge region (see Figure N-1).

1. Demand, Source, and Storage Considerations

The following table summarizes several aspects of the recharge area related to source water availability, local demand, ability of the source to meet the demand, and storage capacity. Proximity data is shown on Figure N-1, and available freeboard is shown on Figure N-2.

Source Basin	Basin 10840
Sufficient Legally Available Water for Pilot Project	No
Source Stream	N/A
Nearest Gage	N/A
Gage POR and below average precipitation	N/A
Representative year flows (source availability)	N/A
	N/A
Local Demand (Reydon)	N/A
Demand Density (PWS Wells)	N/A
Source availability as percent of pilot project demand (minimum of local demand or 1,000 AF*)	N/A
	N/A
Aquifer Storage Availability	N/A
	N/A
	N/A

As indicated in the table, there is not enough legally available water to conduct a pilot test. Thus, this recharge region will not be evaluated for any remaining criteria.



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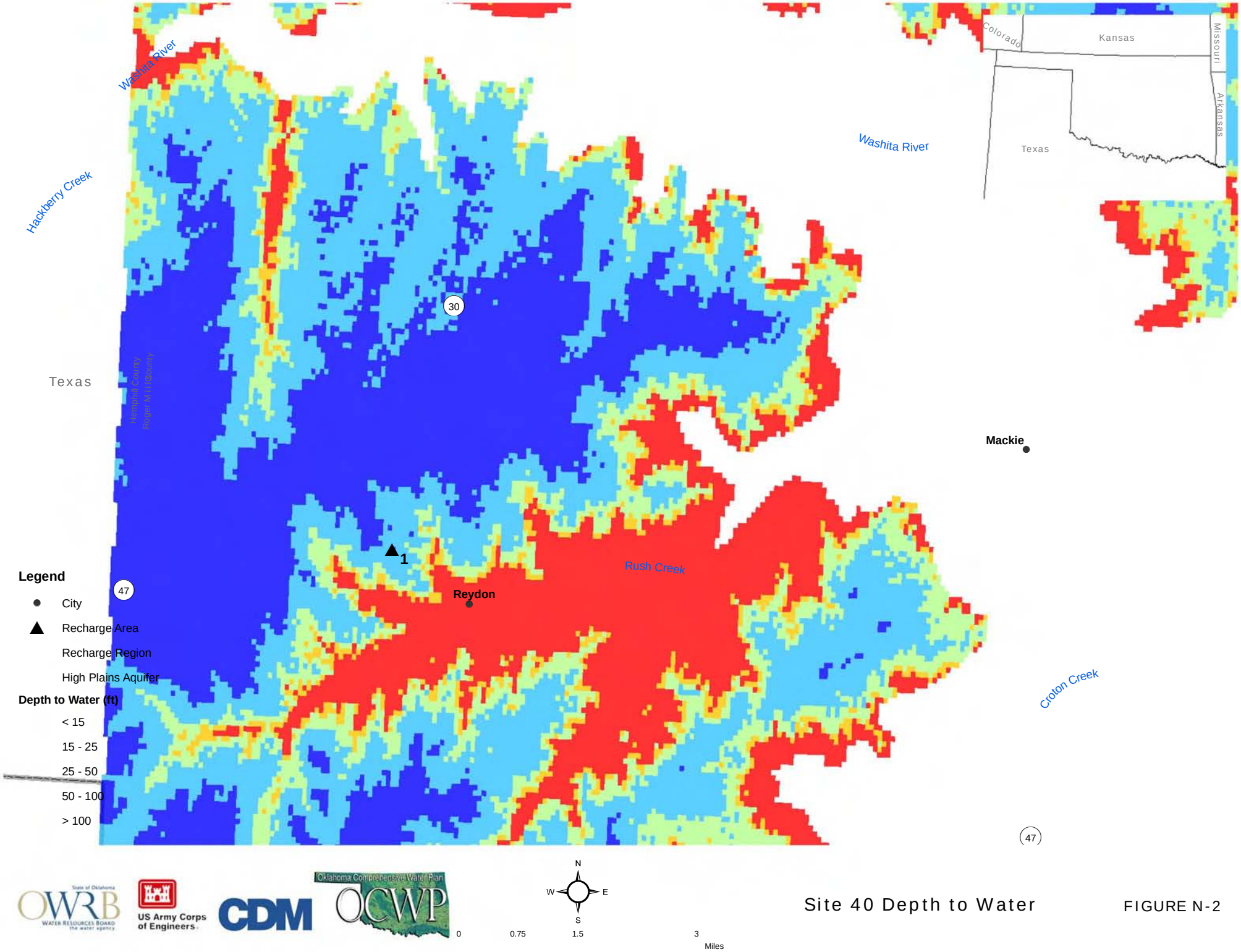
N
W E
S

0 0.75 1.5 3 Miles

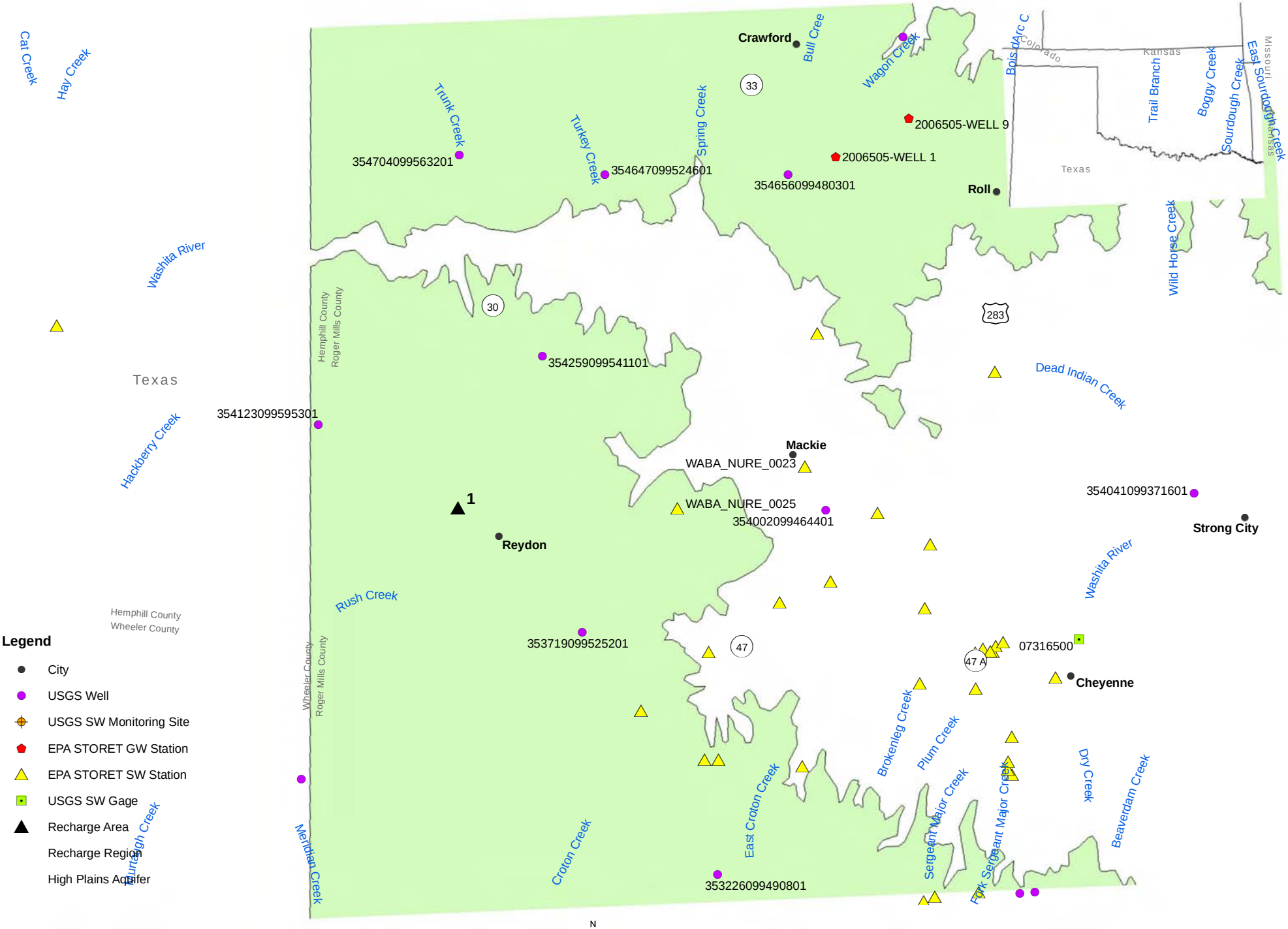
Site 40 Demand and Source Proximity

FIGURE N-1



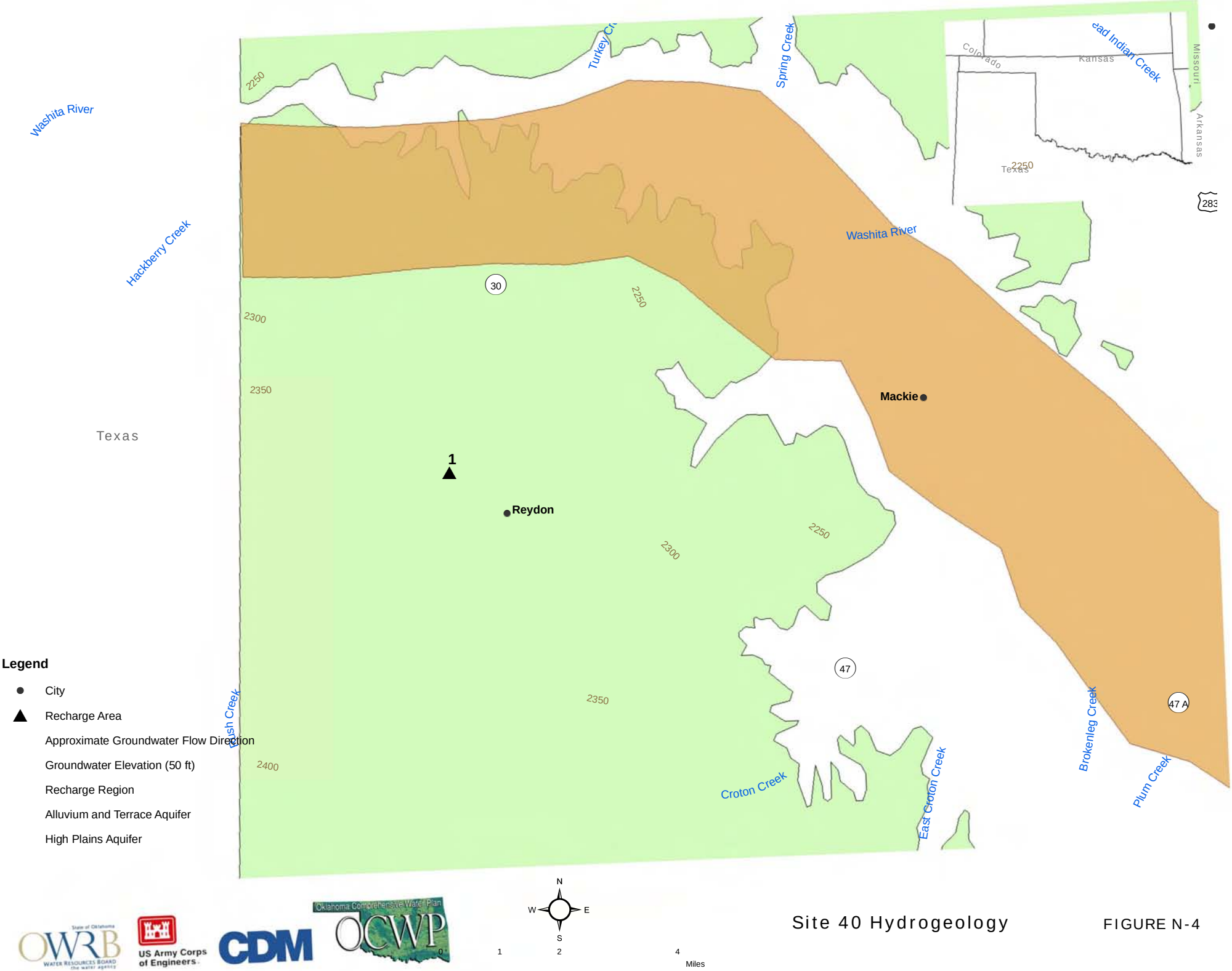
Site 40 Depth to Water

FIGURE N-2



Site 40 Surface and Groundwater Quality Sample Locations

FIGURE N-3



Site 40 Hydrogeology

FIGURE N-4

Appendix O
Detailed Analysis of Recharge Region Number 42, Rush Springs Aquifer near Eakly

Appendix O - Recharge Region 42

Recharge Region 42 is located in the vicinity of the town of Eakly, with the Rush Springs aquifer providing storage for an AR project. According to the U.S. Census Bureau, the town of Eakly had an estimated population of approximately 265 individuals in 2008; year 2000 census data indicated 276 individuals (U.S. Census Bureau). For this recharge region, the demand location was identified as the PWS wells for the town of Eakly, and the source for the potential recharge project was identified as Lake Creek. One potential recharge area was identified based on proximity to demand and source, the available freeboard in the aquifer, and groundwater flow direction. The recharge area is located in the southeast portion of the recharge region (see Figure O-1).

1. Demand, Source, and Storage Considerations

The following table summarizes several aspects of the recharge area related to source water availability, local demand, ability of the source to meet the demand, and storage capacity. Proximity data is shown on Figure O-1, and available freeboard is shown on Figure O-2.

Source Basin	Basin 10832
Sufficient Legally Available Water for Pilot Project	Yes; limited based on Fort Cobb Reservoir yield
Source Stream	Lake Creek. Probable point of diversion approximately 2 miles east-northeast of Eakly
Nearest Gage	USGS 07325850, approximately 1.5 miles downstream of probable point of diversion. Period of record 1969 to 1978; 2004 to 2010. No known major land use changes in the contributing basin since end of the period of record.
Gage POR and below average precipitation	7 years during the gage POR are below average precipitation years. 2006 selected as representative of approximately the 25th percentile of precipitation and occurred within the POR
Representative year flows (source availability)	Annual Flow: 2,491 AF
	Seasonal Distribution: Jan-Feb,Dec 30%; Mar-May 32%; Jun-Aug 22%; Sept-Nov 16%
Local Demand (Eakly)	Annual Total 276 AFY
Demand Density (PWS Wells)	2 wells within 1 mile radius, 0 wells within 2 mile radius. Indicates productive region of aquifer and storage capacity
Source availability as percent of pilot project demand (minimum of local demand or 1,000 AF*)	Annual basis: 100%
	Seasonally: Jan-Feb,Dec 100%; Mar-May 100%; Jun-Aug 100%; Sept-Nov 100%
Aquifer Storage Availability	Specific Yield = 0.24
	0.1 square mile area (radius 0.2 miles) with 25 foot increase in water levels required. Storage capacity is sufficient while maintaining at least 15 feet depth to water

	0.2 square mile area (radius 0.2 miles) with 10 foot increase in water levels. Storage capacity is sufficient while maintaining at least 15 feet depth to water

Based on the availability of flows and the ability of those flows to meet the pilot project demands, the source water availability receives a **moderate** score. This is due to the regulations regarding Fort Cobb Reservoir.

The storage capacity requirement is less than the available storage in the aquifer below the 15 foot threshold; therefore storage availability receives a **high** score.

Based on the location of wells in close proximity to the recharge area, the demand proximity receives a **high** score.

Also, based on the number of wells (less than five) within one mile of the recharge area, demand density receives a **moderately low** score.

The source of water identified for Recharge Region 42 is Lake Creek. Recharge area 1 is located within two miles of Lake Creek, and thus receives a **moderate** score for source proximity.

2. Water Quality

Water quality analysis included the following criteria: source water quality for non-degradation; native groundwater quality; and groundwater geochemical interactions with source water. The following table presents water quality data for those parameters that have an MCL. The MCL was exceeded in at least one recharge area in the State if the parameter is listed. Parameters that did not have any samples collected for the Recharge Region are listed but do not display the min, max, and mean rows. Parameters in **bold** exceed the MCL.

Parameter	Units	EPA MCL		Groundwater	Gage # 07325800	Gage # 07325840	Gage # 07325850
Aluminum	ug/L	200	#	5	1	0	0
			min	1.3	**300**		
			max	**300**	**300**		
			mean*	74	**300**		
Antimony	ug/L	6	#	1	1	0	0
			min	0.14	**350**		
			max	0.14	**350**		
			mean*	0.14	**350**		
Arsenic	ug/L	10	#	3	1	0	0
			min	10	10		
			max	**16**	10		
			mean*	**12**	10		
Beryllium	ug/L	4	#	1	1	0	0
			min	0.01	**10**		
			max	0.01	**10**		
			mean*	0.01	**10**		
Cadmium	ug/L	5	#	1	1	0	0
			min	0.04	5.0		
			max	0.04	5.0		
			mean*	0.04	5.0		
Chloride	mg/L	250**	#	11	1	0	0
			min	3.0	14		
			max	17	14		
			mean*	7.8	14		
Chlorine	mg/L	4	#	0	0	0	0
Chromium	ug/L	100	#	3	1	0	0
			min	0.83	10		
			max	10	10		
			mean*	4.4	10		
Fecal Coliform	cfu / 100 ml		#	0			
Iron	ug/L	300	#	5	1	0	0

Parameter	Units	EPA MCL		Groundwater	Gage # 07325800	Gage # 07325840	Gage # 07325850
			min	8.0	40		
			max	20	40		
			mean*	13	40		
Lead	ug/L	15	**#**	3	1	0	0
			min	0.51	**45**		
			max	**100**	**45**		
			mean*	**17**	**45**		
Manganese	ug/L	50	**#**	5	1	0	0
			min	0.20	**80**		
			max	10	**80**		
			mean*	3.5	**80**		
Mercury	ug/L	2	**#**	0	1	0	0
			min		0.50		
			max		0.50		
			mean*		0.50		
Nitrate / Nitrite+Nitrate (as N)	mg/L	10	**#**	9	187	3	183
			min	0.54	0.16	0.44	0.04
			max	**30**	8.0	1.9	6.5
			mean*	3.6	1.4	0.74	0.81
pH	SU	6.5-8.5**	**#**	11	134	7	69
			min	7.1	7.4	7.6	7.5
			max	8.1	8.5	7.7	**8.6**
			mean*	7.7	7.9	7.7	8.0
Selenium	ug/L	50	**#**	1	1	0	0
			min	0.24	5.0		
			max	0.24	5.0		
			mean*	0.24	5.0		
Sulfate	mg/L	250**	**#**	11	1	0	0
			min	5.2	224		
			max	61	224		
			mean*	13	224		
Thallium	ug/L	2	**#**	1	1	0	0
			min	0.04	**200**		

Parameter	Units	EPA MCL		Groundwater	Gage # 07325800	Gage # 07325840	Gage # 07325850
			max	0.04	**200**		
			mean*	0.04	**200**		
Total dissolved solids	mg/L	500**	#	12	1	0	0
			min	179	**584**		
			max	418	**584**		
			mean*	279	**584**		
Toxaphene	ug/L	3	#	0	0	0	0
*mean - geometric mean							
** Secondary MCL							

The following table presents the native groundwater quality and the source water quality, including general water quality parameters and water geochemistry factors.

Parameter	Units		Groundwater	Gage # 07325800	Gage # 07325840	Gage #07325850
Alkalinity	mg/L as CaCO3	#	11	68	1	65
		min	140	37	77	33
		max	255	320	77	296
		mean*	192	138	77	143
Bicarbonate	mg/L	#	7	65	1	62
		min	172	44	93	39
		max	308	384	93	355
		mean*	253	162	93	167
Calcium	mg/L	#	5	1	0	0
		min	42	118		
		max	69	118		
		mean*	56	118		
Carbonate	mg/L	#	7	65	1	62
		min	0	0	1.0	0
		max	0	3.0	1.0	6.0
		mean*		1.5	1.0	1.8
Chloride	mg/L	#	11	1	0	0
		min	3.0	14		

Parameter	Units		Groundwater	Gage # 07325800	Gage # 07325840	Gage #07325850
		max	17	14		
		mean*	7.8	14		
Fluoride	mg/L	**#**	5	1	0	0
		min	0.10	0.32		
		max	0.27	0.32		
		mean*	0.15	0.32		
Hardness	mg/L as CaCO3	**#**	9	1	0	0
		min	150	420		
		max	270	420		
		mean*	200	420		
Magnesium	mg/L	**#**	5	1	0	0
		min	5.0	25		
		max	19	25		
		mean*	9.5	25		
Nitrate / Nitrite+Nitrate (as N)	mg/L as N	**#**	9	187	3	183
		min	0.54	0.16	0.44	0.04
		max	30	8.0	1.9	6.5
		mean*	3.6	1.4	0.74	0.81
Nitrite (as N)	mg/L as N	**#**	0	62	1	61
		min		0.01	0.03	0.00
		max		0.08	0.03	0.06
		mean*		0.03	0.03	0.02
Orthophosphate	mg/L	**#**	0	0	0	0
pH	SU	**#**	11	134	7	69
		min	7.1	7.4	7.6	7.5
		max	8.1	8.5	7.7	8.6
		mean*	7.7	7.9	7.7	8.0
Phosphorus	mg/L as P	**#**	0	62	1	61
		min		0.01	0.12	0.02
		max		0.29	0.12	0.22
		mean*		0.11	0.12	0.07
Silica	mg/L as SiO2	**#**	3	1	0	0
		min	21	19		

Parameter	Units		Groundwater	Gage # 07325800	Gage # 07325840	Gage #07325850
		max	22	19		
		mean*	21	19		
Sulfate	mg/L	#	11	1	0	0
		min	5.2	224		
		max	61	224		
		mean*	13	224		
Temperature	deg C	#	9	136	9	71
		min	18	3.1	6.4	4.4
		max	19	27	21	33
		mean*	18	16	18	16
Total dissolved solids	mg/L	#	12	1	0	0
		min	179	584		
		max	418	584		
		mean*	279	584		
Total suspended solids (TSS)	mg/L	#	0	0	0	0
Langelier's Saturation Index**	LSI	#	4	1	0	0
		min	-0.51	0.79		
		max	0.83	0.79		
		mean*	0.10	0.79		
*mean - geometric mean						
**Langelier's Index (LSI)						

In general, the source water quality appeared to be good, and may even improve groundwater quality due to lower nitrate concentrations. There were very few exceedences, and they were likely related to high detection limits. There was only one sample for TDS, and it exceeded MCL, suggesting TDS may be a problem for the recharge region. Thus, the source water quality received a **moderate** score, primarily due to uncertainty of the TDS concentration. The groundwater conditions appear to be somewhat favorable, with few MCL exceedences. This resulted in a **moderately high** score for native groundwater quality.

Based on the Langelier's index, the groundwater geochemistry is near neutral for scaling and dissolution, indicating minimal geochemical instability that would impact AR operations. Source water sampling included only one sample with the parameters necessary to calculate the LSI; the sample was more positive than the groundwater. Only one hardness sample was taken for source water; more extensive pH sampling was completed. The pH samples indicate little difference exists between the groundwater and source water, suggesting that minimal interaction may occur. Thus, the geochemical interaction criterion will receive a **moderate** score, primarily due to the data gap for the Langelier's index.

3. Hydrogeologic Suitability

Hydrogeologic suitability of the Rush Springs aquifer includes an evaluation of transmissivity, residence time, and general aquifer properties. The Rush Springs aquifer is a fine-grained, unconfined sandstone aquifer in the immediate vicinity of the Recharge Region, although confined portions are located west of the Recharge Region, where the Cloud Chief Formation overlies the Rush Springs, as indicated on Figure O-4. Groundwater flow in the vicinity of the Recharge Region generally travels in a southern direction, toward the local stream system. Major nearby alluvial systems are located primarily to the west of the Recharge Region at the Washita River, although minor alluvial systems are located on Cobb Creek northwest of the Fort Cobb Reservoir, and possibly along Lake Creek. The Rush Springs aquifer contributes to these creeks and their tributaries, as indicated by areas in red on Figure O-2. Also, there may be springs located to the north of the Recharge Region. The following table provides a summary of aquifer properties and approximate residence time.

Parameter	Value	Source
Transmissivity	670 to 1,740 ft^2/day	USGS
Specific Yield	0.13 to 0.34	AWI
Well Yield	200 to 600 GPM	AWI
% of Recharge Lost in 180 Days	2	Glover
Number of Days Until 25% Loss	760	Glover
Distance to Discharge	0.6 miles	N/A

Based on the aquifer properties, transmissivity received a **high** score.

Based on the Glover calculations, the residence time criterion received a **high** score.

4. Cost: Operation and Maintenance (O&M) and Capital

A table showing the primary cost considerations and whether they apply to the recharge area is presented below.

	Treatment – High TSS	Treatment - Other	Gravity Feed	Forcemain/ Pipeline	Injection Well - Available	Injection Well - Construct	Spreading Basin
Recharge area 1		X		X	X		

The source water will potentially require treatment prior to injection into the aquifer. Due to the topography of the region, a force-main pipeline will be required to deliver water to the recharge project. The depth to water at the Recharge Region is prohibitive of a spreading basin, although the existing PWS wells in the vicinity may be usable for AR. Based on these factors, the Recharge Region received a **moderately low** score for capital cost. The O&M cost received a **moderate** score due to maintenance of the force-main and AR well(s), and operation of the treatment system.

5. Qualitative Considerations

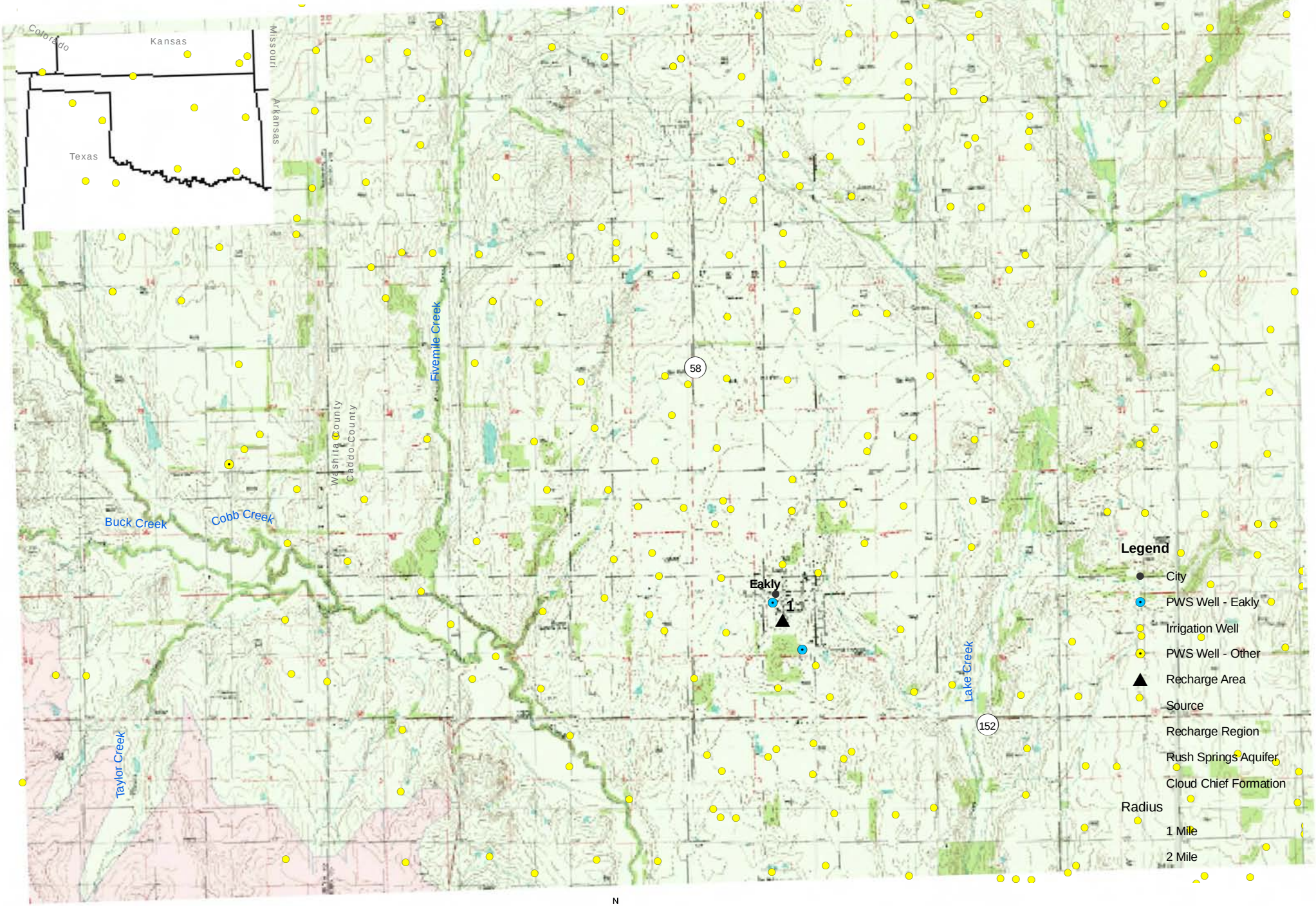
Based on the assumed project size of 1,000 acre-feet, 100 percent of the total demand will be met. Thus, qualitative considerations received a **high** score.

6. Summary

The following table presents a summary of the scores and reasoning for assignment of those scores for Recharge Region 42.

Criterion	Score	Reasoning
Source Availability	Moderate	Adequate flows, but Fort Cobb Reservoir regulations
Demand Proximity (distance from recharge area)	High	PWS wells within 1 mile
Source Proximity (distance from recharge area)	Moderate	Lake Creek < 2 miles
Available Freeboard and Ability to Meet Demand	High	Plentiful volume to meet recharged volume

Demand Density (number of wells)	Moderately low	Less than 5 wells within 1 mile
Source Quality for Non-degradation	Moderate	Few MCL exceedences; possibly high TDS
Native Groundwater Quality	Moderately High	Few MCL exceedances
Geochemical Interactions of Source and Groundwater	Moderate	Limited Langelier's data for source; similar pH
Transmissivity	High	Good aquifer properties for AR
Residence Time	High	2% loss within 180 days, 760 days to 25% loss
Cost (O&M)	Moderate	Possible pretreatment; operation of AR wells and pipeline
Cost (capital)	Moderately Low	Pipeline, retrofit AR wells, possible treatment system
Qualitative Considerations	High	100% of demand met



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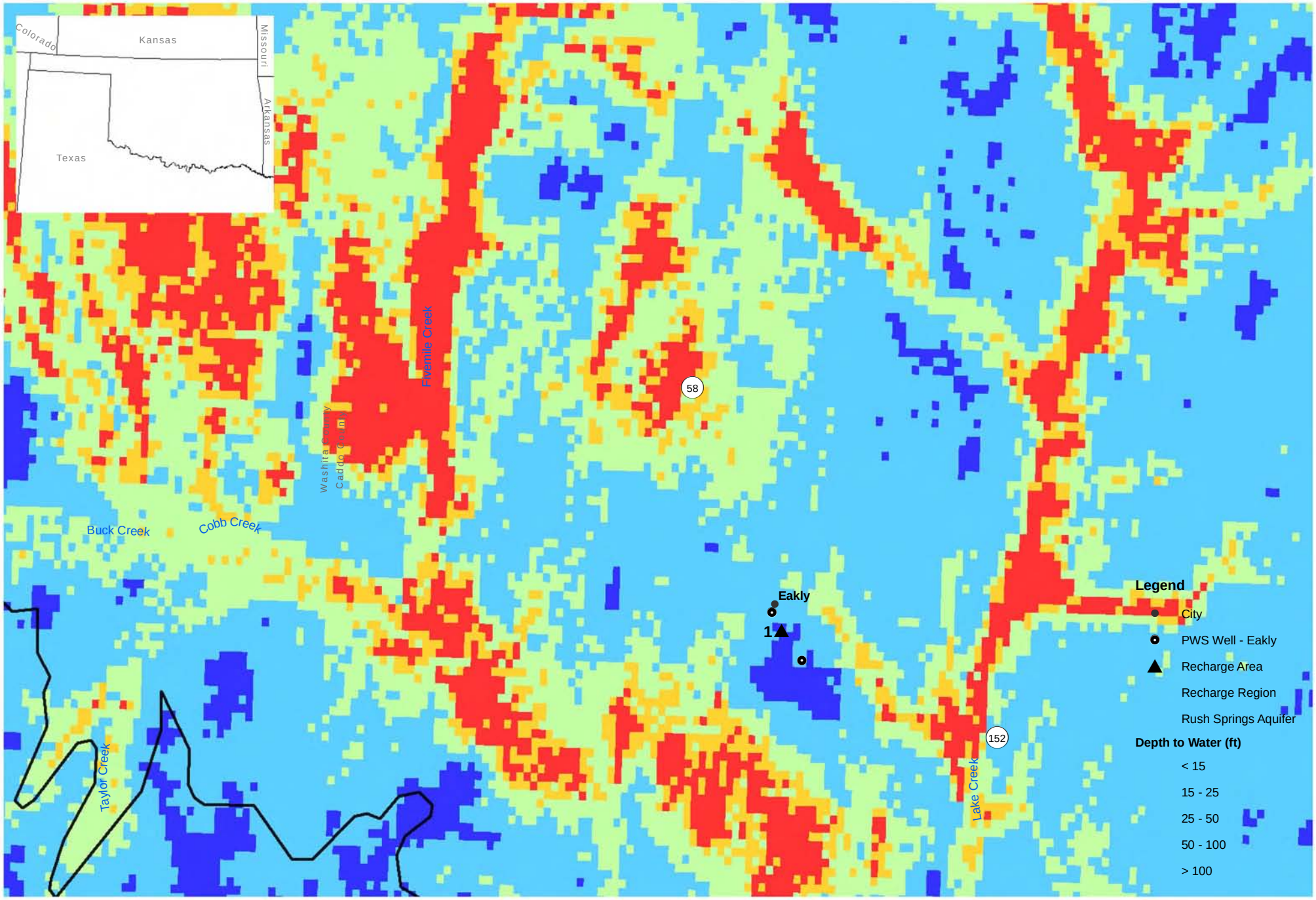
N
W E
S

0 0.5 1 2 Miles

Site 42 Demand and Source Proximity FIGURE O-1

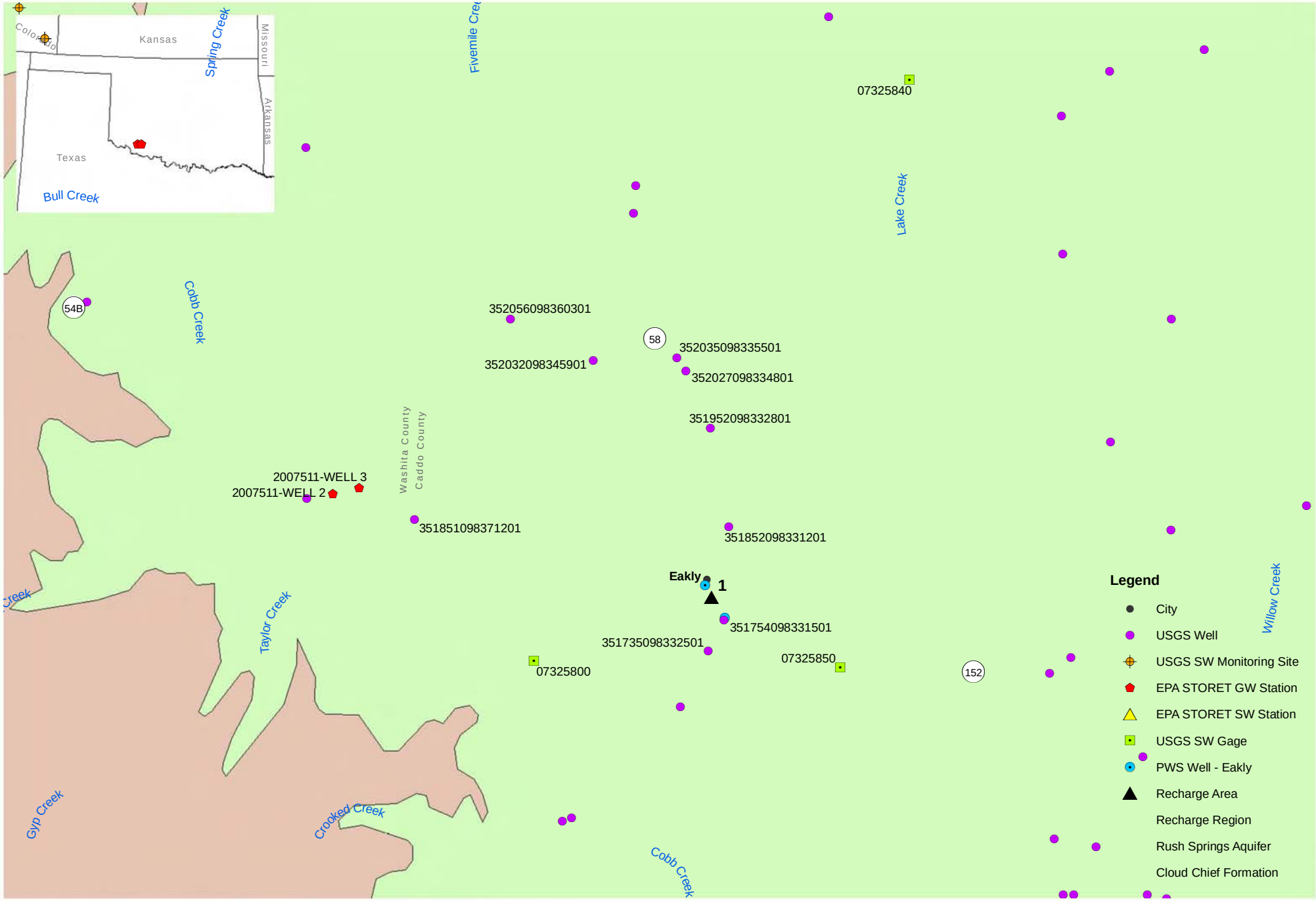


N
W E
S

0 0.5 1 2
Miles

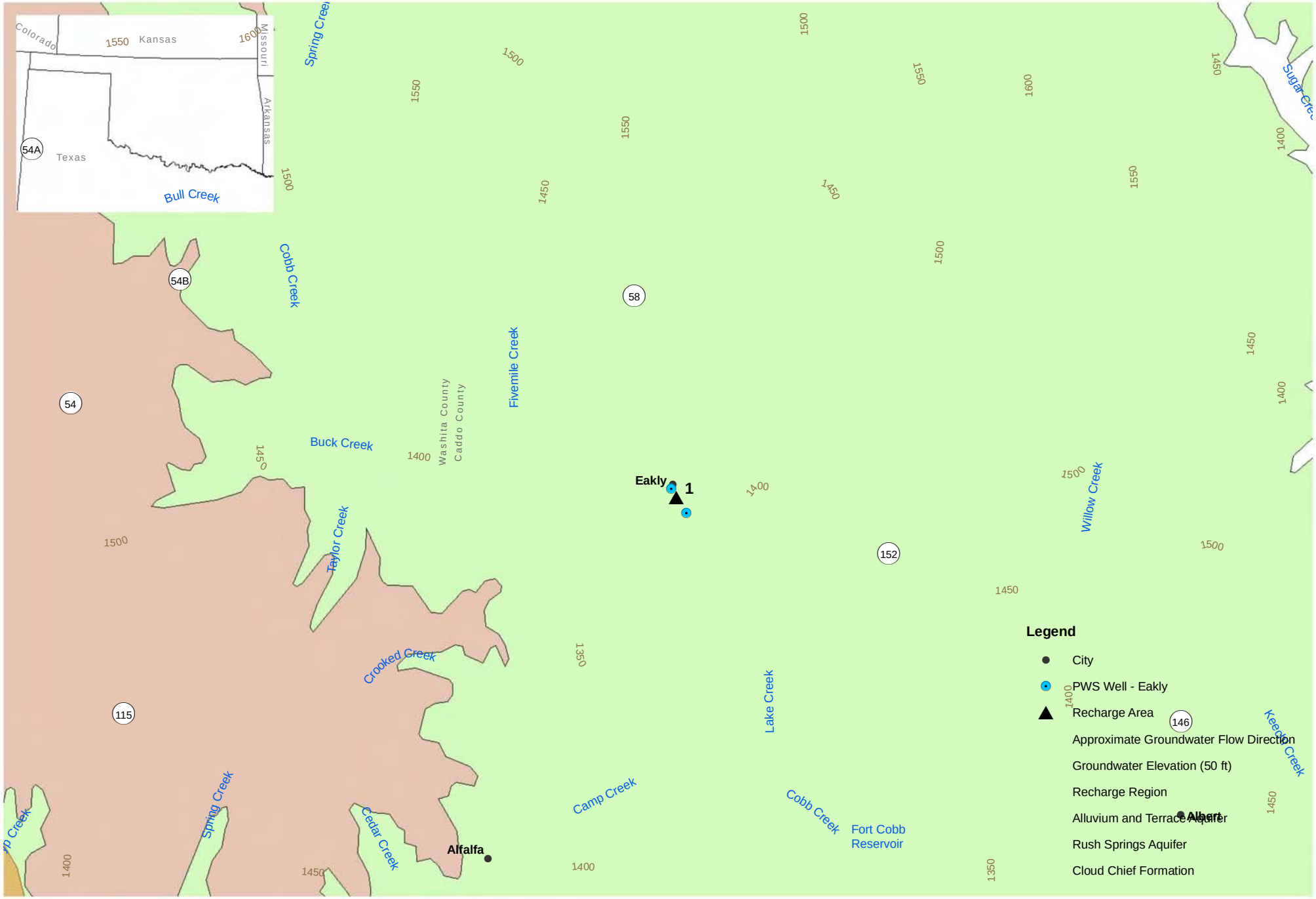
Site 42 Depth to Water

FIGURE O-2



Site 42 Surface and Groundwater Quality Sample Locations

FIGURE O-3



Site 42 Hydrogeology

FIGURE O-4

Appendix P
Work Group Meeting Minutes

Oklahoma Comprehensive Water Plan
Aquifer Recharge Technical Work Group Meeting

AGENDA
December 8, 2008

1:00 p.m.	Welcome and Introductions
1:10 p.m.	Senate Bill 1410 Work Group Background and Goals ◥ Introductory Remarks by Senator Paddack ◥ Overview of SB1410 ◥ Mission, goals, and key schedule milestones for the work group
1:30 p.m.	Presentations: Methods for Assessment of Recharge Potential ◥ Bureau of Reclamation: Collin Balcombe ◥ Colorado Water Conservation Board SB06-193 Underground Water Storage Study: Gordon McCurry
1:50 p.m.	Discussion: Existing Recharge Projects in Oklahoma
2:00 p.m.	Discussion: Criteria for Recharge Potential
2:10 p.m.	Next Steps ◥ Development of Work Plan ◥ Potential recharge site tours ◥ Schedule and topics for Work Group Meetings
2:25 p.m.	Adjourn

CDM

ARTIFICIAL RECHARGE TECHNICAL WORKGROUP MEETING
DECEMBER 8, 2008

The first group meeting occurred in the Offices of the Oklahoma Water Resources Board, 3800 N. Classen Blvd., Oklahoma City, Oklahoma and began at 1:00 pm. Attendees included: Dr. Robert Knox, OU; Bryan Mitchell, CDM; Kyle Arthur, OWRB; Dr. Kim Winton, USGS; Collin Balcombe, USBR; Dr. Kelly Hurt, Chickasaw Nation; Jon L. Craig, DEQ; Saba Tahmessebi, DEQ; Dr. Neil Suneson, OGS; Senator Susan Paddack, Oklahoma State Senate; Dr. Gordon McCurry, CDM; John Rehring, CDM; Noel Osborn, OWRB; Robert Fabian, OWRB; Dave Dillon, OWRB; Terri Sparks, OWRB; Mike Melton, OWRB; Mike Thralls, OCC; Robert W. Toole, OCC; Scott Thompson, DEQ; Derek Smithee, OWRB; Duane Smith, OWRB; and Dr. Robert Puls, EPA Kerr Lab.

Senator Paddack gave an overview of Senate Bill (SB) 1410 (attached) and emphasized consensus building and collaboration in using artificial recharge to help increase the State's available water supplies. Duane Smith gave an overview of the meeting purpose and role of the participants. He noted that participants were being asked to help provide technical expertise in recommending and prioritizing possible aquifer recharge projects.

Collin Balcombe provided a copy of the document "*Planning Framework to Artificial Recharge*" (attached) which resulted from the U.S. Bureau of Reclamation's (Reclamation) work completed in conjunction with Oklahoma State University (OSU) and the Chickasaw Nation. This framework established ten steps, and evaluation criteria, to address while selecting recharge projects based upon specific local needs. The process involved the following four criteria for evaluation: Effectiveness, Efficiency, Acceptability, and Completeness. Mr. Balcombe noted that this process has not been specifically applied for prioritizing recharge projects, but that similar processes had been used by Reclamation in previous technical evaluations. He also noted that a decision tree is being developed and Reclamation is seeking input on this.

Gordon McCurry gave a presentation on Colorado's Underground Water Storage Study, which evaluated the suitability of potential artificial recharge sites in alluvial and bedrock aquifers in the Arkansas and South Platte basins in eastern Colorado. He provided a handout on criteria CDM developed to evaluate and score water recharge projects (attached). This study developed ten criteria that included hydrogeologic, environmental and implementation considerations for evaluating potential recharge areas. The criteria were assigned different weights to reflect local priorities, including where future water shortages are anticipated. An objective decision matrix was developed to prioritize sites. This study concluded that:

1) Many potential recharge areas exist;
2) Further investigation is warranted in areas where stakeholders are interested and potential water supply exists;
3) Site and project-specific factors affect the feasibility of a given project and must be considered.

The advisory group voiced approval of the methods used for the Colorado study with Sen. Paddack voicing support of the scoring factors and objective nature or the site ranking. There was discussion about modifying the specific evaluation criteria to meet Oklahoma's needs.

Collin Balcombe noted that Reclamation and Dr. Kelly Hurt have inventoried what some other states have done. The group discussed how one possible end goal for the SB 1410 evaluations could be a "manual" for how to implement recharge projects in Oklahoma.

Jon Craig suggested that storm-water runoff be investigated as a source of recharge. Treatment and permitting is occurring, but the water runs off pavement and is lost back to streams. EPA has initiated some work in this area.

Dr. Kelly Hurt mentioned the possibility of implementing recharge projects at Oklahoma Corporation Commission (OCC) and/or National Resource Conservation Service (NRCS) flood control projects. Mike Thralls noted that they might be able to include recharge methods in the process of rehabilitating flood control structures in the future. The integration of rain gardens at parking lot and other large pavement areas was also mentioned as potential recharge activities.

Duane Smith suggested that, if acceptable to the group, he would ask CDM to take the Framework developed by the Reclamation and expand it with more specific rating criteria such as developed by CDM in other projects. Senator Paddack suggested that we also begin identifying potential areas where recharge projects could be applicable based on existing information.

Potential sources of funding were then discussed. Collin Balcomb said he thought that Reclamation had some Native American funds that could possibly be available. He said we could probably use the OWRB's existing Water Plan authority with Reclamation to help fund some work, depending on OWRB's priorities. Duane Smith noted we could use some water plan dollars to match if any federal funds were available.

Duane Smith then asked the group if they had other applicable existing or potential projects.

- Bob Fabian gave an overview of previous Oklahoma Water Resources Board projects on the Blaine-Gypsum aquifer;
- Dr. Robert Puls said that EPA Kerr Lab did not have any projects going on now, but could probably provide in-kind services as far as people, equipment and expertise – could potentially have actual cash contribution via the Water Availability Initiative in 2010. He indicated that nationally they have some ongoing project such as rain gardens, impervious pavement, an existing Memo of Understanding with Chickasaw Nation to look at various technologies, etc. He noted that there are no EPA recharge projects in Oklahoma.
- Dr. Knox and Dr. Suneson noted that they were working with OWRB on the Arbuckle-Simpson study. Dr. Suneson pointed out that all aquifers are different, and we couldn't develop one approach for all of them.

- Dr. Kim Winton suggested getting some of USGS' staff to pull some mapping and other information together, but probably would not be able to provide direct funding. The Water Census for America may possibly be a source of money.
- Dr. Hurt indicated that OSU and National Weather Center may have interest and suggested inviting Ms. Suzanne VanCooten (NOAA) to be on the work group.

Duane Smith suggested that the group should seek to show the 2009 legislature early in the session that the work is progressing toward a valuable end point. He also invited the group to serve as a technical review group for work conducted on the SB 1410 evaluations.

The next meeting of the Recharge Technical Work Group was tentatively scheduled for January 21, 2009, at 1:00 p.m. Tasks to be accomplished for consideration at that time include:

- Consider operational recharge projects in other areas that could be toured by the group
- CDM staff will integrate elements of the Colorado Underground Water Storage Study with the BOR's Framework to provide draft guidelines on evaluating and prioritizing Artificial Recharge Projects for review by the entire Workgroup.
- Begin considering potential recharge areas based on existing research and information.

An Act

ENROLLED SENATE
BILL NO. 1410

By: Paddack and Johnson (Constance) of the Senate

and

Hilliard and Harrison of the House

An Act relating to water; stating Legislative findings; directing the Oklahoma Water Resources Board to conduct certain demonstration projects relating to recharging water aquifers; requiring coordination with other entities; stating requirements for certain demonstration projects; providing for public and private funding; requiring Board to collect and publish certain data; providing for noncodification; and declaring an emergency.

BE IT ENACTED BY THE PEOPLE OF THE STATE OF OKLAHOMA:

SECTION 1. NEW LAW A new section of law not to be codified in the Oklahoma Statutes reads as follows:

A. The Oklahoma Legislature hereby finds that protection and conservation of our state's most precious natural resource, water, is our most important duty on behalf of the citizens of Oklahoma.

B. In an effort to meet future water supply challenges, the Legislature finds that measures should be implemented to address population growth needs for water supplies, future water and wastewater infrastructure costs, balance economic development and protection of the environment, satisfy competing water interests equitably, and reduce the state's vulnerability to droughts and flooding.

C. To address one of the potential solutions to future water supply challenges, the Legislature hereby directs the Oklahoma Water Resources Board, in the development of the update to the Oklahoma Comprehensive Water Plan, to establish a technical work group to recommend demonstration projects and criteria to prioritize other projects designed to recharge various types of aquifers located in this state. The technical work group shall include representatives from the Robert S. Kerr Environmental Research Center of the United States Environmental Protection Agency, the United States Geological Survey, the Oklahoma Conservation Commission, the Department of Environmental Quality, the Oklahoma Climatological Survey, the University of Oklahoma and Oklahoma State University and any other governmental entity the Board deems necessary to recommend and prioritize the aquifer recharge demonstration projects.

D. The group shall review and consider the locations throughout the state where aquifer recharge demonstration projects may be most feasible to implement, with particular consideration given to each of the following types of aquifers:

1. Unconfined, alluvial aquifer;

2. Confined, sedimentary aquifer;

3. Unconfined, karst or fractured rock aquifer; and

4. Confined, karst or fractured rock aquifer.

E. Any state agency whose powers and duties are compatible with the demonstration projects recommended by the technical work group is authorized to contribute any available monies otherwise authorized by law to implement aquifer recharge demonstration projects, and private donations by any person, corporation or other governmental entity for such purpose may be accepted and shall be coordinated by the Oklahoma Water Resources Board.

F. As part of the update to the Oklahoma Comprehensive Water Plan, the Oklahoma Water Resources Board shall collect and analyze data resulting from any aquifer recharge projects authorized by this act and make such findings available to the Legislature, other governmental entities and the public in the update.

SECTION 2. It being immediately necessary for the preservation of the public peace, health and safety, an emergency is hereby declared to exist, by reason whereof this act shall take effect and be in full force from and after its passage and approval.

Passed the Senate the 4th day of March, 2008.

Presiding Officer of the Senate

Passed the House of Representatives the 15th day of April, 2008.

Presiding Officer of the House of Representatives

OFFICE OF THE GOVERNOR

Received by the Governor this 16th

day of April, 2008,

at 4:02 o'clock P M.

By: [illegible]

Approved by the Governor of the State of Oklahoma the 21st day of

April, 2008, at 5:15 o'clock P M.

[illegible]

Governor of the State of Oklahoma

OFFICE OF THE SECRETARY OF STATE

Received by the Secretary of State this

22nd day of April, 2008,

at 9:40 o'clock A. M.

By: M. Susan Savage

A PLANNING FRAMEWORK TO ARTIFICIAL RECHARGE

Draft Executive Summary

STEP 1
Identify Need and Establish Planning Objectives

STEP 2
Formulate Alternative Recharge Locations
4 Criteria: Effectiveness, Efficiency, Acceptability, Completeness

STEP 3
Formulate Recharge Methods
Apply Decision-Tree Methodology and Collect Data

STEP 4
Evaluate and Compare Recharge Methods
4 Criteria: Effectiveness, Efficiency, Acceptability, Completeness

STEP 5
Select Preferred Recharge Method
at Each Location (Formulate Recharge Projects)

STEP 6
Evaluate and Compare Recharge Projects
4 Criteria: Effectiveness, Efficiency, Acceptability, Completeness

STEP 7
Select Preferred Recharge Project

STEP 8
Develop Monitoring Protocol
Define Success/Experimental Procedure

STEP 9
Additional Study

STEP 10
Project Implementation

Colorado's Underground Water Storage Study

Senate Bill 06-193

OK Senate Bill 1410
Artificial Recharge Work Group Meeting
December 8, 2008

Dr. Gordon McCurry, CDM

SB06-193 Study - Background

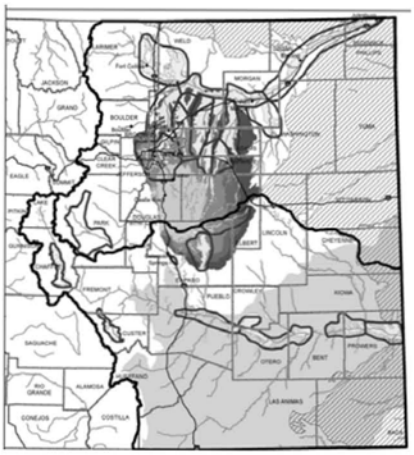
- CWCB to conduct study of potential underground storage areas in South Platte and Arkansas River Basins
- Evaluation based on following considerations:
  - hydrogeologic characteristics
  - environmental factors
  - implementation issues
- CGS Statewide Assessment of Artificial Recharge (Topper et al., 2004) used as starting point
- Legislation passed in spring 2006; final report to General Assembly by March 1, 2007

Scale of SB06-193 Study

- CGS 2004 study was regional (> 80 - 100 sq. mi.)
- SB 06-193 study is subregional (10 - 50 sq. mi. for alluvial)
- Four aquifer regions examined:
  - South Platte alluvial
  - Arkansas alluvial
  - Denver Basin bedrock
  - Dakota/Ogallala bedrock

- Study regions are divided into 44 subregions for evaluation purposes

Overview of Study Regions and Subregions



Evaluation Criteria

Hydrogeologic considerations

- Available storage capacity
- Hydrogeologic suitability
- Residence time

Environmental considerations

- Water quality
- Habitat concerns
- Waterlogging and nonbeneficial consumptive use

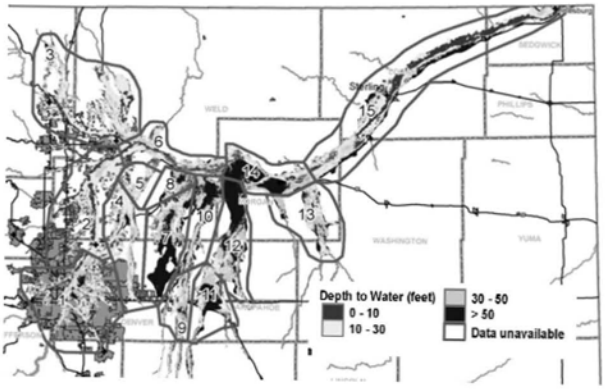
Implementation considerations

- Land ownership and land use
- Existing infrastructure
- Proximity to areas with demand
- Implementation costs

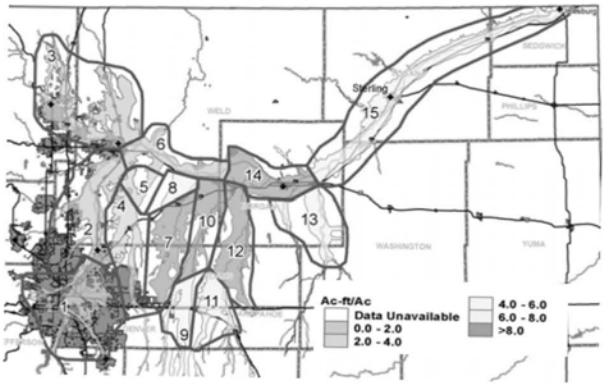
Issues Not Considered in Study

- Available water supply and water rights
- Scale of potential projects
- Potential legal issues
- Water treatment requirements
- Local stakeholder interest
- Other site-specific issues

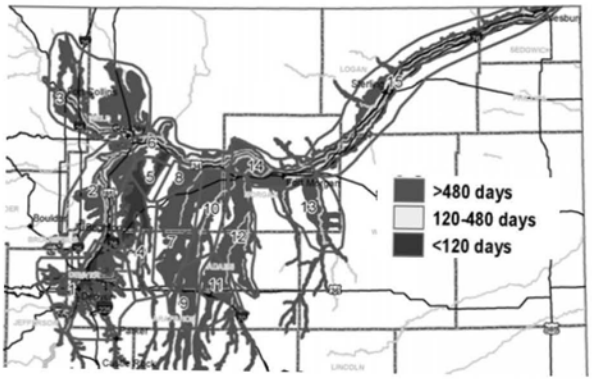
Depth to Ground Water – South Platte

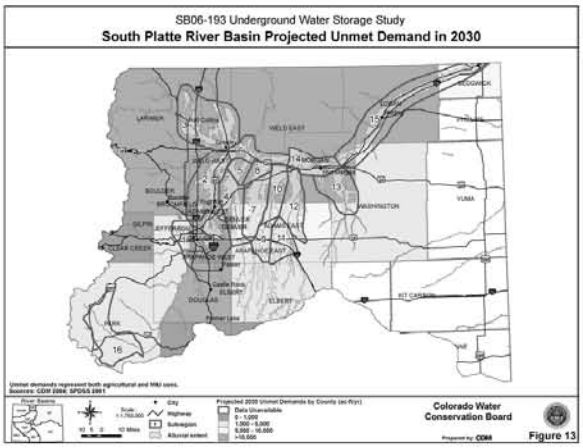


Available Aquifer Storage Capacity



Aquifer Residence Time – South Platte





Evaluation Criteria & Scoring Measures

Evaluation Criteria	Criteria Description	Scoring Measures: High 10 9 8	Medium 7 6 5 4	Low 3 2 1
Hydrogeologic considerations				
1. Aquifer storage capacity	Available capacity for recharge	> 2 AF/Ac	0.25 - 2 AF/Ac	< 0.25 AF/Ac
2. Hydrogeologic suitability • Unconfined aquifers • Confined aquifers	Potential rate of aquifer recharge: - Estimated from aquifer K values - Estimated from aquifer T values	> 250 ft/day > 900 ft²/day	50 - 250 ft/day 300 – 900 ft²/day	< 50 ft/day < 300 ft²/day
3. Residence time • Unconfined aquifers • Confined aquifers	Duration recharged water is in aquifer Subcrop proximity to alluvial aquifers	> 1 year > 3 miles	4 months – 1 year 1 – 3 miles	< 4 months < 1 mile
Environmental considerations				
4. Water quality	Aquifer water quality with respect to State standards, soil leaching potential	No standards exceeded; minimal leaching potential	Limited areas where standards exceeded; minor leaching pot.	Large areas where standards exceeded; strong leaching pot.
5. Habitat concerns	Presence of threatened and endangered species habitat; effect on wetlands	Minor area of T&E habitat; no effect on wetlands	Some T&E habitat; some wetlands affected	Much T&E habitat; wetlands affected
6. Waterlogging and non-beneficial use	Potential to create high water table & increased ET by phreatophytes	Low concerns for waterlogging effects	Medium concerns for waterlogging effects	High concerns for waterlogging effects
Implementation considerations				
7. Land ownership and land use considerations	Proportion of area with accessible public land, multiple jurisdictions	Many areas of public and non-urban land	Some areas of public and non-urban land	Mostly private and/or urban land
8. Existing infrastructure	Proximity of infrastructure (pipelines, ditches, etc.) and available capacity	Suitable infrastructure < 5 miles from area	Suitable infrastructure 5-20 miles from area	Suitable infrastructure >20 miles from area
9. Proximity to areas with demand	Recharge areas nearby to areas of projected unmet demand in 2030	Near areas with demands > 10,000 AF/yr	Near areas with demands of 6,000 – 10,000 AF/yr	Near areas with demands < 6,000 AF/yr
10. Implementation costs • Unconfined aquifers • Confined aquifers	Relative land costs for construction Depth to aquifer and proximity to existing high capacity wells	Low cost < 250 ft; many wells in area	Medium cost 250 - 1,000 ft; few wells in area	High cost > 1000 ft; no wells in area

Scoring Table
South Platte Alluvial Region

Area No.	Subregion	Storage Availability 2	Hydrogeo. Suitability 1.5	Residence Time 1	Water Quality 0.5	Habitat Concerns 0.5	Nonbene-ficial Use 0.5	Land Ownership/Use 0.5	Existing Infrastructure 1	Proximity to Demand 2	Costs 0.5	Overall Score
8	Lower Lost Creek	9	8	9	6	6	7	7	4	8	9	77
7	Upper Lost Creek	10	8	10	5	6	9	6	5	6	9	76
10	Lower Kiowa Creek	10	8	9	5	6	8	7	2	7	8	74
14	SP - Ft. Morgan Area	9	7	4	3	6	8	6	9	8	8	73
5	Lower Beebe/Box Elder Ck	7	8	8	3	5	4	7	10	8	5	72
1	SP - Denver Metro	8	9	4	5	4	7	1	9	9	3	71
12	Lower Bijou Creek	10	6	8	5	10	8	6	1	7	8	71
15	SP - Balzac to State Line	8	9	3	3	3	6	7	10	7	8	70
4	Upper Beebe/Box Elder Ck	8	9	6	4	5	5	6	10	6	4	70
13	Badger/Beaver Creek	8	7	7	4	10	7	8	1	7	9	68
6	SP - Greeley to Ft. Morgan	6	8	5	3	3	6	8	9	9	4	67
2	SP - Metro to Greeley	7	8	5	4	3	5	4	9	8	4	66
3	Poudre River	7	9	4	4	3	4	4	9	8	4	66
9	Upper Kiowa Creek	9	8	10	6	6	7	7	3	3	8	66
11	Upper Bijou Creek	9	6	10	6	10	7	7	1	3	8	63
16	SP - South Park	7	8	7	7	10	6	8	6	2	8	63

Note: Rankings based on scoring measures in Table 5

Ranking is on a 1-to-10 scale with 10 being the highest score

"SP" denotes areas along the mainstem of the South Platte River

Conclusions & Recommendations

- Many potential areas exist for underground water storage in both basins
- Further investigation warranted in areas where there is stakeholder interest and potential water supply
- Site- and project-specific factors affect the feasibility of a given project and must be considered

Table 5 Scoring Measures

Evaluation Criteria	Criteria Description	Scoring Measures		
		High 10 9 8	Medium 7 6 5 4	Low 3 2 1
<u>Hydrogeologic considerations</u>				
1. Aquifer storage capacity	Available capacity for recharge	> 2 AF/Ac	0.25 - 2 AF/Ac	< 0.25 AF/Ac
2. Hydrogeologic suitability	Potential rate of aquifer recharge;			
• Unconfined aquifers	- Estimated from aquifer K values	> 250 ft/day	50 - 250 ft/day	< 50 ft/day
• Confined aquifers	- Estimated from aquifer T values	> 900 ft^2/day	300 – 900 ft^2/day	< 300 ft^2/day
3. Residence time				
• Unconfined aquifers	Duration recharged water is in aquifer	> 1 year	4 months – 1 year	< 4 months
• Confined aquifers	Subcrop proximity to alluvial aquifers	> 3 miles	1 – 3 miles	< 1 mile
<u>Environmental considerations</u>				
4. Water quality	Aquifer water quality with respect to State standards, soil leaching potential	No standards exceeded; minimal leaching potential	Limited areas where standards exceeded; minor leaching pot.	Large areas where standards exceeded; strong leaching pot.
5. Habitat concerns	Presence of threatened and endangered species habitat; effect on wetlands	Minor area of T&E habitat; no effect on wetlands	Some T&E habitat; some wetlands affected	Much T&E habitat; wetlands affected
6. Waterlogging and non-beneficial use	Potential to create high water table & increased ET by phreatophytes	Low concerns for waterlogging effects	Medium concerns for waterlogging effects	High concerns for waterlogging effects
<u>Implementation considerations</u>				
7. Land ownership and land use considerations	Proportion of area with accessible public land, multiple jurisdictions	Many areas of public and non-urban land	Some areas of public and non-urban land	Mostly private and/or urban land
8. Existing infrastructure	Proximity of infrastructure (pipelines, ditches, etc.) and available capacity	Suitable infrastructure < 5 miles from area	Suitable infrastructure 5-20 miles from area	Suitable infrastructure >20 miles from area
9. Proximity to areas with demand	Recharge areas nearby to areas of projected unmet demand in 2030	Near areas with demands > 10,000 AF/yr	Near areas with demands of 5,000 – 10,000 AF/yr	Near areas with demands < 5,000 AF/yr
10. Implementation costs				
• Unconfined aquifers	Relative land costs for construction	Low cost	Medium cost	High cost
• Confined aquifers	Depth to aquifer and proximity to existing high capacity wells	< 250 ft; many wells in area	250 - 1,000 ft; few wells in area	> 1000 ft; no wells in area

Note: Criteria 2, 3 and 10 have separate definitions and scoring measures for unconfined and confined aquifers

Oklahoma Comprehensive Water Plan
Aquifer Recharge Technical Work Group Meeting

PRELIMINARY AGENDA
January 21, 2009
Oklahoma Department of Environmental Quality
707 N. Robinson, Oklahoma City – 10th Floor Conference Room

1:00 p.m.	Welcome and Introductions
1:10 p.m.	Recap of Senate Bill 1410 Work Group Background - Recap of Work Group Meeting 1 (December 8, 2008)
1:20 p.m.	Review and Discussion of Draft Work Plan Outline - Goals, objectives, and end products for this Work Group - Work Plan components - Schedule
1:40 p.m.	Discussion of Potential Evaluation Criteria, Data Needs, and Data Sources

2:25 p.m.	Set Meeting Schedule and Path Forward
	- Potential recharge site tours
	- Schedule and topics for Work Group Meetings
	  o Review/Finalize Work Plan (Feb 2009)
	  o Review draft report (May 2009)
	  o Final recommendations on potential demonstration sites (June 2009
	  o Integration into the Oklahoma Comprehensive Water Plan

2:45 p.m.	Adjourn

CDM

Oklahoma Comprehensive Water Plan
Marginal-Quality Water Technical Work Group Meeting #2

PRELIMINARY AGENDA
RESCHEDULED – February 9, 2009
Oklahoma Water Resources Board Offices – 3800 N. Classen, Oklahoma City
(Teleconference also available – 888-596-9024 / Passcode 778668#)

1:00 p.m.	Welcome and Introductions
1:10 p.m.	Recap of Senate Bill 1627 Work Group Background and Logistics ◥ Recap of Work Group Meeting 1 (December 8, 2008) ◥ Review definitions of Marginal-Quality Water ◥ Selection of Marginal-Quality Water Technical Work Group Vice-Chair
1:20 p.m.	Review and Discussion of Draft Work Plan Outline ◥ Goals, objectives, and end products for this Work Group ◥ Work Plan components ◥ Schedule
2:10 p.m.	Identification of Marginal-Quality Supplies for Potential Development ◥ Inventory of potential supplies ◥ Discussion of constraints on use (by category of marginal-quality supply) ◥ Anticipated data needs and potential resources
2:40 p.m.	Set Meeting Schedule and Path Forward ◥ Schedule and topics for next Work Group Meetings ◥ Meeting #3 (February 2009) i. Examine How Oklahoma May Beneficially Use Marginal-Quality Water ii. Examine How to Address Marginal-Quality Water Treatment Needs iii. Water Day at the Capitol ◥ Meeting #4 (April 2009) i. Recommend Potential Uses of Marginal-Quality Water ◥ Meeting #5 (May 2009) i. Conclusion and Integration into the Oklahoma Comprehensive Water Plan
3:00 p.m.	Adjourn

CDM

ARTIFICIAL RECHARGE TECHNICAL WORKGROUP MEETING
January 21, 2009
Draft Minutes

The second group meeting occurred in the Offices of the Oklahoma Department of Environmental Quality, 707 N. Robinson, Oklahoma City, Oklahoma and began at 1:00 pm. Attendees included: Senator Susan Paddack; Suzanne Van Cooten, NOAA/NSSL; Bob Puls, EPA-Kerr Lab; Wayne Kellogg, Chickasaw Nation; Michael Overbay, EPA Region 6; Bob Fabian, OWRB; Noel Osborn, OWRB; Bob Sandbo, OWRB; Bryan Mitchell, CDM; Kyle Arthur, OWRB; John Rehring, CDM; Gordon McCurry, CDM; Jon L. Craig, DEQ; Robert Toole, Cons. Comm; Kim Winton, USGS; Kelly Hurt, Chickasaw Nation; Patricia Billingsly, Corp. Comm; Saba Tahmassebi, ODEQ; Deke Arndt, OCS; Terri Sparks, OWRB; Mike Mathis, Chesapeake; Derek Smithee, OWRB; and Collins Balcombe, BOR.

Mr. Kyle Arthur, OWRB, began the meeting by asking participants to introduce themselves, and then gave a recap of activities to date.

Gordon McCurry, CDM, continued with a PowerPoint overview (copy attached) of a draft work plan outline, which was compiled by CDM for discussion purposes. The goals and overall process, as shown in the attached PowerPoint, were presented and generally agreed upon by the group. Gordon talked about Phase 1 and Phase 2, with Phase 1 being to define site evaluation methods and then undertake a siting evaluation to identify and prioritize potential regions suitable for recharge, and Phase 2 being the implementation Phase, using site-specific factors to further refine locations, prioritize sites and then implement pilot recharge projects.

Tasks listed for Phase 1 were summed up as:

- Task 1. Site Evaluation Methods
- Task 2. Site Characterization
- Task 3. Site Evaluation
- Task 4. Reporting and Coordination.

Kyle and others noted that the Water Day scheduled at the State Capitol on March10th would provide a good opportunity to give the legislature a status report on workgroup activities and overview of the work plan outline. The group also discussed a possible subsequent presentation to the legislature, on completion of the Phase 1 evaluation, to communicate the results of Phase 1 and pursue legislative funding for implementation activities under Phase 2.

The meeting then moved to a discussion on Task 1, Site Evaluation Methods, which encompasses development of evaluation criteria and determination of criteria weighting factors, as well as input from the technical workgroup and other stakeholders. Gordon went over the criteria and weighing factors used in a recharge study that CDM had conducted in Colorado. (Copies of this information was passed at the previous meeting and attached to that meeting's summary.)

Kelly Hurt, Chickasaw Nation, suggested going back one step further to look at climatic factors and availability of precipitation as a necessary element of assessing the feasibility of a recharge project. He noted he had had discussions with Suzanne Van Cooten, NOAA, on the availability of climate data for project review. Noel Osborne, OWRB, pointed out that precipitation was not necessarily a requisite for a recharge projects—water could be diverted from other sources, such as waste water if appropriate, etc. There was some discussion as to which phase within the evaluation process would be the most appropriate to look at actual water availability. There was general agreement that water availability was an important criterion to include in the evaluation.

Kyle asked Saba Tahmassebi, ODEQ, about regulatory restrictions. Saba noted there could be some substantial obstacles during the permitting process. Jon Craig, DEQ, noted that we need to not only look at quantity, but also quality, i.e., we don't want to degrade existing quality. Kelly Hurt continued to emphasize that he believed that the amount of water and geologic characteristics are of equal importance.

Criteria that were agreed upon as being fundamental to the process included:

- Physical suitability of a potential storage site
- Availability of water for recharge
- Quality of available recharge water, as consistent with the intended use of the water that would be withdrawn from storage.

The group also discussed the potential use of "threshold criteria" that could be used as a pass/fail test, toward preliminary screening of recharge demonstration project areas. By doing so, detailed analysis could be conducted on fewer sites.

The basic elements that would determine need/feasibility of a project include:

- Sufficient recharge capacity at a given location, which can be thought of as a "bucket" in which the recharged water could be stored (viability of groundwater formation/geology)
- Sufficient recharge water (availability and quality)
- Water need, particularly in regards to:
    - utilization of existing sources;
    - physical water supply availability as determined under OCWP "gap analysis"

Collin Balcombe, BOR, mentioned he did some research on BOR's past recharge demonstration projects. He indicated they have funded 41 projects across 17 states, having a wide range in methodologies and projects across a wide array of political boundaries and policies. A committee review of all the projects implied that implementation of rating criteria/methods would be a more efficient way for selecting projects. Collin passed out 3 excerpts from recharge related studies he had reviewed for the groups' information (copies attached). The group noted that BOR's study had a different overall intent than is contemplated under this work group's efforts. Specifically, BOR's recharge demonstration projects were targeted toward demonstrating specific recharge technologies, whereas this work group's focus is

on identifying/prioritizing sites for a recharge demonstration project. The specific recharge technology would then be selected for that site(s) as part of implementation (Phase 2) activities.

Kelly recommended that we needed to develop criteria that would result in projects having the best chances of success, instead of trying to develop something applicable to every part of the state. He also recommended being careful how you characterize "need", because it could put smaller communities at a disadvantage if you define needs in terms of quantities as opposed to immediacy of needs, i.e., smaller communities may have needs in smaller quantities than larger communities, but their needs may be more immediate or more critical than for some larger communities.

Michael Overbay, EPA Region 6, noted that as we go into Phase II, it might be useful to do some "field truthing" to prevent unanticipated problems such as what has occurred in past projects.

Gordon suggested that we begin thinking about sources of data. He also asked about interest in doing a field trip at an active recharge project, as was discussed briefly at the first meeting. The group was very receptive to this, and several projects were mentioned – Edwards Aquifer in San Antonio, the Equus Beds near Wichita, Kansas, the Hueco Bolson aquifer near El Paso, and the ongoing Blaine Gypsum/Dog Creek Shale recharge project in southwest Oklahoma. Mr. Overlay recommended that, if funding for a field trip was a problem, we could look into have someone from one of these projects come and make a presentation to our group.

The next meeting was set for 1:00 pm, March 9, with the location to be announced. Activities to be accomplished in the interim include:

- CDM, based on meeting input and any forthcoming interim recommendations, would work on evaluation criteria and preliminary weighting factors as discussed.
- Senator Paddack asked that each participate advise Kyle of any resources they could bring to the table, be it potential funding, expertise, tools, materials, data collection, etc.

Note: during the course of the meeting, Duane Smith, OWRB Executive Director, and Steve Thompson, ODEQ Director, stepped in to welcome the group. Announcements included Duane's appointment of Kyle as his designee for Chair of the group.

Oklahoma Comprehensive Water Plan
Artificial Recharge Technical Work Group - Senate Bill 1410

Work Plan Outline
Preliminary DRAFT
January 16, 2009

Study Goal:

Develop and implement criteria to prioritize potential locations throughout Oklahoma where aquifer recharge demonstration projects may be most feasible.

PHASE 1 – SITING EVALUATION

1: Site Evaluation Methods

- 1.1 Develop Evaluation Criteria
- 1.2 Determine Criteria Weighting Factors
- 1.3 Advisory Group and Stakeholder Input

2: Site Characterization

- 2.1 Identify and Assemble Data
- 2.2 Preliminary Identification and Screening of Study Regions
- 2.3 Data Evaluation and Mapping
- 2.4 Advisory Group Review

3: Site Evaluation

- 3.1 Characterize Sites Relative to Evaluation Criteria
- 3.2 Score and Rank Sites
- 3.3 Advisory Group Review

4: Reporting and Coordination

- 4.1 Draft Report
- 4.2 Advisory Group Review
- 4.3 Finalize Report
- 4.4 Stakeholder and Legislative Meetings/Presentations

PHASE 2 – IMPLEMENTATION

OKLAHOMA COMPREHENSIVE WATER PLAN

Artificial Recharge Technical Work Group Meeting #2

ODEQ Offices, Oklahoma City

January 21, 2009

OWRB

CDM

Recap of SB 1410 & Work Group Meeting #1

Recap

- Overview of Senate Bill 1410
  - *using artificial recharge to help increase the State's available water supplies through collaboration and consensus building*
- Discussions of potential evaluation criteria
- Discussion on cooperation from USBR, EPA, USGS, others
- Development of Work Plan
- Tours of potential recharge sites

Draft Work Plan Outline

Goals and Overall Process

- Develop and implement criteria to prioritize potential locations throughout Oklahoma where aquifer recharge demonstration projects may be most feasible.
- Phase 1 will undertake a siting evaluation of potential recharge sites
- Phase 2 will implement one or more pilot studies on high-ranking sites from Phase 1, using site-specific factors to prioritize sites

Phase 1 – Preliminary Draft Outline

- **1: Site Evaluation Methods**
- **2: Site Characterization**
- **3: Site Evaluation**
- **4: Reporting and Coordination**

Task 1 – Site Evaluation Methods

- 1.1 Develop Evaluation Criteria
- 1.2 Determine Criteria Weighting Factors
- 1.3 Advisory Group and Stakeholder Input

Task 2 – Site Characterization

- 2.1 Identify and Assemble Data
- 2.2 Preliminary ID and Screening
- 2.3 Data Evaluation and Mapping
- 2.4 Advisory Group Review

Task 3 – Site Evaluation

- 3.1 Characterize Sites Relative to Criteria
- 3.2 Score and Rank Sites
- 3.3 Advisory Group Review

Task 4 – Reporting and Coordination

- 4.1 Draft Report
- 4.2 Advisory Group Review
- 4.3 Finalize Report
- 4.4 Stakeholder and Legislative Presentations

Task 1.1 & 1.2 – Evaluation Criteria and Weighting Factors

- Types of criteria for regional assessment
  - *Hydrogeologic*
  - *Implementation*
  - *Other (cost/benefit, water quality, environmental, etc)*
- Discussion of potential screening criteria
- Discussion of criteria weighting factors

Criteria and Weighting Factors used in CO

Hydrogeologic Critieria	
• Storage Availability	**2.0**
• Hydrogeologic Suitability	**1.5**
• Residence Time	**1.0**
Environmental Criteria	
• Water Quality	**0.5**
• Habitat Concerns	**0.5**
• Nonbeneficial Use	**0.5**
Implementation Criteria	
• Land Ownership/Use	**0.5**
• Existing Infrastructure	**1.0**
• Proximity to Demand	**2.0**
• Costs	**0.5**

Discussion:
Potential Evaluation Criteria
and Weighting Factors

Discussion:
Potential Sources of Data
For Evaluation Criteria

Discussion of
Tours of Potential Recharge Sites

Work Group Meeting Upcoming Schedule and Topics

Potential Future Meetings and Topics

- **#3: Review and Finalize Work Plan (Feb ?)**
- **#4: Review Draft Report (May ?)**
- **#5: Site Recommendations (June ?)**
- **#6: Develop Phase 2 (Sept ?)**

BOR HANDOUT - 01/21/2009 Recharge Mtg.

Chapter III - TECHNICAL EVALUATION OF PROJECT PROPOSALS

Since June 1986, when the 6-month progress report was submitted to Congress, Reclamation received 41 proposals. A wide range of types of recharge project proposals have been received. Some proposals involve using existing recharge projects and increasing the facilities for recharge and/or monitoring. Other proposals plan to use existing conveyance facilities to transport surface water to potential recharge sites; still others propose to use existing pits or ponds to store recharge water supplies and existing or abandoned wells to inject recharge water supplies into the aquifers.

The majority of the proposals however, call for the construction of new facilities. These facilities include channel diversion structures, retention dikes and gates, flushable gravel filters, sediment ponds, dual-purpose (injection and extraction) wells, monitoring systems, spreading mechanisms, percolation ponds, underground barriers, and shallow dry wells.

Several ways to obtain the necessary water supplies are proposed. Some proposals are based upon accumulation of snow and subsequent melting; some use excess spring runoff; and some use treated effluent. Exchanges of water to obtain a recharge supply also are being considered. Some proposals take advantage of fluctuations in seasonal water supply or demand to obtain water for recharge demonstration purposes.

In addition to the objective of increasing aquifer supplies, some proposals will evaluate the reduction or stabilization of land subsidence through injection of water into underlying aquifers. Other proposals will reduce salt-water intrusion into aquifers using injection wells. The uniqueness aspect of groundwater recharge demonstration, noted in the legislative history, was considered by the sponsors.

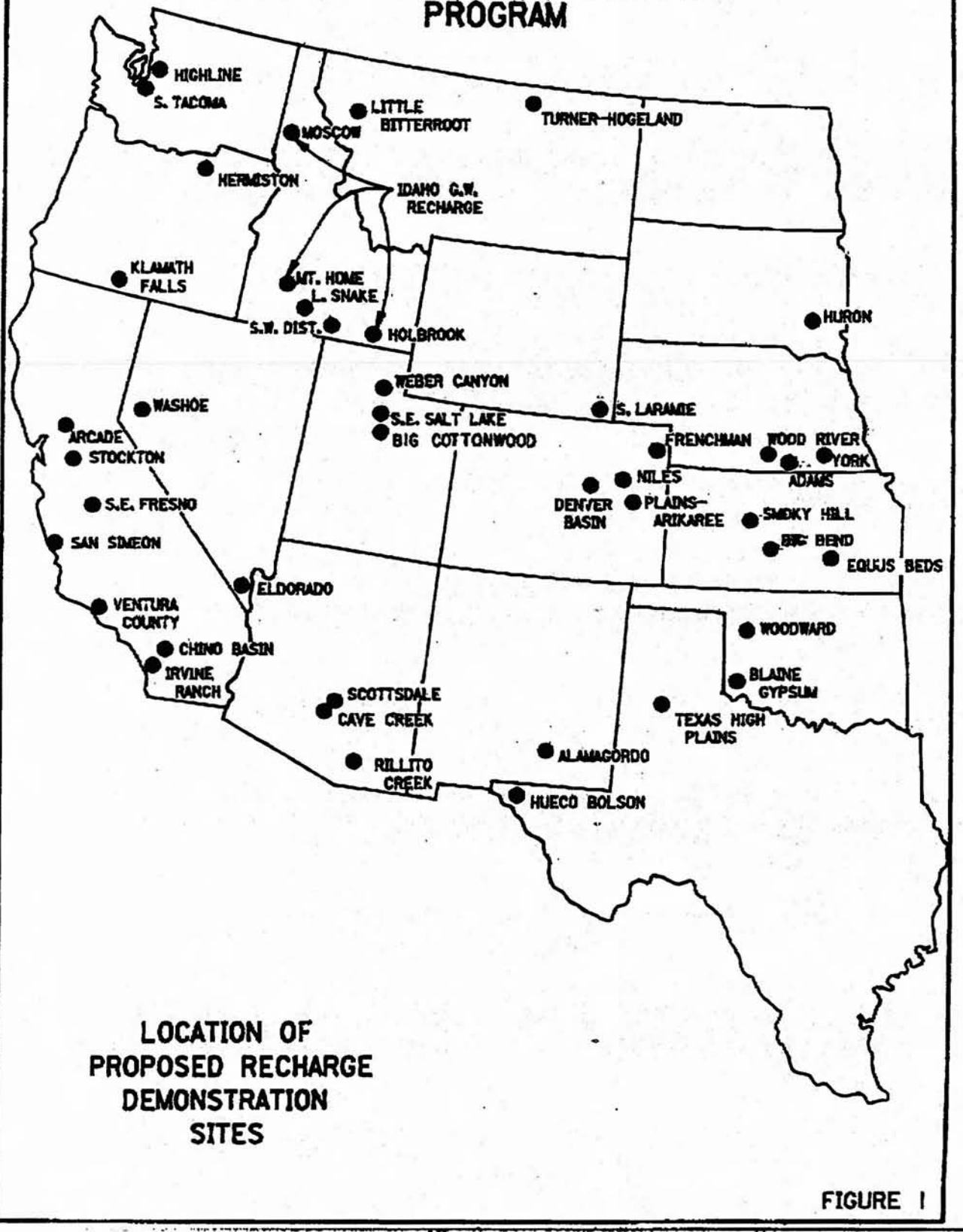
Figure 1 shows the location of all 41 proposals. The proposals have been reviewed and evaluated by the three Federal agencies, using the procedures and criteria detailed below.

A. Technical Evaluation Process

The technical evaluation process was developed jointly by Reclamation, USGS, and EPA. Each proposal was subjected to an initial screening derived from the requirements specified in the Act, including a declining water table, an available surface water supply, and a high probability of physical, chemical, and economic feasibility for recharge of the groundwater reservoir. The specific screening criteria developed were as follows:

Screening Criteria:
- Declining Water Table
- An Available Surface Water Supply
- A Minimum of 20 Percent non-Federal Cost Sharing
- No Serious Environmental Problems
- Public Acceptability of Proposal
- Received priority from the Governor

HIGH PLAINS STATES GROUNDWATER DEMONSTRATION PROGRAM



LOCATION OF PROPOSED RECHARGE DEMONSTRATION SITES

FIGURE 1

As a practical matter, all proposals received were given a full technical evaluation, since on initial screening all appeared to pass the screening tests. The total evaluation process, however, proved to be iterative in that, in some cases, during the detailed evaluations additional information was developed indicating serious environmental problems, lack of Governor's priority, or absence of a declining water table.

Table III-1 lists the technical evaluation factors, weights, and scoring criteria. Each factor of the technical evaluation was assigned a weighted value, so that all factor weights totaled 100. During this portion of the evaluation process each factor was scored by assigning points on a scale of 0 to 1. The proposal's total score was then determined as the sum of each factor weight times the points. Information available in the reviewing agencies was used to evaluate the various factors. The evaluation process resulted in the ranking of proposals, which is shown in Table III-2.

B. Technical Evaluation Findings

A summary of the key information for all 41 proposals is displayed in Table III-2, Evaluation of All Proposals.

State Priority. This is the priority expressed by the Governor or his designated State representative. In some cases States grouped their proposals into primary and secondary priorities. Thus, it is possible to have more than one first priority.

Regional Priority. The proposals were technically evaluated by Reclamation regional evaluation teams with input from USGS and EPA. All regions used the same evaluation system and provisions were made to achieve consistency of scoring for all proposals. The regional priority reflects the relative technical score for each proposal within its Reclamation Region. Table III-1 lists the technical factors evaluated by Reclamation. For convenience, Figure 2 shows the location of the six Reclamation Regions.

Environmental Category. Initially, it was assumed that including environmental problems as a major screening criteria and also including environmental issues as one of the 11 technical evaluation factors would be sufficient to assure that only environmentally sound proposals would be selected. However, during the selection process after the proposals had been received from the sponsors and an initial evaluation conducted by Reclamation Regions, it became apparent that many of the proposals had unanswered questions on possible environmental impacts. Accordingly, a separate environmental compliance review was conducted. Each proposal was ranked according to the anticipated complexity of achieving environmental compliance requirements. Proposals rated as a 1 have potential major compliance problems while those rated a 4 contained enough information to achieve compliance. During this environmental review, Fish and Wildlife Service and State wildlife agencies were solicited for input on potential endangered species issues, probable impacts, and mitigation needs for many project proposals. The requirements of addressing major environmental issues would necessitate preparation of environmental documents and rule out selection of a proposal

Table III-1

Technical Factors, Weights, and Scoring Criteria

Factor	Weight Total=100	Points 0-1	Scoring Criteria
Geohydrologic Feasibility	20	1	Scored by USGS. This is the score on a scale of 0 to 1.0 of the probability that the proposal will operate as designed from a geohydrologic standpoint based on the information presented in the proposal.
		0	
Engineering Feasibility	10	1	The facilities and operations are described with detail and the proposal is feasible.
		.5	The facility and operations are conceptually described and the proposal can be feasible.
		0	The facilities and operations are not described or the proposal is impossible.
Cost Estimate	5	1	Total Phase II costs are presented with details and the estimate is adequate to accomplish the program.
		0	Inadequate estimate or no details.
Legal Access	5	1	Acceptable plan for access or use of existing facilities.
		0	Nonacceptable or no plan.
Monitoring Plan	10	1	An adequate plan is described.
		0	Inadequate or no plan.
Rehabilitation Plan	5	1	Acceptable plan for permanent use of the facilities.
		0	Nonacceptable or no plan.

Factor	Weight Total=100	Points 0-1	Scoring Criteria
Cost Sharing	13	.8	Commitment to share, 80% non-Federal
		.2	Commitment to share, 20% non-Federal (up to .2 Bonus Points were awarded for use of existing facilities and/or cash contributions)
Federal Cost vs Total Cost	12	1	Total Phase II Cost Least Costly Proposal
		0	Most Costly Proposal
			(Scored in proportion to total program costs)
Legal and Institutional Issues	5	1	No significant issues or an adequate plan to resolve them.
		0	Issues are not addressed or there are unresolved issues with no plan to resolve them.
Environmental Issues	5	1	No significant potential issues or there is an adequate plan to resolve them.
		0	No plan to resolve potential issues or no coordination of the environmental analyses.
Uniqueness	10	1	Proposal has unique qualities.
		0	Proposal is entirely routine.

TABLE III-2

Evaluation of All Proposals

Proposal	USBR Region	Priority State	Priority Regional	Environ. Category	USGS Rating	Proposal Cost $
			High Plains States			
Colorado						
Plains-Arikaree	MB	1	2 of 11	4	1.5	196,100
Frenchman	MB	2	7 of 11	4	.1	186,000
Niles Reservoir	MB	3	10 of 11	1	.6	3,400,700
Denver Basin Aquifer	MB	4	2 of 11	4	1.0	2,283,800
Kansas *						
Smoky Hill	MB	1	1 of 11	4	1.0	890,300
Equus Beds	SW	1	3 of 7	4	1.0	3,583,200
Big Bend	SW	2	2 of 7	4	1.0	132,800
Nebraska						
York	MB	1	4 of 11	4	.95	1,169,300
Adams County	MB	2	6 of 11	4	.6	644,800
Wood River	MB	3	8 of 11	1	.5	979,200
New Mexico						
Alamogordo	SW	1	4 of 7	4	.8	581,800
Oklahoma						
Blaine Gypsum	SW	1	6 of 7	4	.4	896,000
Woodward	SW	2	7 of 7	4	.3	861,800
South Dakota						
Huron	MB	1	9 of 11	4	.4	1,132,300
Texas						
Texas High Plains	SW	1	5 of 7	1	.9	1,946,100
Hueco Bolson	SW	2	1 of 7	4	1.0	412,200
Wyoming						
S. Laramie County	MB	1	11 of 11	1	.7	2,126,200

*Kansas, California, Montana, and Nevada proposed projects located in 2 different Bureau of Reclamation regions.

TABLE III-2 (Continued)

Proposal	USBR Region	Priority State	Priority Regional	Environ. Category	USGS Rating	Proposal Cost $
	Other Western States					
Arizona						
Rillito Creek	LC	1	2 of 6	4	.5	2,726,000
Cave Creek Wash	LC	2	1 of 6	4	.9	2,082,000
Scottsdale	LC	3	3 of 6	4	.5	1,488,000
California *						
Arcade	MP	1	2 of 7	4	.9	398,900
Irvine Ranch	LC	1	4 of 6	4	.5	1,989,000
Stockton	MP	2	5 of 7	4	.8	1,055,100
S.E. Fresno	MP	2	3 of 7	4	.9	4,602,000
Chino Basin	LC	2	5 of 6	4	.1	1,495,000
Ventura County	MP	3	6 of 7	3	.8	2,110,400
San Simeon Acres	MP	0	7 of 7	2	.1	523,100
Idaho						
Southwest Irrig Dist	PN	1	6 of 7	4	.9	3,028,000
Lower Snake Aquifer	PN	2/3	5 of 7	3	.7	278,000
Idaho G.W. Recharge	PN	2/3	7 of 7	3	.55	1,231,600
Montana *						
Turner-Hogeland	MB	1	5 of 11	4	.3	795,200
Little Bitterroot	PN	2	4 of 7	3	.9	577,800
Nevada *						
Washoe County	MP	1	1 of 7	4	.9	945,400
Eldorado Valley	LC	2	6 of 6	2	.1	1,261,000
Oregon						
Klamath Falls	MP	1	4 of 7	4	.9	1,158,900
Hermiston	PN	2	3 of 7	4	.75	952,400
Utah						
Weber Canyon	UC	1	2 of 3	4	.75	1,066,700
SE Salt Lake County	UC	2	1 of 3	4	.9	3,335,800
Big Cottonwood	UC	3	3 of 3	4	.8	295,200
Washington						
Highline Well Field	PN	1	1 of 7	4	.7	812,000
South Tacoma Channel	PN	2	2 of 7	4	.8	466,900

* see previous page

BUREAU OF RECLAMATION
REGIONAL BOUNDARIES

FIGURE 2

in the 1 compliance category because an unacceptable portion of the 5 years allowed for Phase II would be devoted to environmental data gathering and compliance rather than recharge demonstration. Environmental evaluation and compliance are discussed further in Section C of this chapter.

USGS Rating. This is the probability score on a scale of 0 to 1.0 of the likelihood that the proposal will operate as designed, based on the information presented in the proposal. It is one of the 11 technical factors that make up the total proposal score. It is displayed specifically because of the central importance of the hydrogeologic feasibility to the success of each recharge project.

Proposal Cost. This is the estimated total proposal costs including both those direct costs that generally will be incurred by the project sponsor and Federal costs for management, monitoring, and report preparation. See Section IV-D, Project Costs and Cost Sharing, for a complete discussion of Project costs.

C. Environmental Evaluation Process and Compliance

Evaluation. All 41 proposals were reviewed to assess the level of effort required for compliance with environmental laws and regulations necessary to begin Phase II of the Program. The review included an evaluation of the potential for significant environmental impacts of the projects proposed to be constructed as well as possible controversial issues. Each project was evaluated based upon the information supplied in the proposal and appropriate contact with local, State, and Federal agencies concerned with wildlife and other environmental resources.

In addition, Reclamation personnel evaluated the proposals based upon their own experience and familiarity with the proposed site areas. Each proposal was assigned a compliance category, a rating that reflects the anticipated difficulty in complying with environmental requirements.

* Category 1 - proposals with a high potential for significant environmental impacts that would require preparation of an Environmental Impact Statement (EIS) or biological assessment (Endangered Species Act compliance). While it may be possible to resolve issues and achieve compliance with environmental laws, the preparation of an environmental impact statement and/or biological assessment, in view of the short timeframe and limited budget of the Program, preclude inclusion of these proposals in the plan.

* Category 2 - proposals appearing to have significant impacts due to their size, the nature of the project, or the potential for impacting drinking water supplies. Compliance would probably include collection of additional data and preparation of an environmental assessment to determine the extent of significant impacts and controversy.

* Category 3 - proposals lacking information but generally small in size or using existing facilities thereby minimizing impacts. It is anticipated that

with additional information acquired through consultation with appropriate State or Federal offices, it could be demonstrated that these projects would result in no significant impacts.

* Category 4 - proposals with sufficient information available to determine that the impacts would not be significant.

Table III-2, Evaluation of All Proposals, displays the numerical rating assigned for the compliance categories. These ratings are the final ratings achieved by each project during the evaluation process. The compliance category system of ranking was an iterative process during which ratings changed as more information was obtained.

Environmental Compliance. Four proposals fall into compliance category 1. These proposed projects appear to involve significant environmental issues; all have potential impact to endangered species. The short timeframe and limited budget of this Program preclude consideration of proposals requiring comprehensive data gathering and analysis. It is likely that these projects would require a full EIS assessing the potential impacts and alternatives. The Wood River Project in Nebraska, and S. Laramie County, Wyoming, for example, could result in flow depletions to designated critical habitat for the endangered whooping crane. These projects would probably require formal consultation with the U.S. Fish and Wildlife Service (FWS) and detailed analyses of potential effects and measures to mitigate any adverse impacts.

Two proposals fall into compliance category 2. These proposals could have significant environmental effects and possibly require environmental assessments and/or impact statements. San Simeon Acres, California, for example, would reduce inflows to a coastal lagoon. This proposal would probably require a permit from the State that could entail long-term environmental analysis to assess the effects of depleting fresh water inflow to the lagoon.

Four proposals fall into compliance category 3. These proposals could probably achieve category 4 compliance level if additional information were supplied. This information could come from consultation with State or Federal agencies to determine the presence of listed endangered species or examination of potential mitigation issues. These were not further investigated due generally to their low priority ranking by the States.

Thirty-one proposals fall into compliance category 4, indicating that no significant impacts are anticipated. State and FWS representatives have reviewed many of the proposals for endangered species and other concerns such as overall project impacts and mitigation needs. Specific mitigation recommendations have been made for several of the proposed projects. Other concerns have been considered in coordination with other Federal, State, and local agency representatives. Each project sponsor will be required to mitigate, as deemed necessary by Reclamation, FWS, and State fish and game agencies, any adverse impacts associated with construction and/or operation, as already agreed to and any additional mitigation as determined by further evaluation in Phase II.

A Finding of No Significant Impact (FONSI) has been prepared for the 21 projects in the recommended plan. After consultation with appropriate State and Federal agencies, it was determined that an EIS is not required for the Groundwater Demonstration Program. The EPA has reviewed the proposals, including the monitoring of groundwater and water quality aspects of the Program.

The Fish and Wildlife Service has also been contacted on many of the proposed projects regarding potential impacts to endangered and threatened species, flow depletion effects, and other impacts to fish and wildlife resources. Where impacts have already been identified and the FWS and/or State fish and game agencies have made recommendations to mitigate those effects, those recommendations have been agreed upon between the FWS and Reclamation and will become part of the negotiated agreement for Phase II activities between Reclamation and project sponsors. For projects where further information and definition of plans is needed to evaluate impacts or where Phase II activities result in the identification of additional impacts, Reclamation will include in the cooperative agreements with project sponsors appropriate mitigation, as determined jointly with the FWS and/or State game and fish agencies. For projects where agreement on mitigation measures cannot be achieved through field-level negotiations, resolution will be elevated to higher decisionmaking levels in the Department of the Interior.

There are currently nine projects for which special mitigation recommendations will be included. These are: Stockton and Arcade, California; York and Adams County, Nebraska; Highline Well Field, Washington; Washoe County, Nevada; Big Bend and Smoky Hill, Kansas, and SE Salt Lake County, Utah.

A copy of the FONSI is on file at Reclamation's Office of Environmental Technical Services, Code D-150, Denver Federal Center, Denver, Colorado (80225) and is available upon request.

BOR

As expected, the type of recharge technology applied is closely related to the controlling physical conditions. In practice, the basic categories of recharge technology also tend to coincide with the recharge purpose and applications. This is illustrated by comparing the general properties of the three basic recharge categories shown in table 8.

Use these basic categories + rank of in each category?

Table 8. Comparison of Basic Categories of Recharge Technology			
Examples	Recharge Application	Costs and Feasibility	Water Quality
Direct Well Injection			
Active pumping operations through pressurized wells Passive recharge through gravity feed injection wells Aquifer storage and recovery from a common well	Control over water source and recharge operations Direct management of aquifer storage and recovery operations Allows greater control over location and impacts on receiving aquifer	Higher costs for construction pump stations, injection wells, and conveyance systems Higher operational costs for pre-treatment, maintenance, and power costs More intensive engineering and investigations of aquifer and injectate properties	Water supply contaminants could be transferred directly to aquifer if undetected Wellhead protection and water quality monitoring plans are essential Compatibility of aquifer and source water chemistry
Constructed Infiltration Facilities			
Passive percolation through spreading basins or ponds Surface spreading operations designed to utilize soil aquifer treatment	Allows passive recharge for where site conditions are suitable for infiltration and deep percolation Soil treatment processes can filter and assimilate some contaminants	Construction and operation costs lower with less active management than injection Maintenance can be required to restore infiltration rates depending on site soils, algae growth, and siltation problems	Open facilities may be exposed to contamination by nonpoint source watershed pollutants in runoff Soil treatment properties requires more specialized investigations
Hydrologic Management Practices			
Facilities designed to capture excess storm runoff or streamflows Land management practices designed to increase infiltration or bank storage	Application varies with land and water management practices, but can provide simple low-cost recharge Can effectively use excess or nonappropriated water supply sources	Lower cost as an increment of existing resource practices, but recharge can be difficult to monitor or regulate Recovery of recharged water uncertain and water rights issues may be complicated	Water quality and exposure to nonpoint contamination are important planning needs Potential for soil treatment and/or site contamination potential require specialized investigation

These recharge categories comprise a gradient of technology ranging from more technical and expensive injection operations to simple spreading basins or hydrologic management practices that are incorporated into ongoing agricultural land practices or other watershed management practices. This gradient is reflected in the common recharge objectives and applications for planned groundwater recharge. Injection operations are often associated with more highly treated water and efficient recovery of water to supplement municipal water supplies. Passive infiltration is favored when direct recovery is less certain or lower priority, and recharge is used to augment widely distributed agricultural water supplies or to produce an incremental benefit to widespread aquifer recharge.

BOK

Financial and Economic Factors

The costs and economic feasibility of groundwater recharge operations are subject to the water management needs and technology applied. The construction costs and recharge operations and maintenance requirements can vary widely. The estimated unit costs per volume of water and economic factors associated with the demonstration projects within each of the basic recharge categories are summarized in table 9.

Table 9. General Economic Results by Recharge Category

Project Examples	Unit Cost (per acre-foot)	Economic Factors
Direct Well Injection		
Active Injection—		Active injection has higher costs for treatment, pumping power, facility operations, maintenance, and monitoring.
Highline Well Field	$176 to $397 } typical	
Southeast Salt Lake	$264 to $346 } typical	
Washoe Project	$368 (estimate) } typical	A range of $100 to $400 per acre-foot was typical for full-scale operations. High range reflects pilot testing and lower recharge water volume. Costs decrease with more recharge over time.
Denver Basin	$798 } high range	
York Project	$1,726 } high range	
Equus Beds	$2,315 } high range	
Huron Project	$97 (estimate) – low end	Washoe and Huron estimated high costs of $9,169 and $31,500 for small-scale and short-term demonstration operations.
Gravity Injection—		
Southwest District	$36 to $177	Gravity injection eliminates well pumping. Less treatment may be required. Using existing retrofit wells can reduce costs.
Blaine Gypsum	$42	
Constructed Infiltration Facilities		
Spreading Basins—		Infiltration lower cost range $25 to $300 expected for long-term operations. Costs vary with recharge efficiency, available water, conveyance, basin rehabilitation, and monitoring costs.
York Project	$220 to $302 (reservoir)	
Wood River	$25, $32, $59	
Infiltration Beds—		York costs were attributed to reservoir costs without accounting for multipurpose benefits. Equus Beds had special features.
Equus Beds	$332	
Hydrologic Management Practices		
Land Management—		Low cost simple land and watershed practices with continued operation. Benefits can be difficult to quantify or gain adequate credit necessary to gain public support or financing.
Turner-Hogeland	$8 to $170,000	
In-Stream Practices—		Extreme range of costs on Turner-Hogeland reflects impacts of monitoring and administrative costs and low recharge volume.
Rillito Creek	$55 (estimate)	

Again, need to categorize?

These results confirm that the overall cost ranges correspond with the basic categories of recharge activities. Overall, these costs are relatively high for water storage and may not be economically feasible without Federal cost-share support. However, if unappropriated excess water supplies are available for recharge, it may represent new water, and the cost of $400 per acre-foot could be comparable to alternative municipal supplies. Somewhat lower costs are expected for longer term, full-scale recharge operations as opposed to the demonstration projects. Given the diversity of projects, it is difficult to isolate costs that represent long-term operations. Consequently, these estimates are probably more useful for comparison rather than absolute values.

Oklahoma Comprehensive Water Plan
Aquifer Recharge Technical Work Group Meeting #3

AGENDA
September 22, 2009
Oklahoma Water Resources Board
3800 N. Classen, Oklahoma City

10:00 a.m.	Welcome and Introductions
10:10 a.m.	Recap of Senate Bill 1410 Work Group Background ◥ Update on work group status ◥ Review Work Plan ◥ Recap of Work Group Meeting #2 (January 2009)
10:30 a.m.	Review and Discussion of Draft Screening Criteria & Methods
11:00 a.m.	Discussion of Data Needs and Data Sources for Recharge Site Screening
11:30 a.m.	Next Steps ◥ Data collection / preliminary screening ◥ Schedule for Work Group meeting #4
11:45 a.m.	Adjourn

CDM

ARTIFICIAL RECHARGE TECHNICAL WORKGROUP MEETING
September 22, 2009
Draft Meeting Summary

The third group meeting occurred on September 22, 2009, in the Offices of the Oklahoma Water Resources Board, 3800 N. Classen Blvd., Oklahoma City, Oklahoma and began at 10:00 am. Attendees included:

Senator Susan Paddack;	Kyle Arthur, OWRB
Matt Bliss, CDM	Bob Fabian, OWRB
Noel Osborn, OWRB	Bryan Mitchell, CDM
Suzanne Van Cooten, NOAA NSSL	John Rehring, CDM
Kim Winton, USGS	Saba Tahmassebi, ODEQ
Terri Sparks, OWRB	Collins Balcombe, BOR
Julie Cunningham, OWRB	Renee McPherson, OCS
Neil Suneson, OGS	Mark Belden, OWRB
Angie Burckhalter, OIPA	Mike Smith, CDM

Wayne Kellogg, Chickasaw Nation

Mr. Kyle Arthur, OWRB, opened the meeting with introductions and brief summary of the activities and the purpose of the meeting. A meeting agenda is attached.

John Rehring, CDM, continued with a PowerPoint overview (copy attached) of the work plan outline, which was discussed at previous meetings. The focus of the meeting then turned to Task 1.1, Evaluation Criteria. Matt Bliss, CDM, presented a Conceptual Overview of the screening process (refer to attached presentation).

Matt explained that the preliminary screening of groundwater basins consisted of two tests: fatal flaw and threshold. Basins which may be eliminated from further consideration due to the fatal flaw screening process could be those that have obvious water quality limitations. Candidate basins surviving the fatal flaw tests would then undergo threshold criteria evaluation. The combined fatal flaw and threshold screening is expected to result in 10 to 15 candidate areas. The 10 to 15 candidate areas will be evaluated on a more detailed level using a weighted Scoring Matrix and will result in recommendations of the most suitable areas for consideration. It was stressed that the analysis would be based on existing data; no field work was anticipated. The preliminary screening will be completed by Wayne Kellogg of the Chickasaw Nation under a grant from the Bureau of Reclamation. Results from the preliminary screening will be used for the detailed analysis that will be completed by CDM.

Mike Smith, CDM, discussed the more detailed analysis, including potential evaluation and weighting criteria. (Potential criteria scoring screening levels and weighting factors are shown in the attached presentation.) There was some discussion on the difference between alluvial and bedrock aquifers, e.g. 20% storage coefficients in alluvial aquifers vs. 1/10 to 1/100% in confined bedrock aquifers.

Some of the questions, recommendations and issues brought up during the ensuing group discussion included:

▪Would it be better to start with long-term needs or short-term seasonal needs that could be evaluated in a shorter timeframe.

▪Both have merit; depends on what you want the project to demonstrate.

▪Original intent of the authorizing legislation is to show that the technology exists and prove that it can be successful.

▪Pursue short-term, successful projects (low hanging fruit) that can be used as tool in the Oklahoma Comprehensive Water Plan (OCWP).

▪Seasonality of demands/supply may change in 5-10 years; so use short term projects to feed into long-term projects

▪Consider choosing one short-term and one long-term project

▪Possible to focus on a seasonal project where there would be application for long-term

▪Could look at month-to-month needs by using the OCWP gap tool

▪As climate change occurs, the need for the project might change

▪Timing of precipitation and surplus water is critical, especially looking at seasonality

▪Many gaps occur in the summer when demands cannot be met; perhaps a project could look at meeting peak demands as opposed to long-term

▪Does criteria cover a range of not met demands; is it all or none or is there some range

▪Is there a way to figure out if a community is having problems because they are wasteful vs. communities that have done everything, but still have needs

▪Smaller communities may have lesser needs, but the impact of meeting that need may be greater; they may require more attention than meeting the needs of more urban areas, which generally are more capable of helping themselves.

▪Might need two criteria tables; one aimed at bedrock and one at alluvial

▪Might need four tables; short-term bedrock, short-term alluvial, long-term bedrock, and long-term alluvial

▪Under EPA requirements, a separate permit would be needed for each injection site; EPA standards need to be considered

▪There are many areas where EPA criteria are not set now, but may be in the future

▪Probably would not use wastewater as an injection source because of water quality constraints (or advanced treatment requirements), regulatory uncertainties, and/or public perception considerations

▪How would you characterize residence time on a regional basis

▪Depends on hydraulic conductivity on alluvium (an example from a Colorado study was given of calculation on travel time from discharge site)

▪Sites considered should not be limited to alluvium; maybe use on unconfined bedrock aquifers

▪Need to consider interstate impacts when looking at “border” basins

John Rehring suggested that CDM do more work on preliminary screening and finalize the criteria weighting later. He also noted that he could provide copies of provisional gap maps from the in-progress OCWP analyses. The next steps would be data collection and analyses.

The goal of the next meeting will be to confirm/revise preliminary screening and detailed screening. The meeting adjourned around noon.

OKLAHOMA COMPREHENSIVE WATER PLAN

Artificial Recharge
Technical Work Group Meeting #3

OWRB Offices, Oklahoma City
September 22, 2009

Agenda

- Welcome and introductions
- Recap of SB1410 background and previous meetings
- Draft screening criteria and methods
  - *Confirm/finalize criteria*
- Data needs and data sources for screening
  - *Identify sources of data relative to screening criteria*
- Next steps

SB1410 Goals and Overall Process

- Develop and apply criteria to prioritize potential locations throughout Oklahoma where aquifer recharge demonstration projects may be most feasible.
- Phase 1: Identification of most suitable area(s)
- Phase 2: Demonstration project(s) at one or more areas from Phase 1

Recap of Previous Work Group Meetings

- Overview of Senate Bill 1410
  - *Using artificial recharge to help increase the State's available water supplies through collaboration and consensus building*
- Discussions of work plan and potential criteria
- Discussion on cooperation from USBR, EPA, USGS, others
- Identification of key criteria:
  - *Sufficient storage capacity*
  - *Sufficient source availability and quality*
  - *Demand gaps*

Goals for Today's Meeting

- Prioritization of End Use
  - *Short-term storage*
  - *Long-term storage*
- Feedback on Selected Criteria and Relative Weighting Factors
- Identify Potential Data Sources

Phase 1 – Work Plan Outline

- **1: Develop Site Evaluation Methods**
- **2: Preliminary Screening of Potential Sites**
- **3: Detailed Evaluation of Potential Sites**
- **4: Reporting and Coordination**

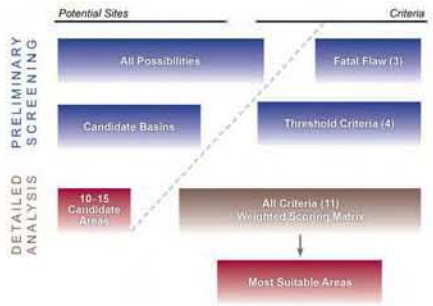
Task 1 – Site Evaluation Methods

- 1.1 Develop Evaluation Criteria
- 1.2 Determine Criteria Weighting Factors
- 1.3 Advisory Group Review

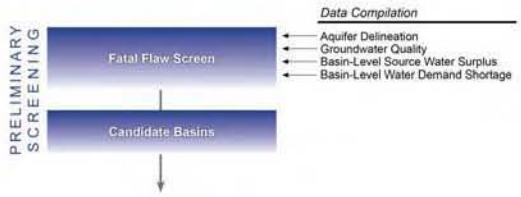
Task 1.1 – Evaluation Criteria

- Assessment of recommendations from various studies/reports
  - *Colorado SB-06 193, USBOR, NAS, ASCE*
- Studies included recommended criteria
- Determine which criteria are most appropriate to SB1410 and Oklahoma
- Consideration of different "steps" in the screening process

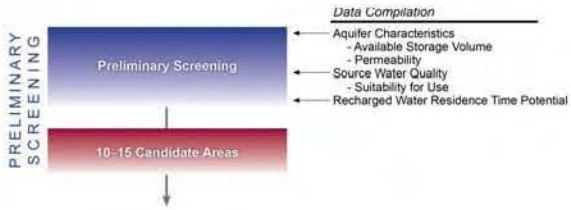
Conceptual Overview of Screening Process



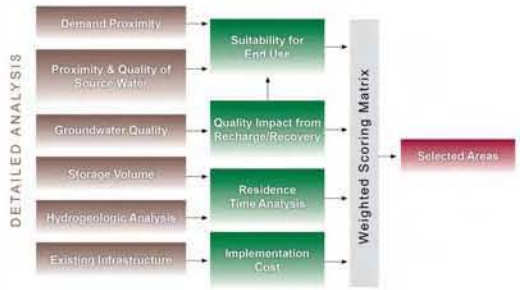
Preliminary Screening – Fatal Flaw



Preliminary Screening - Threshold



Detailed Analysis



Task 1 – Criteria Scoring

		Scoring		
Criteria	**Aquifer Type**	High	Medium	Low
1 Proximity to Demand				
2 Source Water Proximity and Availability				
3 Available Storage Volume and Ability to Meet Local Demand				
4 Hydrogeologic Suitability	Unconfined			
	Confined			
5 Source Water Quality				
6 Residence Time	Unconfined			
	Confined			
7 Groundwater Quality				
8 Effects on Groundwater Chemistry				
9 Implementation Cost				
10 Existing Infrastructure				
11 End Use				

Screening Levels and Criteria Weighting Factors

	Screening Level			Weighting*	
Criteria	Fatal Flaw	Threshold	Detailed	SB06-193	OWRB
1 Proximity to Demand	x		x	2	2
2 Source Water Proximity and Availability	x		x		2
3 Available Storage Volume and Ability to Meet Local Demand		x	x	2	2
4 Hydrogeologic Suitability		x	x	1.5	1
5 Source Water Quality		x	x		1
6 Residence Time		x	x	1	1
7 Groundwater Quality	x		x	0.5	0.5
8 Effects on Groundwater Chemistry			x		0.5
9 Implementation Cost			x	0.5	0.5
10 Existing Infrastructure			x	1	1
11 End Use			x		0.5

* ASCE and NAS did not provide general weighting information; US BOR weighting was site-specific

Task 1.1 – Evaluation Criteria

- Criteria scoring
  - *Determine what presents a good/average/poor score for each criterion*
- Work group discussion of draft criteria

Task 1.2 – Criteria Weighting

- Assessment of recommendations from various studies/reports
  - *Colorado SB-06 193, USBOR*
- USBOR weighting determined to be more site-specific in nature
- Evaluated order of importance to the evaluation for the selected criteria

Screening Levels and Criteria Weighting Factors

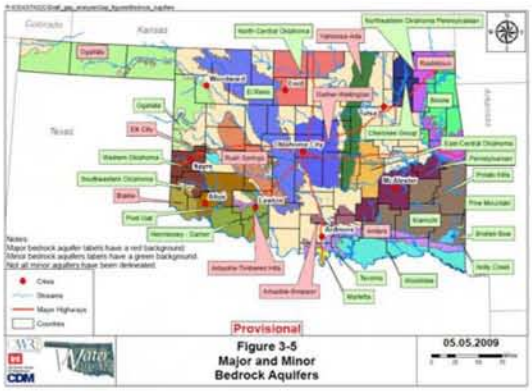
		Screening Level			Weighting*	
	Criteria	Fatal Flaw	Threshold	Detailed	SB06-193	OWRB
1	Proximity to Demand	x		x	2	2
2	Source Water Proximity and Availability	x		x		2
3	Available Storage Volume and Ability to Meet Local Demand		x	x	2	2
4	Hydrogeologic Suitability		x	x	1.5	1
5	Source Water Quality		x	x		1
6	Residence Time		x	x	1	1
7	Groundwater Quality	x		x	0.5	0.5
8	Effects on Groundwater Chemistry			x		0.5
9	Implementation Cost			x	0.5	0.5
10	Existing Infrastructure			x	1	1
11	End Use			x		0.5

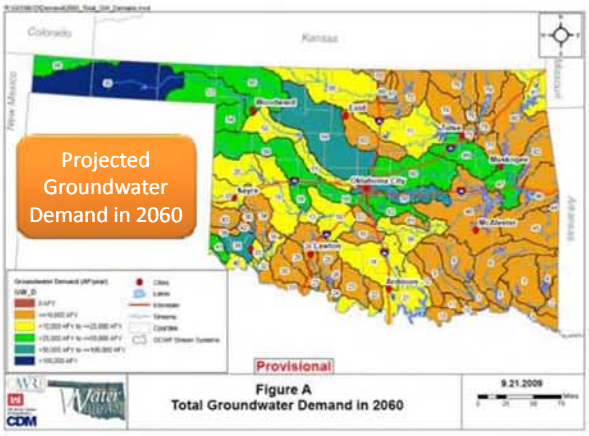
* ASCE and NAS did not provide general weighting information; US BOR weighting was site-specific

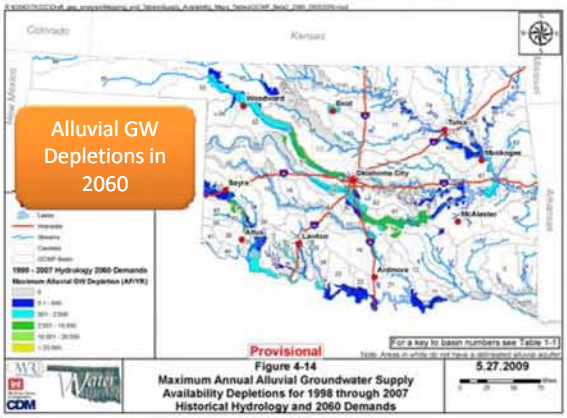
Task 1.2 – Criteria Weighting

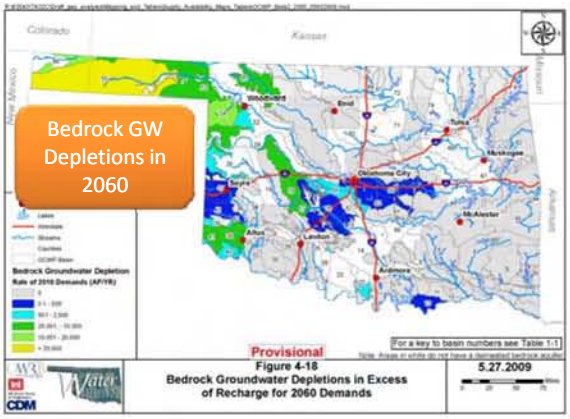
- Work group discussion of draft weighting

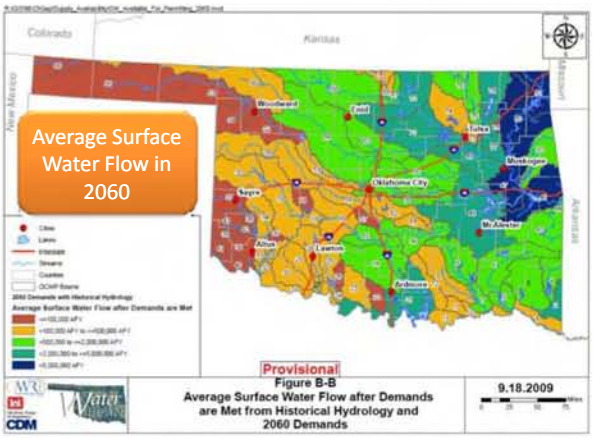
Glance at Preliminary Screening











Next Steps

- After agreement by work group on criteria, CDM/Wayne Kellogg will compile data
- Preliminary screening to be completed by Wayne Kellogg
- CDM anticipates Task 2 will result in 10-15 areas included for detailed evaluation (Task 3)

Next Steps

- Data collection & analysis
  - *Identified sources*
    - *OCWP supply/demand ("gap") analysis*
    - *Oklahoma cooperative partners*
    - *GIS data repositories (online)*
  - *Other potential data sources*
- Task 2 – Preliminary screening
- Task 3 – Detailed screening

Key Remaining Work Group "Checkpoints"

- Confirm/Revise Preliminary Screening (Task 2) – Work Group Meeting #4
- Confirm Detailed Screening / Draft Report (Task 3/4) – Work Group Meeting #5
- Target dates?

OKLAHOMA COMPREHENSIVE WATER PLAN

Artificial Recharge
Technical Work Group Meeting #3

OWRB Offices, Oklahoma City
September 22, 2009

Oklahoma Comprehensive Water Plan
Aquifer Recharge Technical Work Group Meeting #4

AGENDA
January 12, 2010
Oklahoma Water Resources Board
3800 N. Classen, Oklahoma City

2:30 p.m.	Welcome and Introductions
2:40 p.m.	Recap of Senate Bill 1410 Work Group Background ◥ Update on work group status ◥ Review Work Plan ◥ Recap of Work Group Meeting #3 (September 2009)
2:50 p.m.	Review and Discussion of Finalized Screening Criteria & Methods
3:10 p.m.	Review and Discussion of Draft Preliminary Screening Report
3:50 p.m.	Next Steps ◥ Finalization of preliminary screening ◥ Detailed ranking process and criteria weightings ◥ Schedule for Work Group meeting #5
4:30 p.m.	Adjourn

ARTIFICIAL RECHARGE TECHNICAL WORKGROUP MEETING
January 12, 2010
Draft Meeting Summary

The fourth group meeting occurred on January 12, 2010, in the offices of the Oklahoma Water Resources Board, 3800 N. Classen Blvd., Oklahoma City, Oklahoma and began at 2:30 pm. Attendees included:

Senator Susan Paddack	Kyle Arthur, OWRB
Matt Bliss, CDM	Bob Fabian, OWRB
Noel Osborn, OWRB	Bryan Mitchell, CDM
Kelly Hurt, Chickasaw Nation	John Rehring, CDM
Kim Winton, USGS	Saba Tahmassebi, ODEQ
Terri Sparks, OWRB	Collins Balcombe, BOR
Tim Ward, ODEQ	Robert Toole, OK Cons. Comm.
Neil Suneson, OGS	Mike Overbay, EPA
Angie Burckhalter, OIPA	Mike Smith, CDM
Baxter Vieux, OU	Doug Beak, USEPA
Gary McManas, OCS	Mike Mathis, Chesapeake
Mark Becker, USGS	Duane Smith, OWRB

Wayne Kellogg, Chickasaw Nation

Mr. Kelly Hunt, Chickasaw Nation, opened the meeting with introductions. John Rehring, CDM, continued with a PowerPoint overview of activities to date, and Matt Bliss, CDM, reviewed the work plan outline, which was discussed at previous meetings. (Copy of combined PowerPoint presentations attached.)

Matt went over the goals for today's meeting: 1) review of technical site evaluation and criteria memo; 2) feedback on preliminary screening report; 3) finalize criteria weightings for detailed analysis; and 4) identify other potential data sources. He noted that CDM's "Technical Memorandum 1 – Site Evaluation Methods and Criteria," was provided to the Workgroup prior to this meeting. This memorandum incorporated feedback on the draft memorandum discussed at the September 2009 meeting and provided direction for Wayne Kellogg to complete the preliminary screening review document. He then presented a conceptual overview of the screening process.

After presentation of a conceptual overview of the screening process, Matt turned the discussion over to Wayne Kellogg to present an overview of his site selection screening document. The main report, "Artificial Aquifer Recharge Site Selection Screening Document," was provided to participants prior to the meeting. However, Wayne noted that appendices to the report were not sent out by e-mail because of volume, but could be made available. He explained that his rationale for selection of potential preliminary sites included three major criteria: 1) select one potential site in each surface water basin containing a portion of a major aquifer; 2) select sites within each basin where demands were projected to be greatest; and 3) select areas where municipalities are already seeking additional water supplies.

Mr. Kellogg noted that he looked for ground water wells with yields greater than 150 gpm. (Refer to PowerPoint slides showing maps of wells with greater than 150 gpm and maps showing locations of public water supply wells, irrigation wells, and oil and gas well locations.)

One recharge site was located in each basin close to areas of identified needs. By applying the "fatal flaw" screening analysis, he started with 57 potential sites and narrowed them down to 30. The fatal flaw criteria that must be met in order for an aquifer to pass included: consideration of heavily developed aquifers, proximity of recharge location to demand and source water, and quality of groundwater (TDS <2000 mg/l.) He looked at CDM's projected demands for bedrock and alluvial aquifers and compared them to recharge to see which aquifers might be stressed. A criteria table was developed to apply and analyze fatal flaw factors. Aquifers that passed the fatal flaw test were carried onto "threshold" analysis.

Threshold analysis started with 30 potential sites and ended with 15. For the threshold analysis, Wayne looked at availability of surface water that could be used for recharge purposes, water quality and hydrogeologic suitability. He pulled 30 references to make a table of hydraulic properties. He also looked at OWRB website showing water table levels (GW) and USGS website data. The threshold analysis narrowed potential recharge sites down to about 15 areas.

Mike Smith, CDM, then went over the major criteria for the detailed analysis. Some of the major considerations include:

*Groundwater Quality – Impact on receiving waters
*Storage – Conductivity; pressure
*Hydrogeologic Analysis – Need to site so as to accomplish purpose
*Infractructure – Availability of infrastructure to deliver and use water
*More detailed analysis and ranking of criteria applied in the preliminary screening

Mike explained that the goal was to come up with weighting factors today, which would be applied to the 15 sites identified in the threshold analysis. Several participants requested more elaboration on each site or "square" on the map represented. Mike explained that each site is comprised of approximately one township (6 miles by 6 miles) in its respective basin, which was evaluated as the best area. He noted that it may be flexible to move several miles within that site, noting that many of the data for criteria ranking is available on a surface water basin and aquifer level. He also noted that there was more detailed information on the site selected in the previously mentioned Appendices of the Site Selection Screening Document prepared by Wayne Kellogg (American Water Institute). Kelly Hurt, Chickasaw Nation, noted they had projects involving thermal imaging, and that technology may help narrow down best sites within a region identified in the preliminary screening.

Mike Smith then suggested going through and explaining/discussing the following detailed ranking categories and criteria, then voting on criteria weighting factors. (Note: these categories and criteria are discussed in more detail in "Technical Memorandum 1-Site Evaluation Methods and Criteria.")

Demand Categories

▪Frequency-looking for seasonal demand-supply imbalance that will show more immediate results for purposes of demonstration project. Discussion ensued on frequency in fatal flaw vs. frequency as meant here, which refers to seasonality.

▪Proximity-balance in location of source water to recharge site and where demand occurs.

▪Density-highest density of groundwater use has potential for greater payback, storage availability and potentially easier incorporation into existing infrastructure.

Source Water Categories

▪Proximity; reasonable distance to avoid cost of pipeline/ditches

▪Quality: balance operations so recharge water will not degrade existing aquifer quality.

▪Regulatory challenges: legal availability of water.

Hydrogeologic Suitability Categories

▪Available storage volume and ability to meet local demand: self-explanatory.

▪Transmissivity: ability to get water in and out of an aquifer at an acceptable rate for the project.

▪Residence Time: amount of time recharged water can be expected to remain in the aquifer. Locations next to stream channels where rapid water loss occurs are not as favorable; the aquifer needs to hold the recharged water until needed.

▪The group also discussed different aquifer characteristics and decided that the ranking would include two classes of aquifers: alluvium and bedrock.

Groundwater Quality Categories

▪Native quality - if native groundwater quality is better than recharge source water quality, this is not a very suitable site.

▪Geochemical interactions - changes that source water and native water interaction may cause. Important to avoid precipitating solids that can clog the aquifer and/or wells.

Cost Categories

The Cost Categories criteria were originally introduced as recharge methods (how water is delivered for the project; infrastructure available; well recharge vs. spreading basins) and proximity. However, after group discussion, it was agreed that the "Cost Categories" should be subdivided as follows:

▪Capital: one time construction-type costs.

▪Operation and Maintenance: treatment and other O&M costs

Project Impact Categories

▪Qualitative ranking factors - the group agreed that the following should be included in qualitative ranking factors: time schedule, political will, and local cooperator support. It was noted that it would be hard to rate these factors upfront because of the many unknowns. However, these factors might be useful in differentiating between two otherwise equal ratings.

CDM requested input from the group regarding importance of the criteria for use in scoring the sites. Each participant was provided with dot stickers to vote for criteria they thought in their professional opinion are the most important to consider. The criteria voting proceeded with each meeting participant receiving 14 dots to distribute among the 14 identified criteria in

accordance to their perceived magnitude of importance. The results of the voting are shown in the table below (dots = votes).

Category	Criteria	Dots
Source	Quality for Non-Degradation	27
Hydrogeologic Suitability	Available Storage Volume and Ability to Meet Local Demand	25
Groundwater Quality	Native Quality	20
Groundwater Quality	Geochemical Interactions with Source Water	20
Demand	Proximity	19
Source	Proximity	19
Hydrogeologic Suitability	Transmissivity	16
Hydrogeologic Suitability	Residence Time/Distance to Discharge	14
Demand	Frequency	10
Demand	Density	10
Cost	O&M	10
Cost	Cap	8
Source	Regulatory Challenges	7
Project Impact	Qualitative Considerations	5

Other comments noted during subsequent discussion included:

▪Recommendation to stick with criteria that is easy to measure at this time;

▪Concern that resulting weighting of criteria importance depends on who votes at the time; subject to change with more information. (John Rehring responded that CDM could conduct a sensitivity analysis of weighting results.)

▪Recommendation that sites with similar final ranking be resolved by choosing the least costly alternative

▪Concern over how ratings would address different uses; difficult to compare/prioritize. (Mike Smith responded that uses should fall out as ranking proceeds.)

▪Question concerning opportunity for public input. (OWRB to give thought about public input. It is probably premature to request broad public input at this time; however, the OWRB could make a presentation at an OWRB Board meeting and provide information during the upcoming legislative session at a minimum, particularly to providers in the regions that score highest in the final ranking to help determine local interest and support for a pilot project.

Mike Smith, CDM, again noted that a sensitivity analysis would be done as part of the final ranking analysis. Meeting participants were asked to submit any additional comments on Wayne Kellogg's report ("Artificial Aquifer Recharge Site Selection Screening Document") by two weeks from Friday (January 29, 2010) and advised that the appendices to the report would be put on either the OWRB or CDM website/server (see instructions for CDM FTP site below).

CDM will develop a draft report summarizing the findings of the detailed analyses for discussion at the next meeting, which tentatively will be held in 7-8 weeks.

Mike Overbay, EPA, announced that a conference on Aquifer Storage Recharge is scheduled for the February 23-25 in San Antonio. He will send additional information to those on the Technical Work Group e-mail list.

The meeting adjourned around 4:30 p.m.

* * * * * * * * * * *

Instructions for CDM's FTP site to access materials from the meeting:

ftp.cdm.com
Username: OWRB_Recharge
Password: Recharge2010 (case sensitive)

Note: if clicking on the ftp.cdm.com link does not work, type it into a Windows explorer or web browser address bar.

OKLAHOMA COMPREHENSIVE WATER PLAN

Artificial Recharge
Technical Work Group Meeting #4

OWRB Offices, Oklahoma City
January 12, 2010

Agenda

- Welcome and introductions
- Recap of SB1410 background and previous meetings
- Screening criteria and methods Tech Memo
- Preliminary Screening (Wayne Kellogg)
- Criteria Weighting
- Next steps
  - *Finalize preliminary screening*
  - *Detailed ranking and criteria weighting*
  - *Schedule*

SB1410 Goals and Overall Process

- Develop and apply criteria to prioritize potential locations throughout Oklahoma where aquifer recharge demonstration projects may be most feasible.
- Phase 1: Identification of most suitable area(s)
- Phase 2: Demonstration project(s) at one or more areas from Phase 1

Recap of Previous Work Group Meetings

- Overview of Senate Bill 1410
  - *Using artificial recharge to help increase the State's available water supplies through collaboration and consensus building*
- Discussions of work plan and potential criteria
- Discussion on cooperation from USBR, EPA, USGS, others
- Identification of key criteria:
  - *Short-term/seasonal for quick success*
  - *Sufficient storage capacity*
  - *Sufficient source availability and quality*
  - *Demand gaps*

Phase 1 – Work Plan Outline

- **1: Develop Site Evaluation Methods**
- **2: Preliminary Screening of Potential Sites**
- **3: Detailed Evaluation of Potential Sites**
- **4: Reporting and Coordination**

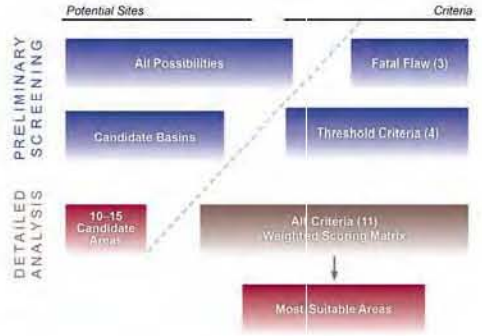
Goals for Today's Meeting

- Review and discussion on screening criteria Tech Memo
- Feedback on preliminary screening report
- Discussion of criteria weightings for detailed analysis
- Identify other potential data sources

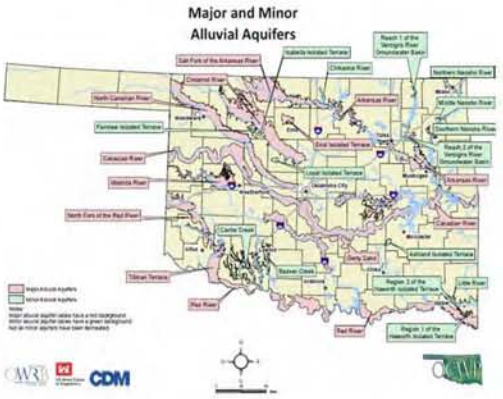
Task 1 – Site Evaluation Methods

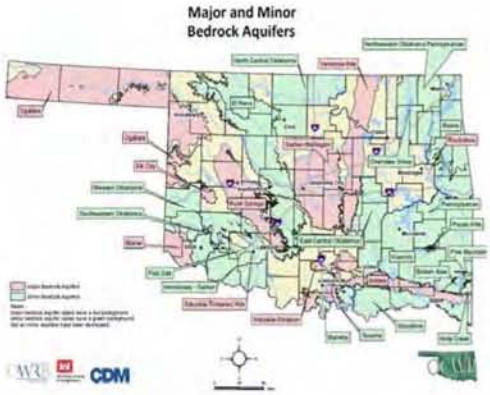
- Advisory Group Review (Sept 2009)
  - *Received feedback on draft memo, incorporated into final*
  - *Provided direction for Wayne Kellogg to complete preliminary screening*
  - *Agreed to finalize criteria weightings at today's meeting*
- Task 1 Technical Memo (distributed last week)
  - *Revision of criteria weightings based on today's discussions*
  - *Final version will be incorporated into final report*

Conceptual Overview of Screening Process



Preliminary Screening by Wayne Kellogg



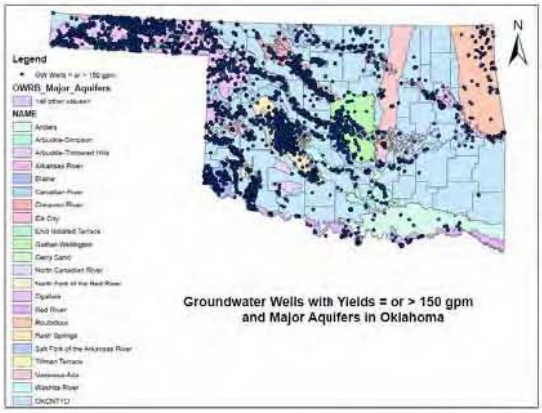


SELECTION OF POTENTIAL SITES

- Picked at least one potential site in each surface water basin that contained a portion of a major aquifer.

- Tried to pick sites within each of those basins where demand would be greatest such as near municipal water supply well fields, heavily irrigated areas, areas of heavy oil field drilling activity (Woodford shale gas play).

- Also tried to pick areas where municipalities are known to be looking for additional water supplies. (Ada, Shawnee, Norman, El Reno, Newcastle)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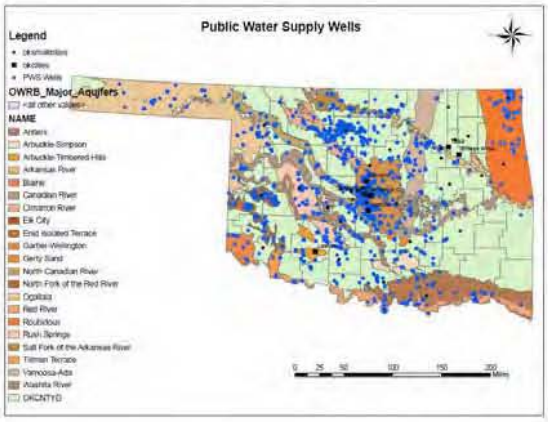
and Major Aquifers in Oklahoma
N


Public Water Supply Wells
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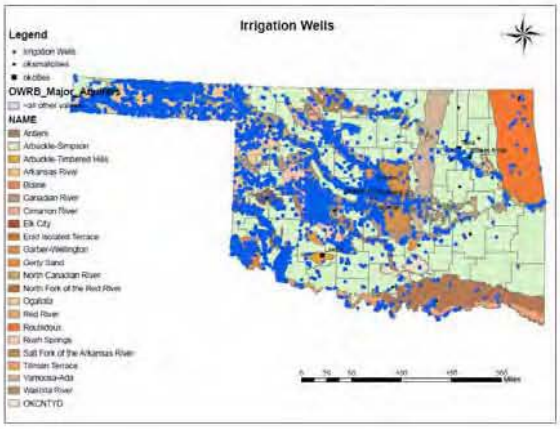
Arbuckle-Timbered Hills
Arkansas River
Blaine
Canadian River
Cimarron River
Elk City
Enid Isolated Terrace
Garber-Wellington
Gerty Sand
North Canadian River
North Fork of the Red River
Ogallala
Red River
Roubidoux
Rush Springs
Salt Fork of the Arkansas River
Tillman Terrace
Vamoosa-Ada
Washita River
OKCNTYD


Irrigation Wells
Legend
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Arbuckle-Simpson
Arbuckle-Timbered Hills
Arkansas River
Blaine
Canadian River
Cimarron River
Elk City
Enid Isolated Terrace
Garber-Wellington
Gerty Sand
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Ogallala
Red River
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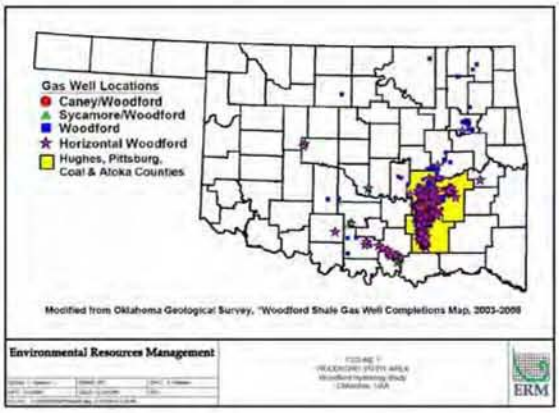
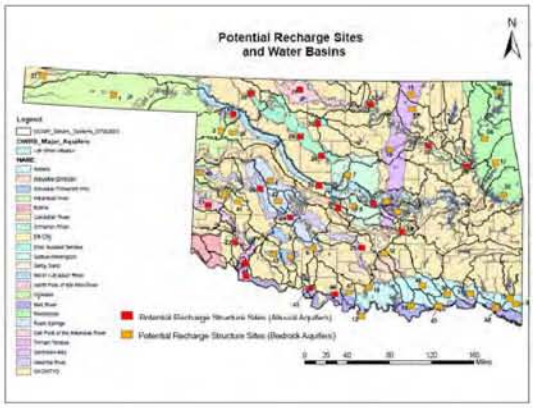
Rush Springs
Salt Fork of the Arkansas River
Tillman Terrace
Vamoosa-Ada
Washita River
OKCNTYD



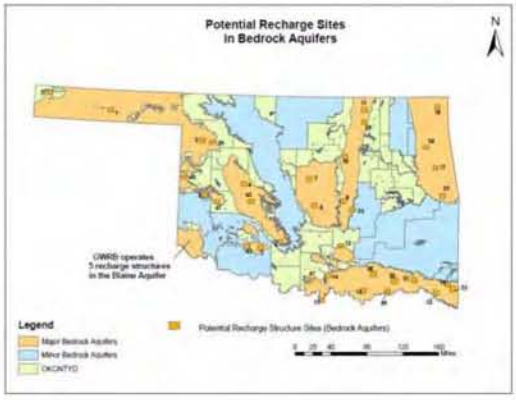


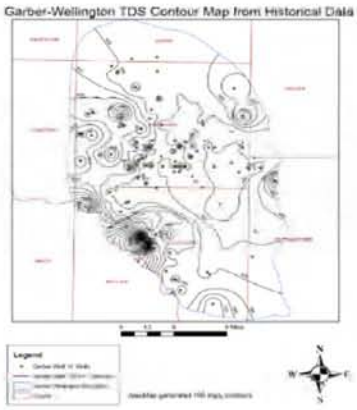
Site Selection of an Artificial Aquifer Recharge Demonstration Project

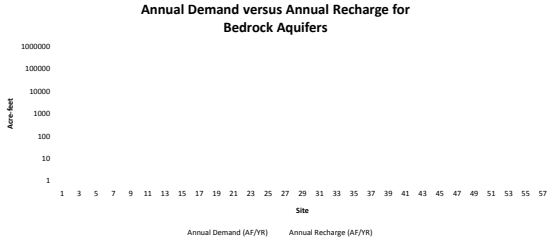
Fatal Flaw Analysis **Started with 57 potential sites and ended with 30**

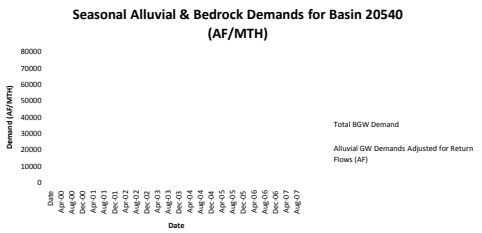
Criteria

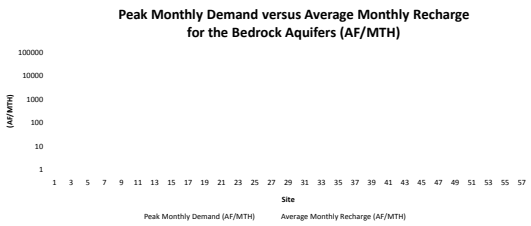
- Heavily developed aquifer
- Proximity of recharge location to demand and source water
- Quality of ground water (TDS < 2,000 mg/l)

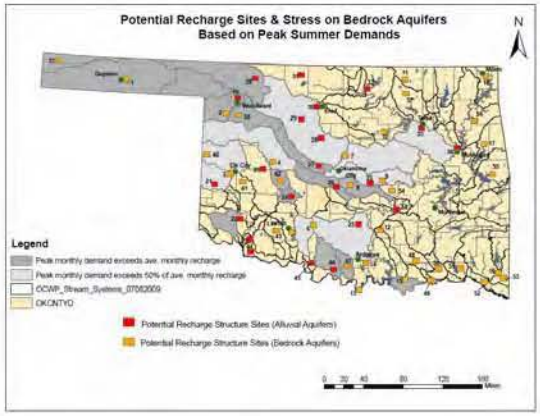

Potential Recharge Sites
in Bedrock Aquifers
N
OWRB operates
5 recharge structures
in the Blaine Aquifer
Legend
Major Bedrock Aquifers
Minor Bedrock Aquifers
OKCANYG
Potential Recharge Structure Sites (Bedrock Aquifers)

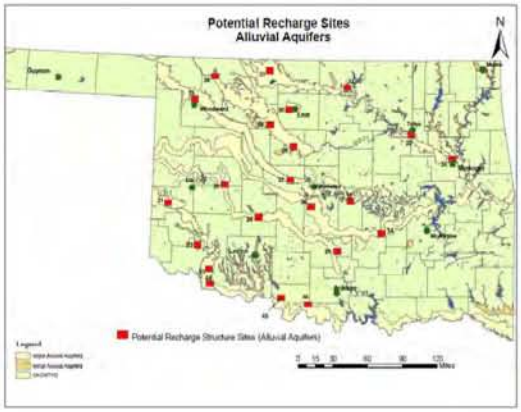

Garber-Wellington TDS Contour Map from Historical Data
Legend

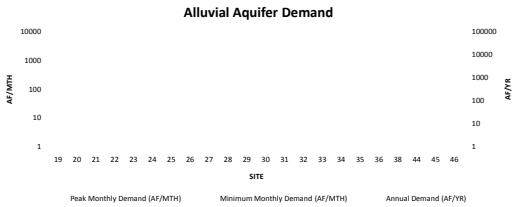

Annual Demand versus Annual Recharge for
Bedrock Aquifers
1000000
100000
10000
1000
100
10
1
Acre-feet
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57
Site
Annual Demand (AF/YR)
Annual Recharge (AF/YR)


Seasonal Alluvial & Bedrock Demands for Basin 20540
(AF/MTH)
Demand (AF/MTH)
80000
70000
60000
50000
40000
30000
20000
10000
0
Date
Apr-00
Aug-00
Dec-00
Apr-01
Aug-01
Dec-01
Apr-02
Aug-02
Dec-02
Apr-03
Aug-03
Dec-03
Apr-04
Aug-04
Dec-04
Apr-05
Aug-05
Dec-05
Apr-06
Aug-06
Dec-06
Apr-07
Aug-07
Date
Total BGW Demand
Alluvial GW Demands Adjusted for Return Flows (AF)


Peak Monthly Demand versus Average Monthly Recharge
for the Bedrock Aquifers (AF/MTH)
(AF/MTH)
100000
10000
1000
100
10
1
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57
Site
Peak Monthly Demand (AF/MTH)
Average Monthly Recharge (AF/MTH)


Potential Recharge Sites & Stress on Bedrock Aquifers
Based on Peak Summer Demands
N
Legend
Peak monthly demand exceeds ave. monthly recharge
Peak monthly demand exceeds 50% of ave. monthly recharge
OCWR_Stream_Systems_07082009
OKCNTYD
Potential Recharge Structure Sites (Alluvial Aquifers)
Potential Recharge Structure Sites (Bedrock Aquifers)


Potential Recharge Sites
Alluvial Aquifers
N
Potential Recharge Structure Sites (Alluvial Aquifers)


Alluvial Aquifer Demand
AF/MTH
AF/YR
10000
1000
100
10
1
100000
10000
1000
100
10
1
19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 38 44 45 46
SITE
Peak Monthly Demand (AF/MTH)
Minimum Monthly Demand (AF/MTH)
Annual Demand (AF/YR)

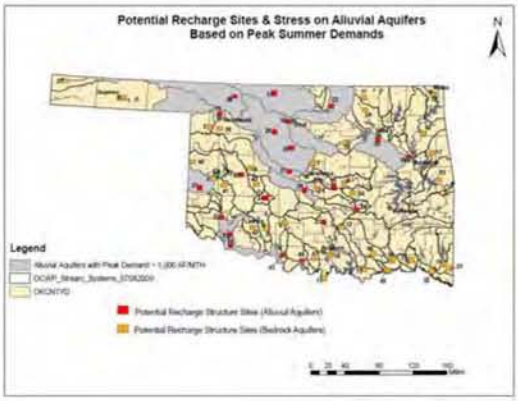
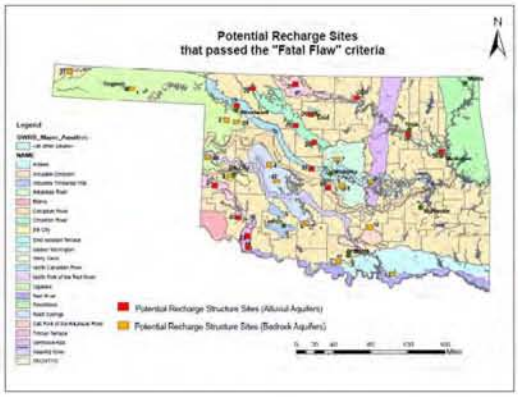

Potential Recharge Sites & Stress on Alluvial Aquifers
Based on Peak Summer Demands
N
Legend
Potential Recharge Structure Sites (Alluvial Aquifers)
Potential Recharge Structure Sites (Bedrock Aquifers)

Table 2 - Summary of Fatal Flaw Analysis for Bedrock Aquifers

			Groundwater Quality	Proximity Factors	
Site	Aquifer	Bedrock GW Recharge Exceeds or Equals Demand	TDS > 2000 mg/l	AR > 10 miles from demand	AR > 10 miles from source
5	Arbuckle Timbered Hills	YES Recharge > > demand	NO TDS < 1,000 mg/l	NO City of Lawton has one well within 3 miles	NO Within 1 mile of East Cache Creek
6	Rush Springs	NO Demand > 50% of recharge	NO TDS < 500 mg/l	NO Within 2 miles of the City of Marlow well field	NO Within 3 miles of Little Beaver Creek
7	Garber Wellington	NO Demand > 50% of recharge	NO TDS < 500 mg/l	NO Within 4 miles of the City of Edmonds Well Field	NO Within 4 miles of Lake Arcadia
8	Garber Wellington	NO Demand > 50% of recharge	NO TDS < 500 mg/l	NO Within 1 mile of some of the City of Norman's Well field	NO Within 3 miles of Lake Thunderbird

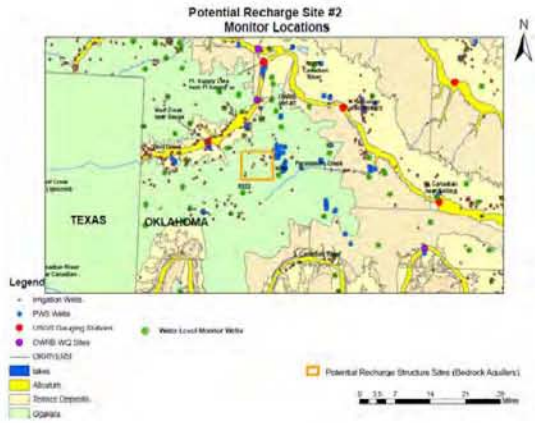
Note: Cells that are shaded in yellow passed the "Fatal Flaw" criteria (had all NOs)
Cells that are shaded in blue did not pass the "Fatal Flaw" criteria (had at least one YES)



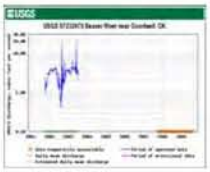
Site Selection of an Artificial Aquifer Recharge Demonstration Project

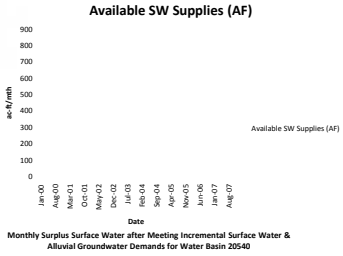
Threshold Analysis **Started with the 30 sites that passed the Fatal Flaw analysis and ended with 15 that would be evaluated further in the detail analysis.**

- Water quality of source water
- Source water availability
- Groundwater quality (nitrate in addition to TDS)
- Hydrogeologic suitability
  - Aquifer storage
  - Transmissivity
  - Residence time



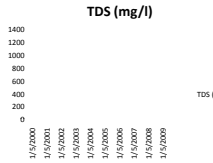
Some sites failed the threshold analysis because available surface water was unavailable for extended periods of time.

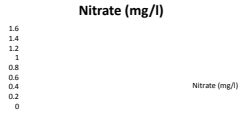




Monthly Surplus Surface Water after Meeting Incremental Surface Water & Alluvial Groundwater Demands for Water Basin 20540

Graphs of surface water quality data obtained from OWRB's BUMP Sites or USGS Gauging stations were plotted and evaluated for each site.





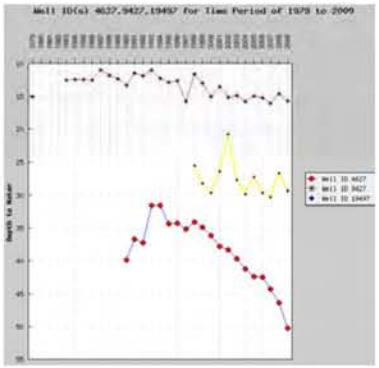
Hydrogeologic properties of the aquifer were evaluated at each site for recharge suitability.

Hydraulic properties of Aquifer

The hydraulic properties of the Ogallala aquifer typically are as follows:

Yield	5 – 500 gpm
Hydraulic conductivity	2.1 – 55 ft/day
Transmissivity	500 – 11,800 ft^2/day
Storativity	0.002
Specific Yield	0.11 to 0.185

Water level changes over time were evaluated to determine if water levels declining, staying the same or rising.



Potentiometric surface maps were included to determine groundwater flow direction when the data was available.

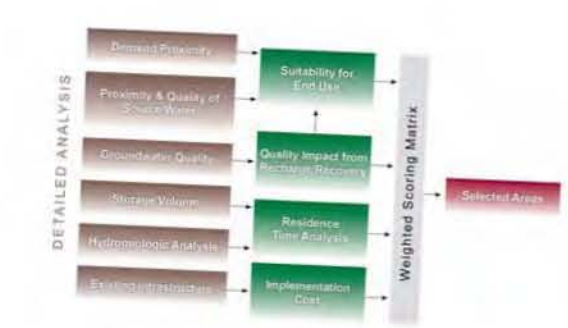
Depth to the base of the treatable water was included in the write-up for each site.

Table 4 - Summary to Threshold Analysis for Bedrock Aquifers

Site	Proximity to Demand	Source Water Proximity	Suitability of Storage Volume	Source Water Availability	Source Water Quality	Hydrogeologic Suitability	Aquifer Stress	Groundwater Quality	Residence Time
1	High	High	High	Low	Moderate	High	High	High	High
2	High	High	High	Moderate	Moderate	High	High	High	High
3	High	High	High	High	Moderate	High	Low	High	High
4	High	High	High	High	Moderate	High	Moderate	Moderate	Moderate
6	High	High	High	Moderate	Unknown	High	Moderate	High	Moderate
7	High	High	High	High	High	High	Low	Moderate	Moderate
8	High	High	High	High	Moderate	High	High	Moderate	Moderate
9	High	High	High	High	High	Moderate	Moderate	High	Moderate
12	High	High	High	Moderate	Unknown	High	Moderate	High	Moderate
15	High	High	High	High	High	High	Moderate	Moderate	High
37	High	High	High	Low	Unknown	High	High	High	Moderate
39	High	High	High	Low	Moderate	High	High	Moderate	High
40	High	High	High	High	Moderate	Moderate	Moderate	Moderate	High
42	High	High	High	High	Moderate	High	High	Moderate	Moderate
47	High	High	High	Low	Unknown	Moderate	Moderate	High	Moderate

Shaded yellow – passed the threshold analysis (no low scores)
Shaded blue – failed the threshold analysis (had at least one low score)

Detailed Analysis



Discussion of Screening Criteria Weighting

Table 3. Sample Scoring Matrix with Criteria Weighting Factors

Category		Criteria	Score (1 to 5)	Weight ∑ = 100%	Weighted Score
Demand	Category ∑ = 30	Frequency	1	**10**	10
		Proximity	2	**15**	30
		Density	3	5	15
Source Water	Category ∑ = 25	Proximity	4	**15**	60
		Quality for Non-Degradation	5	***5***	25
		Regulatory Challenges	1	***5***	5
Hydrogeologic Suitability	Category ∑ = 26	Available Storage Volume and Ability to Meet Local Demand	2	***10***	20
		Transmissivity	3	***8***	24
		Residence Time/Distance to Discharge	4	***8***	32
Groundwater Quality	Category ∑ = 12	Native Quality	5	**6**	30
		Geochemical Interactions with Source Water	1	6	6
Cost	Category ∑ = 6	Recharge Method	2	6	12
Project Impact	Category ∑ = 1	Qualitative Considerations	3	1	3
			Total:	100	**272**

Relative Weighting Comparison

Table 4. Comparison of Relative Importance of Criteria

Criteria	Proposed OWRB Weighting	Colorado SB06-193	BOR
Proximity to Demand	1	1	NA
Proximity to Source	1	NA	NA
Demand Frequency	2	NA	NA
Suitable Storage Volume	2	1	1
Hydrogeologic - Transmissivity	3	2	1
Hydrogeologic - Residence Time/Distance to Discharge	3	3	1
Native Groundwater Quality	4	4	NA
Geochemical Interactions with Source Water	4	4	NA
Cost/Recharge Method	4	4	2/3/5
Demand Density	5	NA	NA
Source Water Quality for Non-Degradation	5	NA	NA
Source Water Regulatory Challenges	5	NA	4/5
Project Impact/ Qualitative Considerations	6	3	NA
Land Ownership/Use	NA	4	NA
Existing Infrastructure	NA	3	NA
Engineering Feasibility	NA	NA	4
Monitoring Plan	NA	NA	4
Rehabilitation Plan	NA	NA	5
Environmental Issues	NA	4	5
Uniqueness	NA	NA	4

Next Steps

- Finalize Preliminary Screening based on today's feedback
- Detailed Ranking work will begin utilizing feedback on final criteria selection and weighting received today

Key Remaining Work Group "Checkpoints"

- Confirm Detailed Screening / Draft Report (Task 3/4) – Work Group Meeting #5
  - *Target date: end of February / early March*
- Final Report end of March / early April

OKLAHOMA COMPREHENSIVE WATER PLAN

Artificial Recharge
Technical Work Group Meeting #4

OWRB Offices, Oklahoma City
January 12, 2010

Oklahoma Comprehensive Water Plan
Aquifer Recharge Technical Work Group Meeting #5

AGENDA
April 6, 2010
Oklahoma Water Resources Board
3800 N. Classen, Oklahoma City

1:00 p.m.	Welcome and Introductions
1:15 p.m.	Recap of Senate Bill 1410 Work Group Background ◥ Update on work group status ◥ Review Work Plan ◥ Recap of Work Group Meeting #4 (January 2010)
1:30 p.m.	Review and Discussion of Final Preliminary Screening Report
2:00 p.m.	Review and Discussion of Detailed Screening Results and Final Report
2:45 p.m.	Next Steps ◥ Comments on Final Report ◥ Discussion of Phase II (Implementation)
3:00 p.m.	Adjourn

ARTIFICIAL RECHARGE TECHNICAL WORKGROUP MEETING NO. 5
April 6, 2010
Draft Meeting Summary

The fifth group meeting occurred on April 6, 2010, in the offices of the Oklahoma Water Resources Board, 3800 N. Classen Blvd., Oklahoma City, Oklahoma and began at 1:00 pm. Attendees included:

Kyle Arthur, OWRB	Renee McPherson, OCS/OU
Matt Bliss, CDM	Noel Osborn, OWRB
Bryan Mitchell, CDM	Pat Billingsley, OK Corp. Comm.
Kim Winton, USGS	Saba Tahmassebi, ODEQ
Terri Sparks, OWRB	Wayne Kellogg, Chickasaw Nation
Robert Toole, OK Cons. Comm.	Neil Suneson, OGS
Mike Overbay, EPA	Mike Smith, CDM
Baxter Vieux, OU	Suzanne Van Cooten, NOAA/NSSL

Mr. Kyle Arthur, OWRB, opened the meeting with self-introductions around the room. He then went over the agenda for the day (copy attached).

Matt Bliss, CDM, then began a PowerPoint presentation (copy attached) with an overview of SB1410 goals and overall study process, recap of the four previous work group meetings and summary of the Work Plan Outline. He noted that the primary purpose of today's meeting is to get feedback on the detailed screening report and discuss implementation steps.

Mr. Bliss indicated that a copy of the meeting agenda and draft final report was e-mailed earlier. He noted that the criteria selection technical memo incorporating the group's comments on the draft document were included as Chapter 2 of the draft final report. Wayne Kellogg's preliminary screening report with red-lined comments/suggestions resulting from the group's review was also attached. The associated appendices to these documents, which were too large to e-mail, were uploaded to CDM's ftp site for review (see end of summary for information on accessing this information).

Mr. Bliss noted that the preliminary screening, conducted by Wayne Kellogg, started with 57 sites based on aquifer and available surface sources and known areas of demand. After the fatal flaw analysis, 30 sites remained; threshold screening identified 15 sites as suitable for the detailed screening phase. CDM indicated they used 1,000 acre-feet or the demand shortage as the target size of the pilot project.

Mr. Bliss indicated that the detailed ranking reviewed in greater detail several criteria used in the fatal flaw analyses: availability of source water at diversion point rather than basin wide; more detailed water quality assessment; and depth-to-water maps were generated for storage capacity evaluation. He then went over the criteria and factors for the detailed ranking methods, using a slide of Table 6 from the draft final report for reference (see PowerPoint attached). Assessing point-water availability included looking at gage data, land use, and

number of irrigation wells installed since gage was operational. The period of record for gage data are not consistent from gage to gage at the different sites. To help identify comparable low-flow years, long-term precipitation records were reviewed and the lowest 25% of years were identified. If at least one low precipitation year was included in a gage's period of record, a low precipitation year was selected as a representative year and used in the flow availability analysis.

Mike Overby asked what the difference was between Demand Proximity and Source Proximity. Mr. Bliss agreed that some criteria did overlap and one way to address this could be to give them lighter weight. Neil Suneson, OGS, asked why they choose between 1-2 miles as weighting for proximity criteria. Mr. Bliss explained that enough sites fell out at greater distances. Suzanne Van Cooten questioned why sites as far as 20 miles were included on page 44 of the preliminary screening report. Mr. Bliss noted that was summarizing preliminary screening criteria; 1-2 miles was used in the more detailed screening.

Matt Bliss noted that several maps were generated for each site for the detailed ranking. The maps included a general proximity and existing wells map, a water quality location map, a depth-to-water map, and a groundwater flow and aquifer configuration map. He noted geochemical interactions and scaling potential were assessed using the Langelier index when it could be computed, and comparison of hardness and pH when there was insufficient data. Transmissivity and storativity data was estimated using several sources, but there appeared to be little difference in ranges between alluvial and bedrock values. Residence time (loss to streams) was estimated using Glover Equation. The ability to meet a portion of a local municipality's demands was used for qualitative factors (i.e. larger impact if larger portion of demand could be met). It was noted, however, that the greatest factor of all could be local input and interest that could be included in the qualitative factors score as well.

Mike Smith, CDM, then discussed the scoring process, using Table 7 from the draft final report, Weighted Scoring Matrix (see attached PowerPoint). The three sites recommended for pilot projects are: Recharge Region 12, located near the town of Ada, with the Blue River providing a water source to the Arbuckle Simpson aquifer; Recharge Region 42, located near the town of Eakly, with Lake Creek providing water to the Rush Springs aquifer; and Recharge Region 19, located near Woodward, with the North Canadian River providing water to the North Canadian alluvial and terrace. He talked about CDM's sensitivity analysis as to how sensitive the decision tool is to the score. Scoring that resulted in the above sites having the highest ranking was initially performed using weights developed at the January 2010 workgroup meeting. Using weightings similar to those used in a Bureau of Reclamation report, the ranking of the top sites was the same. Using weightings similar to those used in a Colorado study, the top three sites remained within the top four. In all three comparisons, Ada was No. 1. Change in cost proved sensitive, but Ada and Eakly were still in the top three.

One participant noted that most rainfall in Oklahoma came in the Spring and Fall and questioned whether that would affect cost of year round projects. Mr. Smith said that was an underlying assumption— that approximately three monthly recharge periods would be utilized. The water availability analysis used years in the bottom quartile of precipitation, though some discussion was held about why this was selected rather than the mean precipitation year. CDM noted this was to develop a conservative estimate of available water.

A question regarding the use of runoff collection as a source instead of streamflow was raised. Mr. Smith said they looked at continuous source data (i.e. gage data) since we do not have good data on storm runoff. In addition, streamflow is an indicator of runoff potential in various sites. He noted that the final site selection was based on diverting from streams using stream gage data; none looked at runoff.

Mr. Viex asked if TSS [total suspended solids] was considered when looking at spreading basin, etc. and was told that bed load TSS was not taken into account. Kim Winton, USGS, mentioned that transmissivity was high in the Arbuckle Simpson because of the Karst, while it was high in the Woodward area because it was alluvial and terrace (A&T) deposits. She asked if all other factors were equal, would CDM pick A&T or Karst. Mr. Smith said probably A&T because the injected water is unlikely to follow a preferential pathway to discharge points. More discussion followed on transmissivity and residence time. Ms. Winton noted that if there are known methods, such as a constructed barrier, to slow down movement in A&T, that could be one more parameter to evaluate and could make other sites more viable. She questioned why not pick a site where you could demonstrate using a barrier in the A&T. Mr. Smith said you could do so, but there would be added costs of constructing the barrier.

Ms. Van Cooten noted that source water quality looked more sensitive because of the spread in scores. Mr. Smith agreed and said it was given greater weight in accordance with the group's vote last meeting. She also questioned whether the Arbuckle Simpson scored higher because there was more data available—she was concerned that interested persons would demand more money be spent on their aquifer so it could receive higher ranking. Mr. Smith agreed that more data resulted in less uncertainty and perhaps higher ranking. Noel Osborn, OWRB, noted that there was already very good data on A&T (Woodward) and did not think there was much to improve.

Mike Smith noted that almost all sites have public wells as a driving factor. Mr. Viex asked why other uses, such as irrigation, were not considered. Mr. Smith said the benefit-cost for irrigation would make a pilot project unfeasible. In addition, an irrigation project would benefit private individuals as opposed to a public project that benefits a municipality. Mr. Overbay also noted that irrigation takes a much larger quantify of water.

The slide view of the Weighted Scoring Matrix was set up to be interactive, so that participants could suggest changes in parameters and the resulting changes in score would be calculated. Mike Smith noted they tried several scenarios with changing weights and the top three sites always fell within the top four.

The top three sites from the detailed ranking were discussed. The Ada site was ranked highest with the understanding that hydrogeologic suitability of the specific site would be required due to the channelized nature of a karst aquifer. It is important to ensure recharged water could be recovered. Concerns about recharging the Arbuckle-Simpson without any pre-treatment were raised from a regulatory and water quality standpoint. Pat Billingsley, Ok Corp. Comm. noted that the sites on the Blue River might face opposition because there is support to have the river designated as a state scenic river. Mr. Smith noted that while the BOR criteria rated habitat as a significant factor, the group had not voted to do so for screening purposes due to the regional nature of the selection criteria – it was assumed that a suitable site (a few acres)

could be identified within most regions evaluated. Ms. Oborn noted that any project that received federal funding would require a rigorous Environmental Impact Study. Wayne Kellogg, Chickasha Nation, asked that if the Arbuckle Simpson study resulted in Ada's water rights going from 1 acre-foot/acre to .15 acre-foot/acre, could they get credit if they initiated a recharge project—could be an incentive to support a project there.

The Eakly site was discussed next. Ms. Billingsley noted that are several oil wells near Eakly and suggested adding the oil wells to the map. Ms. Van Cooten noted that there is radar capability for storm tracking near this site as well as the Ada site, which could be beneficial in project operations.

Mike Smith went on to explain that the Woodward site, has good hydrogeologic characteristics, but could be somewhat problematic due to source water quality and availability concerns. The gage used for the availability analysis is downstream and regulation of Canton Reservoir could impact the project size. The screening did not reveal the impact of the reservoir and further investigation into Canton Reservoir operations and available flow at the point of diversion should be carried out before building a project. The source water contains high levels of TDS. Pat Billingsley noted that many of the high TDS readings likely come in slugs from oil and gas discharges and water quality might be suitable otherwise. CDM noted they will look at the TDS samples more closely to see if that could be verified.

In summing up, Matt Bliss said that John Rehring, CDM, specifically asked him to see if the group thought that three sites were enough to move forward. Noel Osborn expressed she thought, in view of uncertainty, that at least five should be recommended. Neil Suneson pointed out that if you picked the top seven, two fall out due to population. He suggested adding two alternatives, areas 30 and 15 (Antlers and Rush Springs), and these sites were supported as alternatives by the group.

The group discussed whether to make the final report available on the web. It was mentioned that Duane Smith, OWRB, had previously suggested presenting the results at an OWRB Board meeting and to the Legislature. Ms. Van Cooten recommended sending it specifically to the impacted legislators and tribal leaders.

In response to Mr. Overbay's question on project implementation, Kyle Arthur noted that funding was uncertain at this time, but as the OCWP moves toward implementation, additional funds may be available. However, he believes it will need to be a highly collaborative effort, where we would be the agency to coordinate funding and implementation. The first objective for Phase II would be to see who could help with funding. Mr. Kellogg mentioned that Kerr Lab might be interested. Kyle mentioned BOR funding, and Mr. Overbay noted that State Revolving Funds might be used. Mr. Baxter suggested that an entity showing interest in willingness to pay might increase an area's ranking.

Ms. Osborn expressed concern that there may be more issues that need to be considered, such as impacts on standards, ODEQ permit requirements, etc. It was requested that any comments on the draft final report, including suggestions in general on laws, regulations, or other aspects that need consideration, be submitted to the OWRB by April 30, 2010. The meeting ended at approximately 3:30 p.m.

* * * * * * * * * * *

Instructions for CDM's FTP site to access materials from the meeting:

ftp.cdm.com
Username: *OWRB_Recharge*
Password: *Recharge2010 (case sensitive)*

Note: if clicking on the ftp.cdm.com link does not work, type it into a Windows explorer or web browser address bar.

Oklahoma Comprehensive Water Plan
Aquifer Recharge Technical Work Group Meeting #5

AGENDA
April 6, 2010
Oklahoma Water Resources Board
3800 N. Classen, Oklahoma City

1:00 p.m.	Welcome and Introductions
1:15 p.m.	Recap of Senate Bill 1410 Work Group Background ◥ Update on work group status ◥ Review Work Plan ◥ Recap of Work Group Meeting #4 (January 2010)
1:30 p.m.	Review and Discussion of Final Preliminary Screening Report
2:00 p.m.	Review and Discussion of Detailed Screening Results and Final Report
2:45 p.m.	Next Steps ◥ Comments on Final Report ◥ Discussion of Phase II (Implementation)
3:00 p.m.	Adjourn

OKLAHOMA COMPREHENSIVE WATER PLAN

Artificial Recharge
Technical Work Group Meeting #5

OWRB Offices, Oklahoma City
April 6, 2010

Agenda

- Welcome and introductions
- Recap of SB1410 background and previous meetings
- Finalized Preliminary Screening (Wayne Kellogg)
- Detailed Screening Results and Report
- Next steps
  - *Comments on report*
  - *implementation*

SB1410 Goals and Overall Process

- Develop and apply criteria to prioritize potential locations throughout Oklahoma where aquifer recharge demonstration projects may be most feasible.
- Phase 1: Identification of most suitable area(s)
- Phase 2: Demonstration project(s) at one or more areas from Phase 1

Recap of Previous Work Group Meetings

- Overview of Senate Bill 1410
  - *Using artificial recharge to help increase the State's available water supplies through collaboration and consensus building*
- Discussions of work plan and potential criteria
- Discussion on cooperation from USBR, EPA, USGS, others
- Identification of key criteria:
  - *Short-term/seasonal for quick success*
  - *Sufficient storage capacity*
  - *Water quality concerns*
  - *Demand*

Phase 1 – Work Plan Outline

- **1: Develop Site Evaluation Methods**
- **2: Preliminary Screening of Potential Sites**
- **3: Detailed Evaluation of Potential Sites**
- **4: Reporting and Coordination**

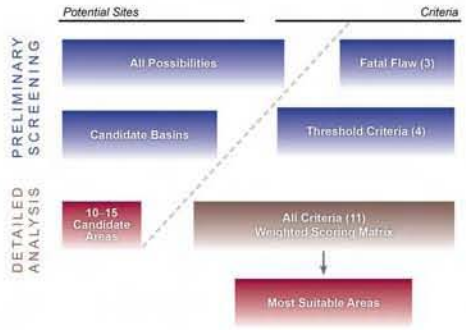
Goals for Today's Meeting

- Review and discussion on finalized preliminary screening memo
- Review and discussion of detailed screening report
- Discuss next steps for implementation

Task 1 – Site Evaluation Methods

- Advisory Group Review (Sept 2009, Jan 2010)
  - *Received feedback on draft memo, incorporated into final*
  - *Provided direction for Wayne Kellogg to complete preliminary screening*
  - *Finalized weighting via dot-voting at Jan-2010 meeting*
- Task 1 Technical Memo
  - *Finalized based on feedback and comments at previous meetings*
  - *Incorporated into final report as Section 2*

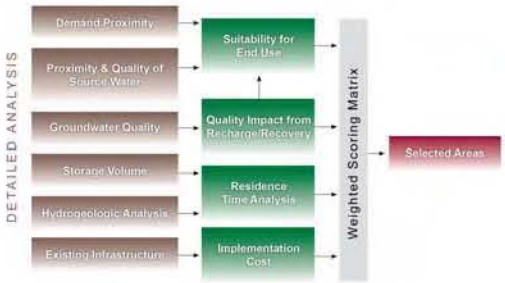
Conceptual Overview of Screening Process



Preliminary Screening

- AWI addressed comments in document provided prior to this meeting
- Preliminary Screening started with 57 sites based on aquifer-surface water basin pairings and known areas of demand
- After Fatal Flaw, 30 sites remained
- After Threshold Screening, 15 sites remained and were passed on to the detailed screening

Detailed Analysis



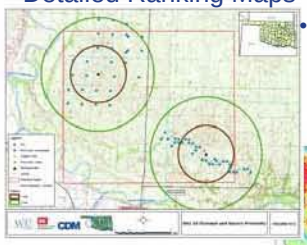
Detailed Ranking and Scoring

- Evaluation of each of the criteria identified in the Task 1 Tech Memo and refined through Workgroup participation
- Several criteria used in fatal flaw and threshold were reviewed in more detail
  - *Availability of source water at probable diversion point rather than basin-wide*
  - *More detailed water quality assessment*
  - *Depth to water maps generated for available storage capacity evaluation*

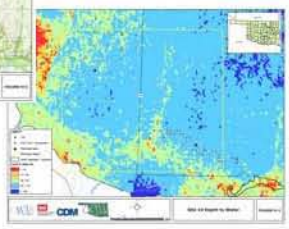
Detailed Ranking Methods

Demand Proximity (distance from recharge area)	Within 1 mile	Approximately 1.5 miles	Greater than 2 miles
Source Availability	Sufficient available water year-round for project with recent data	Sufficient available water for project during part of year. Older or more distant gage dagt	Sufficient water not available at proposed point of diversion.
Source Proximity (distance from recharge area)	Within 1 mile	Approximately 1.5 miles	Greater than 2 miles
Available Freeboard and Ability to Meet Demand	Plentiful volume for meeting the associated demand; no areas will raise water level to less than 15 feet bgs	N/A	Not enough volume to meet the associated demand; may raise the water level to less than 15 feet
Demand Density (number of wells)	Greater than 10 PWS wells within 1 mile	5 to 10 PWS wells within 1 mile	Less than 5 PSW wells within 1 mile

Detailed Ranking Maps



- Vicinity Map shows well locations, source location, demand density



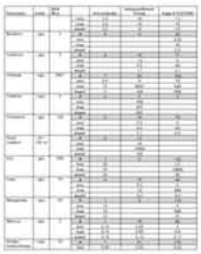
- Depth to water map used to assess available storage capacity

Detailed Ranking Methods

Source Quality for Non-degradation	Similar concentrations as groundwater or lower concentrations that will improve groundwater; no MCL exceedences; low TDS	Borderline TDS; few exceedences of MCLs	Quality will degrade groundwater; high TDS; many MCL exceedences
Native Groundwater Quality	Low TDS (<500 mg/L); no exceedences of MCLs	Borderline TDS; few exceedences of MCLs	High TDS (>500 mg/L); many exceedences of MCLs
Geochemical Interactions of Source and Groundwater	Similar Langelier Indices (source and groundwater within 0.5 units); similar pH values	Langelier index unable to be computed, but similar pH and hardness values	Langelier indices that are greater than 0.5 units different; largely different pH or hardness values
Transmissivity	T>1,000 ft2/d	T>500 ft2/d, but less than 1,000 ft2/d	T<500 ft2/d
Residence Time	Less than 10% loss in 180 days, >480 days to 25% loss	10 to 25% loss in 180 days, 180 to 480 days to 25% loss	>25% loss in 180 days

Detailed Scoring

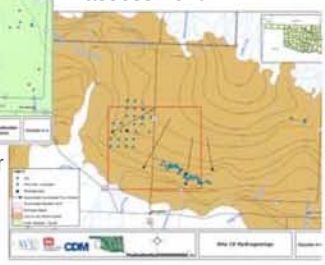
- Water Quality data from USGS and EPA online databases at nearby locations, summarized for each site



- Glover Equation used for residence time calculations
- Transmissivity and storativity data from several sources including AWI 2010
- Little difference in ranges between alluvial and bedrock T values

Detailed Ranking Maps

- Water quality sampling locations mapped to help WQ assessment



- GW contours, aquifer footprint used for residence time analysis

Detailed Ranking Methods

Cost (O&M)	No pretreatment required; gravity flow delivery; spreading basin use		Pretreatment required; ASR wells utilized; force mains required
Cost (capital)	Gravity flow delivery; ASR well retrofit	Spreading basin in rural area	Spreading basin near municipality; ASR well construction; pipeline construction
Qualitative Considerations	Project size meets 100% of demand	Project size meets 25% of demand	Project size meets <10% of demand

Weighted Scoring Matrix (Table 7)

weighting factor	*1.8*	*1.8*	*1.8*	*2.4*	*0.9*	*2.5*	*1.9*	*1.9*	*1.5*	*1.3*	*0.9*	*0.8*	*0.5*	
12	3	5	4	5	3	4	5	5	5	5	3	3	1	85
42	3	5	3	5	2	3	4	3	5	5	3	2	5	75
19	3	5	2	5	4	1	5	3	5	5	3	1	2	70
2	3	5	1	5	3	3	3	3	5	5	3	3	1	69
15	3	2	2	5	1	5	3	2	5	5	3	1	2	66
30	3	5	1	5	4	1	3	2	5	5	5	3	1	65
4	2	5	3	5	5	1	2	3	5	5	2	1	3	65
28	4	5	5	1	2	1	3	4	5	1	3	1	4	59
6	1	5	1	5	5	1	2	2	5	3	2	1	3	55
8	1	5	3	1	4	3	4	2	3	1	3	3	1	53
31	3	5	1	1	2	2	1	2	5	3	4	3	5	51
21	2	5	1	1	1	1	2	3	5	1	3	1	2	43
9	4	1	1	1	1	4	4	2	1	1	3	1	2	43
27	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
40	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Recommended Sites for Pilot Project

Recommended Pilot Project Sites

- Site 12 – Near Ada, Arbuckle-Simpson Aquifer
  - *Score 85*
  - *Good groundwater and source water quality, compatible water chemistry*
  - *PWS wells nearby, potential diversion point on Blue River within 1 mile*
  - *Favorable hydrogeology*
  - *Pre-treatment likely not required*

Recommended Pilot Project Sites

- Site 42 – Near Eakly, Rush-Springs Aquifer
  - *Score 75*
  - *Favorable hydrogeology*
  - *Lower demand could be entirely by a pilot project*
  - *Water quality appears good, but further characterization recommended due to sparse data.*
  - *Pre-treatment may be required pending additional water quality results*
  - *Source water availability somewhat of a concern due to nearby Fort Cobb reservoir. Operations should be coordinated with appropriate entities*

Recommended Pilot Project Sites

- Site 19 – Near Woodward, N. Canadian alluvium
  - *Score 70*
  - *Favorable hydrogeology*
  - *Sufficient source availability but should be coordinated with Canton Reservoir operations*
  - *Good groundwater quality*
  - *Poor source water quality would require pre-treatment*

Next Steps

- Finalize Report based on today's feedback
- Phase II – Implementation

Appendix Q
Response to Comments

CDM

Memorandum

To: *Terri Sparks, Kyle Arthur, Noël I. Osborn (Oklahoma Water Resources Board)*

From: *Matt Bliss, Mike Smith, John Rehring (CDM); Wayne Kellogg (American Water Institute*

Date: *June 10, 2010*

Subject: *Response to Noël I. Osborn's comments regarding the Artificial Aquifer Recharge Site Selection Screening Document, which was submitted to the Artificial Recharge Work Group, January 12, 2010*

Wayne Kellogg with the American Water Institute (AWI) and Matt Bliss, Mike Smith, and John Rehring with CDM reviewed the comments provide by Ms. Osborn. Ms. Osborn's comments are attached and comments from both AWI and CDM are provided below each comment. Mr. Kellogg has indicated that the appropriate changes were made in his final version of the artificial aquifer recharge site selection screening document provided under separate cover to the OWRB.

Sincerely,

Matt Bliss
Task Manager

MEMORANDUM

DATE: January 27, 2010

TO: Terri Sparks

FROM: Noël I. Osborn, Water Resources Geologist, Oklahoma Water Resources Board

SUBJECT: Comments regarding the *Artificial Aquifer Recharge Site Selection Screening Document,* which was submitted to the Artificial Recharge Work Group, January 12, 2010

Listed below are a couple of comments and suggestions regarding *Artificial Aquifer Recharge Site Selection Screening Document,* which was submitted to the Artificial Recharge Work Group on January 12, 2010.

1. I question why source water was limited to major streams and reservoirs in the analysis. This seems to be rather limiting, considering there are other viable sources such as runoff, flood retention ponds, and re-used or gray water. One problem with relying on major streams and reservoirs is that they are commonly groundwater discharge areas, which are generally not good candidates for artificial recharge. The water table is much shallower in discharge areas, thus limiting the storage capacity for recharged water. In addition, discharge areas tend to be downgradient from pumping centers, where recharge to the aquifer does not benefit the producers.

   AWI Response: Most of your high yield wells and public water supply wells completed in alluvial aquifers and along the major streams. One of the criteria we were looking at was choosing a site that we could inject about 150 gpm (which equates to ~ 0.25 MGD).

   The City of Ada is looking at flood retention ponds as a source of water for aquifer recharge so I did include this site. However, most NRCS flood control structures are pretty small and designed to hold flood water for only a 10 to 14 day period. It may take more than one pond to make a significant impact on the aquifer. I'll see what CDM has to say after they finish the detailed analysis.

   Retention time and distance to recharge was considered in the analysis. Sites for bedrock aquifers could be located 3,000 feet from an alluvial aquifer and sites for alluvial aquifers could be located 3,000 feet from the river. This should give enough retention time to recover the water before it discharges to the river.

   Using gray water may be useful on a small scale, but I don't know if businesses in Oklahoma goes to the trouble of separating their gray water from their regular

sanitary system.

CDM Response: The use of stormwater runoff was discussed at the April workgroup meeting. Stormwater runoff was not considered in the evaluation of source availability due to limited data on storm runoff flows and a continuous source is desirable for a pilot project. In addition, streamflow is an indicator of runoff potential at some sites and further investigation into the availability of stormwater runoff could be used to augment the project.

For example, the potential source waters for Sites 7 and 8 in the Garber-Wellington aquifer are Lake Arcadia and Lake Thunderbird, respectively. Lake Arcadia is on the Deep Fork River and Lake Thunderbird is on the Little River. These rivers are the primary discharge areas for the Garber-Wellington aquifer. Lake Arcadia supplies municipal water to Edmond, and Lake Thunderbird for Norman. Both lakes are downgradient from Edmond and Norman's well fields. I fail to see how artificial recharge at these sites would benefit these cities. More suitable locations would be located upgradient from the well fields, where recharge water could augment water depletion from well withdrawals, and where the aquifer is thicker. Water sources to augment the cities' drinking water supply other than the cities' drinking water supply should be considered.

AWI Response: The site at Edmond did not pass the threshold analysis so I won't go into much detail, but the situation at Edmond is very similar to the situation at Norman. The City of Norman plugged some of its water supply wells due to high arsenic concentrations (>50 mg/l) when EPA lowered drinking water standards from 50 ppb to 10 ppb. These wells are primarily on the west side of Norman. Norman is blending some wells with moderate arsenic levels (10 -50 ppb) with water from other sources to reduce the arsenic levels. Norman is also conducting pilot tests on treatment options (well modification and the use of an iron-oxide treatment to reduce the arsenic levels). In addition, Norman is looking at drilling additional wells in the northeast part of the city for future supplies and to replace the wells they plugged. Lake Thunderbird has a large flood pool (76,660 ac-ft) which could be treated and injected into the subsurface during wet periods to save the water in the subsurface for the dry summer months. The infrastructure is in place to pump water from the lake to the treatment plant which is located in the NE part of the City. I put the potential recharge area on the east part of Norman primarily to get away from any potential arsenic problems and minimize the distance to the water treatment plant. ASR wells have been successfully used in other areas of the nation that had arsenic problems, but it was my understanding the task force preferred to avoid the complexity of arsenic chemistry for the demonstration project.

Most domestic wells in the Garber Wellington are completed fairly shallow 50 – 150 feet, but the public water supply wells are typically completed from 300 to 600 feet below surface. Tinker Air Force Base has done a lot of work on the Garber Wellington and have over 1,200 monitoring wells which they gauge and sample. Many of the wells are nested with the shallow wells typically testing the aquifer around 50 feet, then an intermediate depth well around 100 feet deep and deeper wells around 150 feet and some even have a fourth well that tests up to

250 feet. Tinker has found variations in the static water levels in these nested wells indicating confining or at least semi-confined conditions exists in the deeper sands. Therefore, I think a deep well injection would be appropriate for the Norman area as opposed to shallow type of recharge structure. Therefore, I think an ASR well would be appropriate for the Norman area as opposed to shallow type of recharge structure and I think we could recover the water before it had a chance to make it to any discharge point.

CDM Response: for the pilot project, a seasonal demand was desired so the project impact could be seen every year rather than only in drought years. The AWI response provides a good example of the seasonal availability at Lake Thunerbird. In the detailed analysis, Site 8 (Norman) specifies the use of an injection well as recommended by AWI.

2. If I'm not mistaken, the Oklahoma Corporation Commission "Base of Treatable Water" maps reflect altitude rather than depth to water.

AWI Response: You can get the surface elevation, subsurface elevation of the base of the treatable water BTW, and the depth from surface to BTW by adding the point shapefile, but the contour lines represent depth of BTW below the surface.

CDM Response: AWI Response sufficient.

3. There are much better sources of water quality data on major aquifers than the ODEQ water quality database. Most published aquifer studies, many of which are listed in Appendix D, contain water quality data and statistics.

AWI Response: When I asked the water quality people at OWRB, they said they did not have a good groundwater quality database so I went with ODEQ's maps. The published reports may be used for the detailed analysis, but it was thought that ODEQ's website was a good source for pre-screening.

CDM Response: CDM utilized online USGS and EPA databases for water quality data. The water quality tables provided in the appendices for each site provide very detailed water quality data.

4. Note that at Site 15, the Antlers aquifer is confined under the Woodbine Minor Groundwater Basin and is hundreds of feet below surface. Maps published in OGS Circular 81 [Geohydrology of the Antlers Aquifer (Cretaceous), Southeastern Oklahoma by Donald Hart and Robert Davis] indicate TDS in the Antlers aquifer in this area is generally greater than 1,000 mg/L.

AWI Response: I agree, but we used a TDS > 2,000 mg/l as our cut-off to eliminate a site. An ASR well could be used at this site.

CDM Response: The native groundwater quality criterion received a moderate score in the detailed analysis for this site due to the higher levels of TDS.

5. I suggest changing the last sentence on page 6, regarding the Blaine aquifer to: "The Blaine aquifer was excluded from this analysis because artificial recharge to the aquifer has been conducted since 1968 and has been demonstrated to be effective."

AWI Response: I will make this change.

CDM Response: none – reference is to AWI's report.

6. I suggest some clarification and elaboration on the section regarding Existing Recharge Structures on page 7:

Under the "High Plains States Groundwater Demonstration Program Act" of 1983, the Oklahoma Water Resources Board (OWRB), in cooperation with the U.S. Bureau of Reclamation U.S. Environmental Protection Agency (EPA), the U.S. Geological Survey (USGS), and the Southwest Water and Soil Conservation District, conducted a 5-year groundwater recharge demonstration project in the Blaine aquifer. The purpose of the demonstration project was to demonstrate the feasibility and effectiveness of recharging surface runoff into the cavernous Blaine aquifer with gravity-flow wells to augment groundwater supplies in an aquifer heavily pumped for irrigation. The project expanded the Southwest Water and Soil Conservation District's existing recharge program, which began in 1968. Prior to the demonstration project (1990s), the District had constructed about 70 recharge wells and four diversions.

The Blaine aquifer is highly mineralized, reflecting dissolution of gypsum and dolomite in the Blaine Formation. Total dissolved solids range from about 3,000 to 35,000 mg/L, and have a median concentration of about 3,600 mg/L. Sulfate ranges from about 1,500 to 2,000 mg/L. Although not used as a drinking water supply, water from the Blaine aquifer is used extensively for irrigation of cotton, winter wheat, alfalfa and other row crops.

OWRB constructed five recharge wells and 1 impoundment within 3 miles of the city of Hollis. The gravity-flow recharge wells intercept surface runoff during storm events and channel the untreated water into cavities within the aquifer. Results from the project demonstrated that artificial recharge using gravity-flow recharge wells in the Blaine aquifer is economically feasible. Operation and maintenance costs were very low largely because water treatment was not required.

AWI Response: I will add this text.

CDM Response: none – reference is to AWI's report.

CDM

Memorandum

To: *Terri Sparks, Kyle Arthur, (Oklahoma Water Resources Board)*

From: *Matt Bliss, Mike Smith, John Rehring (CDM); Wayne Kellogg (American Water Institute)*

Date: *June 10, 2010*

Subject: *Response to Bureau of Reclamation comments regarding the Artificial Aquifer Recharge Site Selection Screening Document, which was submitted to the Artificial Recharge Work Group. Comments dated January 21, 2010*

Wayne Kellogg with the American Water Institute (AWI) and Matt Bliss, Mike Smith, and John Rehring with CDM reviewed the comments provide by the Bureau of Reclamation (BOR). The BOR's comments are attached and comments from both AWI and CDM are provided below each comment. Mr. Kellogg has indicated that the appropriate changes were made in his final version of the artificial aquifer recharge site selection screening document provided under separate cover to the OWRB.

Sincerely,

Matt Bliss
Task Manager

Artificial Recharge Site Selection Screening Document
Comments by the U.S. Bureau of Reclamation
01-21-10

1. General: The potential recharge sites identified on Page 8 could be interpreted as arbitrary locations based on the analysis presented. It is suggested that a systematic, step by step approach be developed to identify these potential sites. For instance, it would be helpful to see a GIS map showing well fields of municipalities, areas of heavy irrigation, or areas of an actively drilling well field (as indicated on Page 7). It also would be helpful to present a GIS map of "proximity factors" (Table 2: distance from supply/demand sources).

   Response: Detailed write-ups for each site are presented in the appendices. These include GIS maps that show PWS wells, irrigation wells, streams. Municipalities, etc. I can add maps of public water supply wells, irrigation wells and drilling activity for the Woodford shale gas play to the main text of the report and perhaps some more text on methodology for picking locations.

2. General: It is recommended that consistent terminology and definitions be utilized between the AWI 2010 report and the CDM 2010 report.

   Response: Ask Matt about this. He said he tried to get some clarification from Collin on this point after the meeting.

   CDM Response: Collins Balcombe noted some differences between terminology related to demand frequency between the two reports. CDM will work with AWI to use the same terminology for the final reports.

3. Page 1:
   a. The "heavily developed aquifer" fatal flaw criterion is not listed as a fatal flaw criterion outlined by CDM 2010.
      Response: I think this was discussed at our Sep 18 meeting when we decided to also look at seasonal demands versus aquifer recharge.
   b. Source water availability is listed in CDM 2010 as a fatal flaw criterion, whereas it is listed here as a threshold criterion.
      Response: CDM also brought this up when I submitted the fatal flaw analysis to them. Since I had already started some of the detail site reports for the Threshold analysis and included it in this section, they thought it would be all right to leave it in the Threshold analysis just as long as it was covered. I ended up with 30 sites that passed the fatal flaw. Adding another criteria would have eliminated about four of those sites.

4. Page 2: Source data should include aquifer recharge/demand data
   Response: I will include a sentence that states I received demand data and recharge data from CDM.

CDM Response: CDM received aquifer recharge data from OWRB and published reports.

5. Page 7: The discussion presents the location of well fields of municipalities, areas of heavy irrigation, and areas of actively drilling well fields, as if these are criteria. If so, these should be listed as such and a discussion should ensue that justifies each one.
   Response: I tried to pick the initial locations based on these criteria. I can add more discussion on why I thought these might have a need for aquifer recharge.

6. Page 8: Figure 4 should include a disclaimer, either on the figure or in the text, that clarifies that these locations are "general" and not "specific". It also should clarify the spatial extent of the area (i.e., township, range, etc..).
   Response: I will add some text that the locations are approximately a township in size and the specific recharge site can be moved anywhere within that area or possibly even in close proximity if the detailed analysis proves up a more suitable site nearby.

7. Page 14:
   a. The criterion "Current Development of Aquifer" is not listed as a fatal flaw criterion outlined by CDM 2010.
      Response: I believe we discussed adding seasonal demands at our Sep 18 meeting.
   b. In order to be consistent with Table 2, as well as threshold data presented in criterion listed below, the Current Development of Aquifer criterion should explicitly state that demand must equal or exceed 50 percent of recharge.
      Response: I will rephrase to include this statement.
   c. This section also should contain a reference/source data on how natural recharge was calculated.
      Response: I will need to check with CDM on this since they supplied this data.

      CDM Response: CDM received aquifer recharge data from OWRB and published reports.

   d. Threshold values (i.e., demands > 1,000 af/mo., 10 mile distance to demand source, etc) seem arbitrary and should be supported by a defendable rationale for their selection.
      Response: Demands > 1,000 af/mth was somewhat arbitrary and chosen to eliminate approximately ½ of the alluvial sites. It would have been preferable to compare demand to recharge, but recharge data was unavailable for the alluvial sites.
      The 10 miles to demand and source water was also somewhat arbitrary, but after examining existing well fields throughout the state, these well fields were generally within 10 miles of the municipalities they serve. Greater distances would mean greater infrastructure costs. Does CDM have any costs/mile for laying water lines?

CDM Response: At this level of analysis, cost will be ranked based on a relative cost of the required infrastructure.

8. Page 20:
    a. Suggest that the Table 2 criteria be presented in a fashion that "YES" answers lead to the threshold analysis rather than "NO" answers. The current method is a little counterintuitive.
    Response: I can probably rephrase the headings so that a YES answer leads to the threshold analysis and a NO answer eliminates that site from further analysis.
    b. Table 2 indicates that a fatal flaw criterion is whether "Bedrock GW Recharge Exceeds or Equals Demand or >50% of recharge". This terminology is inconsistent with the term "heavily developed aquifer", as indicated on Page 1.
    Reponse: It should be Demand >recharge or even 50% of recharge leads to a heavily developed aquifer.
    c. It is unclear why Table 2 shows TDS > 2000 mg/l as a criterion, yet answers are presented in the context of being < 500 mg/l. This could be confusing to some readers.
    Response: IF TDS is >2,000 mg/l, the site fails the fatal flaw analysis. I can change those that passed the fatal flaw to be < 2,000 mg/l rather than using 500, 1,000 & 2,000 mg/l if that will be less confusing.

9. Page 22: Site #12: the source proximity factor is answered incorrectly It should state that the site is located in proximity to an NRCS flood control structure on the Blue River.
    Response: I will make this correction.

10. Page 35: Suggest that Data sources be elaborated to provide further justification of why certain thresholds were selected (i.e., why 10 miles? Why 1,000 mg/l?)
    Response: 10 miles seemed appropriate based on the distance most municipalities are from there well fields. Increasing the distance will increase the infrastructure costs. Drinking water standards for TDS = 500 mg/l. A TDS of 1,000 mg/l can generally be blended or easily treated to obtain 500 mg/l so anything less than 1,000 mg/l was considered high (good). A TDS > 2,000 mg/l failed the fatal flaw analysis and were ranked low (poor) and concentrations from 1,000 mg/l to 2,000 mg/l were ranked moderate.

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Acronyms

AF	acre-feet
AFY	acre-feet per year
AR	artificial recharge
ASR	Aquifer Storage and Recovery
ASCE	American Society of Civil Engineers
AWI	American Water Institute
bgs	below ground surface
BOR	United States Bureau of Reclamation
CDM	Camp Dresser & McKee Inc.
DEM	digital elevation models
EPA	United States Environmental Protection Agency
GIS	geographic information system
gpm	gallons per minute
LSI	Langelier Saturation Indices
M&I	municipal and industrial
MCL	maximum contaminant level
NAS	National Academy of Sciences
NOAA	National Oceanographic and Atmospheric Agency
NSSL	National Severe Storms Laboratory
O&M	operations and maintenance
OCC	Oklahoma Corporation Commission
OCS	Oklahoma Climatological Survey
OCWP	Oklahoma Comprehensive Water Plan
ODEQ	Oklahoma Department of Environmental Quality
OGS	Oklahoma Geologic Survey
OU	University of Oklahoma
OWRB	Oklahoma Water Resources Board
PWS	public water supply
T&E	threatened and endangered
TDS	total dissolved solids
TM	Technical Memorandum
TSS	total suspended solids
USGS	United States Geologic Survey
WSTB	Water Science and Technology Board

Section 1
Introduction

The Oklahoma Water Resources Board (OWRB) is developing a major update to the Oklahoma Comprehensive Water Plan (OCWP). The Oklahoma Legislature passed Senate Bill 1410 (SB1410) in 2008, requiring OWRB to develop and implement criteria to prioritize potential locations throughout Oklahoma where artificial recharge (AR) demonstration projects may be most feasible.

The SB1410 work is divided into two phases. The goal of the Phase 1 investigation is to identify locations in both alluvial and bedrock aquifer settings that would be most suitable for AR demonstration projects to help meet future water supply challenges. Work under Phase 2 would implement the recommendations from Phase 1, including pilot project field demonstration(s) of AR.

Work for Phase 1 was authorized under a contract between Camp Dresser & McKee Inc. (CDM) and the OWRB and includes the following tasks:

- Task 1 - Develop Site Evaluation Methods
- Task 2 - Preliminary Screening of Potential Sites
- Task 3 - Evaluation of Potential Sites
- Task 4 - Reporting and Coordination

Task 1 includes the development of a set of criteria to be used to evaluate potential AR sites. A Technical Memorandum (TM) that described criteria selection was produced (CDM 2010) with feedback from the advisory work group. Section 2 of this report is a copy of that TM with minor revisions for incorporation into the final report.

A variety of sources were recommended to assist in criteria development, including the draft United States Bureau of Reclamation (BOR) Planning Framework for Artificial Recharge (BOR 2008), the National Academy of Sciences (NAS) Water Science and Technology Board's (WSTB) Prospects for Managed Underground Storage of Recoverable Water (WSTB 2008), the American Society of Civil Engineers' (ASCE) Managed Aquifer Recharge Standards (ASCE 2001), and previous regional assessments such as the Colorado Senate Bill 06-193 Underground Water Storage Study (CDM 2007).

The criteria are intended to serve as an objective method to identify potential AR areas and consist of a set of quantitative metrics from which numeric scores can be assigned to each potential AR site. The criteria are focused on the Phase 1 goal of identifying areas within the state where demonstration projects may be most feasible. A project size of 1,000 acre-feet (AF) was used as the maximum for the pilot project. It was assumed that a recharge project would be able to divert water into underground storage for 3 months of the year. This corresponds to a maximum recharge rate of 2,500 gallons per minute (gpm) for 3 months. Agricultural needs were not considered for a pilot-project because such a project would likely benefit private individuals as opposed to a public project that benefits the broader public through a public entity such as a municipality or public water provider.

An irrigation based project would require a large amount of water with a likely lower cost-benefit ratio than a municipal provider. Additionally, the feasibility of a recharge project has been demonstrated in the Blaine aquifer for agricultural use by the OWRB. However, the implementation of a demonstration or full-scale project would be expected to benefit all users of the recharged aquifer in the general vicinity of the project, and additional demonstration or full-scale recharge projects could be implemented for agriculturally-dominated aquifers.

Site-specific considerations, such as land ownership, were not considered at this level. Variations on a given criteria will be developed for different aquifer settings such as unconfined and confined aquifers. Results from this study and additional insight gained from a Phase 2 pilot project can be used to meet longer-term needs, such as drought protection.

The OWRB has successfully demonstrated AR in the Blaine aquifer in southwest Oklahoma. The sites were in karst aquifers and utilized gravity flow infiltration and recharge methods. Sites in this area were not considered in this study since AR has already been demonstrated in that region.

Criteria were developed for both a preliminary screening and a more detailed ranking process. The purpose of the preliminary screening was to eliminate many areas from further consideration based on relatively simple application of a small number of the criteria. All sites not eliminated through the preliminary screening would likely be suitable for an AR demonstration project. The more detailed ranking process identified the most feasible of the suitable sites identified through the preliminary screening. Figure 1 represents this process graphically.

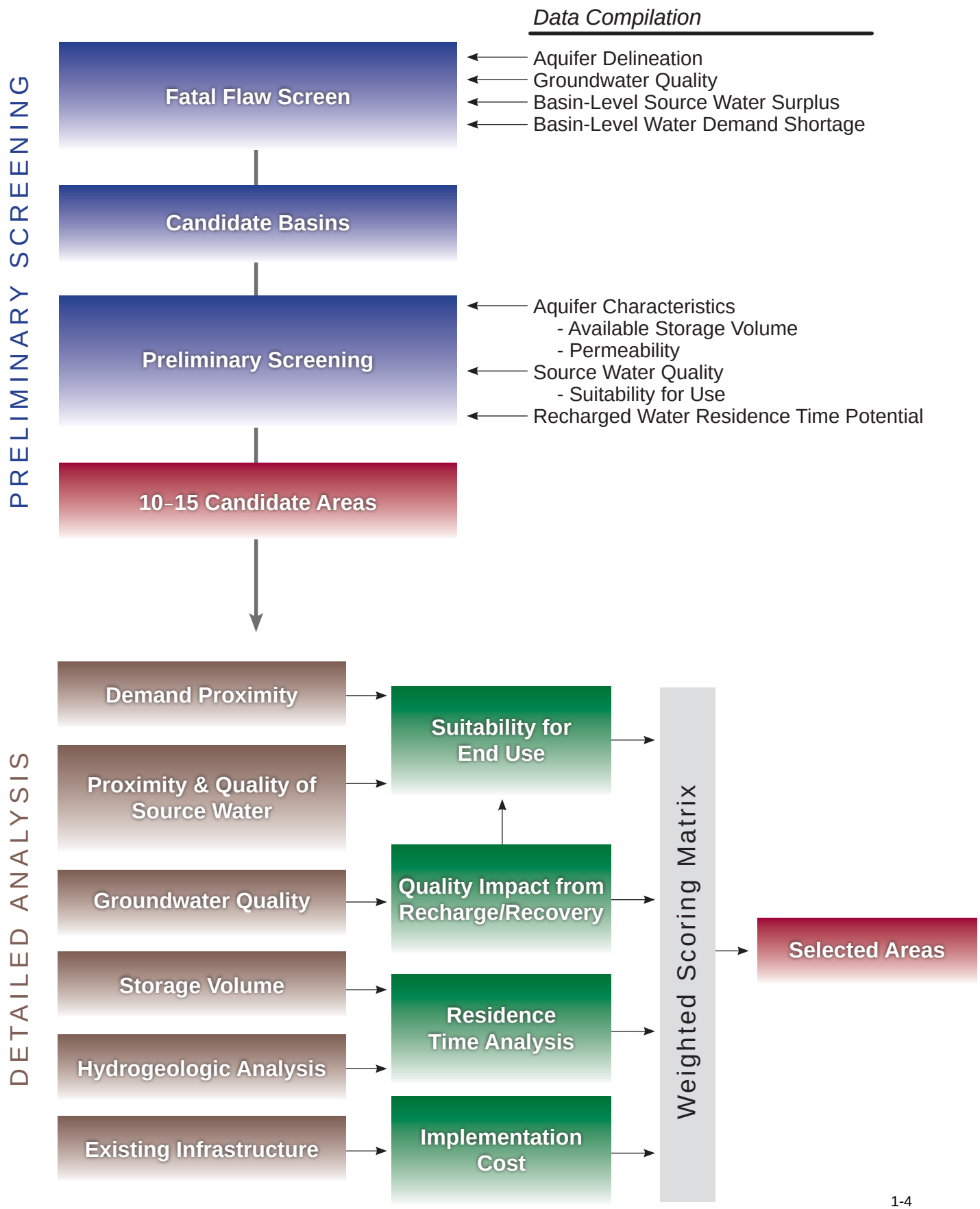
The preliminary screening was divided into a fatal flaw analysis and a threshold analysis. The fatal flaw analysis applies a limited set of criteria that, if the necessary characteristics are not present, would eliminate regions or aquifers from any further analysis. The fatal flaw screening criteria were developed to be able to use readily available information and relatively simple analyses of data. The threshold level screening was used to eliminate additional aquifers or areas from further consideration based on several key factors, and thus will expedite the more detailed analysis of remaining areas. The preliminary screening was performed by Wayne Kellogg with the American Water Institute (AWI) (2009) based on criteria outlined in Section 2 of this report. A summary of the conclusions from the preliminary screening is presented in Section 3 of this report. Through the detailed ranking, the entire suite of criteria and criteria weightings were applied to each remaining suitable site, resulting in a score for each site that identified the most feasible AR sites for the field demonstration projects.

Through the course of the work group meetings, comments and questions surfaced regarding the definition of the word 'site' for this project. A site is defined differently for the different phases of the project. In the preliminary screening, a site refers to a larger region of approximately a township (6 miles by 6 miles) that generally identifies a favorable portion of an aquifer and associated surface water basin. The boundaries of a preliminary screening site are not set and in some instances were expanded or moved in the detailed analysis. The maps presented in the detailed analysis appendices use the term recharge region, referring to the preliminary screening township-sized site. Within each recharge region, there is at least one recharge area of approximately 1 square mile and can be referred to as a site in the detailed analysis. Smaller design-level sites were not identified as part of this phase of the pilot project and are anticipated for Phase 2. References to site-specific criteria that were excluded from this phase of the project refer to the smaller scale design-level site size.

CDM would like to acknowledge the many organizations that provided invaluable data and technical input through the work group meetings for this project.

- Oklahoma Water Resources Board (OWRB)
- Oklahoma Geologic Survey (OGS)
- United States Geologic Survey (USGS)
- American Water Institute (AWI)
- Chickasaw Nation
- United States Bureau of Reclamation (BOR)
- Oklahoma Corporation Commission (OCC)
- United States Environmental Protection Agency (EPA)
- Oklahoma Department of Environmental Quality (ODEQ)
- University of Oklahoma (OU)
- Oklahoma Climatological Survey (OCS)
- National Oceanographic and Atmospheric Agency, National Severe Storms Laboratory (NOAA, NSSL)
- Oklahoma Conservation Commission (OCC)
- State Senator Susan Paddack

FIGURE 1:
Screening Process



Section 2
Site Evaluation Methods and Criteria

2.1 Potential Screening Criteria

Several previous studies have identified important criteria to consider for AR projects (CDM 2007; ASCE 2001; BOR 2008; NAS WSTB 2008). Table 1 lists the criteria that were considered for each of the studies and provides brief descriptions of each; more detailed descriptions follow the table. During previous meetings of the OWRB work group (December 8, 2008; January 21, 2009), several criteria were discussed as being most important to this study. Criteria that were used in other studies were also considered for inclusion for this project. It should be noted that there can be overlap between several of these criteria (e.g., source water availability could be limited by poor source water quality rather than physical availability).

Table 1. AR Project Criteria Identified by Various Entities Considered for Phase 1 Site Screening

			Source/Reference				
	Criteria	Criteria Description	SB1410 Meetings 1 & 2	Colorado SB06-193	BOR	NAS WSTB	ASCE
1	Proximity to Demand	Proximity of recharge project to areas with a demand, including seasonal demands	x	x	x	x	x
2	Source Water Proximity and Availability	Proximity to and availability of (consistent/seasonal/etc) source water	x		x	x	x
3	Source Water Quality	Suitable water quality of source water	x		x	x	x
4	Regulatory Concerns	Regulatory, water rights, or public involvement issues			x	x	x
5	Available Storage Capacity	Available capacity for recharge water storage in the aquifer	x	x	x	x	x
6	Hydrogeologic Suitability	Potential rate of aquifer recharge/conductivity	x	x	x	x	x
7	Residence Time	Duration recharged water is in aquifer		x	x	x	x
8	Groundwater Quality	Aquifer water quality	x	x	x	x	x
9	Effects on Groundwater Chemistry/Clogging	Potential for groundwater and recharge water to interact or for aquifer clogging			x	x	x
10	End Use	Drinking water, M&I, streamflow augmentation	x		x	x	x
11	Land Ownership/Land Use	Proportion of area with accessible public land		x	x	x	x
12	Proximity to Existing Infrastructure	Proximity of infrastructure (pipelines, ditches, etc)		x			x
13	Cost	Likely method of recharge and recovery and need to treat source water		x	x	x	x
14	Habitat Concerns	Presence of threatened and endangered species or wetlands		x	x	x	x

Table 1. AR Project Criteria Identified by Various Entities Considered for Phase 1 Site Screening

			Source/Reference				
	Criteria	Criteria Description	SB1410 Meetings 1 & 2	Colorado SB06-193	BOR	NAS WSTB	ASCE
15	Impacts to Nearby Streams	Potential to create gaining streams			x	x	
16	Waterlogging and Non-beneficial Use	Potential to create high water table/losses to vegetation or gaining streams		x	x	x	x
17	Existing Aquifer Use	Current use of the aquifer			x	x	x

Proximity to Demand

The proximity to the groundwater demand to be met by the AR project is an important consideration primarily from a cost perspective. Projects sited far from the demand location could require costly infrastructure to deliver the water to the demand location. Total annual demand as well as seasonal demands should be considered. For example, shortages may appear minimal on an annual basis, but an AR project may be beneficial where supplies are stressed by elevated seasonal demands. Projected unmet municipal and industrial (M&I), agricultural, and petroleum demands for the year 201 can be used for this criterion; the unmet demand data can be obtained from the OWRB's OCWP Gap Analysis (CDM 2009). Demand locations can further be identified in the detailed ranking through a demand density analysis using well permit information to show which areas within a given region have higher groundwater demand density. Demand projections for the year 206 can be used for siting future projects where demands are projected to increase significantly.

Source Water Proximity and Availability

The legal and physical availability of source water, and the distance to the AR site, is an important consideration from a project cost perspective. The proximity to source water will be generally measured in miles, but topographic data can be utilized to determine whether the AR site can be supplied by gravity flow, or if pumping would be required. Right-of-way concerns should also be considered, particularly in or through urban areas. The availability of source water is meant to provide an evaluation of the consistency of the source whether the source could be continuously utilized, seasonally, or only during periodic storm events. Climatic considerations in relation to amount of precipitation may also factor into this criterion.

Source Water Quality

Source water quality will be evaluated for general water quality parameters as data are available. Factors that should be considered include the presence of nutrients, high concentrations of effluent, high salinity or total dissolved solids (TDS), or any other common water quality parameter that could have a negative effect on the implementation of an AR project. Presence of negatively-impacting parameters could be mitigated through treatment prior to AR, but would lead to increased implementation costs and are therefore less desirable. Source water should not cause degradation of the native groundwater.

Regulatory Concerns

There are a variety of regulatory and political concerns that may affect the feasibility of AR projects. These include drinking water quality standards and public health concerns, water rights considerations, funding challenges, land ownership, permitting, and other regulatory requirements that may help or hinder specific locations. For this study, water rights with respect to source water will be considered to the extent possible, so as to avoid the assumption that source water is available from streams when the extraction would negatively impact senior water rights. Regulatory concerns that apply to all potential AR sites in the state regardless of location (e.g., funding and statewide regulatory requirements) will not be used in the ranking to prioritize sites since they would not differentiate any site over another.

Available Storage Capacity

Available storage capacity describes the availability of additional storage volume within an aquifer. The available storage consists of the unsaturated zone of an unconfined aquifer and the ability to inject water under reasonable pressures into a confined aquifer while minimizing loss through confining beds or other discharge pathways. The available storage in a confined aquifer is dependent on the overburden pressure and existing potentiometric surface depth. Aquifer properties such as porosity, depth to water, and top of formation are important for quantifying the available storage capacity. The available storage per unit area is much higher in unconfined aquifers. Generally, storage is available in aquifers that have been pumped in excess of current recharge and can be identified by declining water levels. Storage capacity may be available in more heavily pumped areas of an aquifer, even if other areas within the aquifer do not share the same declining water level trends.

Hydrogeologic Suitability

Hydrogeologic suitability is the characterization of an aquifer's ability to transmit water (receive recharge or yield water). Characteristics such as hydraulic conductivity (K) and transmissivity (T) and storage coefficients (S, Sy) are important aspects to consider. Aquifer characteristics must be assessed for the ability of the aquifer to accept or produce water at a rate appropriate for the associated project source and demand. Different criteria are necessary for alluvial and bedrock aquifers since hydraulic properties vary widely between alluvium and bedrock.

Residence Time

Residence time quantifies length of time a recharged volume of water will remain in the aquifer and can be readily retrieved. The purpose of the AR project will play an important role in selecting an appropriate aquifer (e.g., short-term seasonal use could tolerate short residence time aquifers, but long-term drought protection would need multi-year residence times). In the Colorado SB06-193 study, alluvial aquifer residence times of 120 and 480 days were used. For the SB1410 study, similar increments would be utilized if the data are available, as these residence times represent the time for water to remain in storage for part of a growing season or for more than a year. If data are not available, estimates of residence times will be made based on aquifer properties, groundwater

hydraulic gradients, and distance to discharge areas (e.g., nearby streams or aquifer outcrop areas).

For the unconfined portions of bedrock aquifers, the proximity of alluvial aquifers or other discharge areas and relative difference between water levels and discharge elevations can be used to evaluate this criterion. Maps showing the locations of alluvial aquifers and aquifer outcrop areas that overlie or are proximal to the unconfined portions of the bedrock aquifers could be used for the bedrock aquifer evaluation.

The residence time in the confined portions of bedrock aquifers is a function of the distance to potential discharge areas and can be significant (years to decades) for areas sufficiently distant from points of discharge.

Groundwater Quality

The water quality within the aquifer is important to consider; both for how it could impact the quality of the source recharged water and how it might be affected by it. Poor groundwater quality that degrades higher quality recharge water will potentially result in water unsuitable for its intended use or generate additional treatment costs when extracting for reuse. The potential to enhance the native aquifer water quality also exists under certain conditions (e.g., arsenic immobilization and dilution of TDS). The criterion also addresses the concern of degrading aquifer water quality by leaching of minerals naturally found in soils when recharge water is added. Locations where there is a high leaching potential (e.g., saline soils for spreading basins) could render that area unsuitable for aquifer recharge.

Effects on Groundwater Chemistry and Clogging

This criterion is concerned with the potential for source water and groundwater geochemical interactions. This could include interactions of source water with the aquifer matrix, as well as the potential for clogging aquifer pore spaces due to geochemical or biological interactions. Differences in water properties, such as pH or reduction/oxidation (redox) characteristics, could lead to dissolution of undesirable metals or minerals within the aquifer, or conversely, the immobilization of some elements or compounds. Detailed analysis of specific geochemical properties of the aquifers and source waters, including potential for clogging due to interaction, is more appropriate for evaluation of specific implementation locations rather than the more general investigation intended for Phase 1 of the study. However, simple comparisons of pH and redox conditions could be completed for this investigation, as data are available.

End Use

The requirements of the end user of AR recovered water will have an effect on the need for treatment of the recovered groundwater. Municipal, industrial, agricultural, petroleum industry, and power generation all have different requirements for treatment upon extraction. It is important to ensure that the water quality of the recovered groundwater is suitable for its intended use. Some aspects of this criterion can be addressed through source water and groundwater quality criteria.

Land Ownership/Land Use

This criterion examines general land use, including the location of urban, agricultural, native and range lands, public vs. private land ownership, and the location of inaccessible lands (such as military reserves). A key assumption is that recharge projects will be more easily sited on accessible public lands and non-urban lands. Land acquisition costs will play an important role in determining economic feasibility.

Proximity to Existing Infrastructure

The presence of water conveyance structures and other infrastructure is an important consideration affecting the cost and overall feasibility of an underground water storage project. This criterion considers the proximity of major ditches and pipelines on the basis that existing water conveyance structures will improve the suitability of an area and reduce cost to deliver water for recharge activities. This criterion should evaluate existing infrastructure that can be used to supply source water and/or deliver water to the demand. This criterion will likely not apply during the regional-level preliminary screening, but will become increasingly important as the size of potential sites decreases.

Cost

This criterion considers anticipated facility construction and operational costs for potential underground water storage projects. Cost associated with water treatment is not included in this criterion due to the site-specific nature of the water to be used for recharge. Land acquisition for projects that utilize spreading basins is likely the single largest cost. Land cost for a project sited away from metropolitan areas will generally be relatively low. For the confined bedrock aquifers, the depth to the aquifer and the presence of existing high-capacity wells that could be utilized for the project are key factors in comparing the relative cost of implementing projects. Projects located in unconfined aquifers are likely to be lower in cost than for confined aquifers since construction costs for spreading basins are relatively small. However, in situations where bedrock wells and associated infrastructure already exist, the construction-related cost for bedrock recharge would be only for retrofitting existing wells.

Habitat Concerns

The presence of habitat for federally designated threatened and endangered (T&E) species, or wetlands that could be adversely impacted by construction or operation of potential underground water storage projects should be considered for AR project siting. Depending on timing and operation of a recharge project, the impacts on habitat could be either positive or negative. For example, recharge ponds could provide beneficial waterfowl habitat in the fall and winter months, but may impact habitat for a T&E species. This criterion plays a minor role in the confined aquifer settings due to the small surface area associated with artificial recharge wells and associated piping. This criterion will likely not apply during the regional-level preliminary screening, but will become increasingly important as the size of potential sites decreases.

Impacts to Nearby Streams

This criterion includes the potential for an AR system to affect local streams through additional contribution to stream baseflow. This criterion is influenced by the type of aquifer (alluvial versus bedrock; bedrock aquifers would likely not affect streams unless it is an unconfined/outcrop area), as well as the general distance of the AR location to the stream.

Waterlogging and Non-beneficial Use

This criterion considers the potential for shallow water table conditions, both near a potential recharge area as well as downgradient of the area, which could promote the growth of undesirable vegetation such as tamarisk and lead to non-beneficial water consumption. The shallow water table conditions could also lead to waterlogging of soils, creation of undesirable wetlands, and flooding of basements. For the Colorado SB06-193 study, the maximum depth to which this criterion was estimated to have any impact was 30 feet below ground surface (bgs), which is the approximate depth to which tamarisk is capable of extending its roots. This criterion applies mainly to alluvial systems. Underground water storage in the bedrock aquifers is expected to have minimal potential to cause waterlogging or non-beneficial use. This criterion often overlaps with storage availability, as waterlogging due to the AR project can be considered an indication that there is no available storage or that hydrogeologic parameters are not suited for the scale of the project.

Existing Aquifer Use

Current aquifer use is a potential concern for selecting AR locations. The different source water qualities could affect the current aquifer use if a lesser-quality water is used for AR than what is currently present in the aquifer. Additionally, the operation of the AR facility could result in a fluctuating water table that would change the ability to use existing wells in the aquifer. This criterion may overlap with other concerns addressed in the groundwater and source water quality criteria.

Qualitative Factors

Other factors such as individual town or cities' desire to have the project in their area, overall public support or other non-quantitative factors may be considered in the final siting of the pilot project. Qualitative factors will likely only distinguish between otherwise equally feasible sites.

Selection of Criteria

Based on discussions at the OWRB work groups, previous regional studies and national guidelines and standards set forth by government and professional organizations, the following criteria are recommended for inclusion in the evaluation of potential AR locations. The criteria are organized by major category. Some criteria described above have been divided into multiple criteria as recommended in the work group meeting held September 22, 2009. Application of the selected criteria is discussed in detail in Section 3 of this document.

Demand

- Proximity to demand
- Frequency and seasonality of demand
- Demand density

Source Water

- Source water physical and legal availability and proximity to AR site
- Source water quality for non-degradation
- Regulatory challenges

Hydrogeologic Suitability

- Aquifer storage capacity (current utilization of aquifer / declining water levels)
- Aquifer conductivity, transmissivity, and storativity (K, T, S, Sy)
- Residence time/distance to discharge locations

Groundwater Quality

- Native groundwater quality for intended use
- Geochemical interaction with source water

Cost

- Recharge method
- Proximity and infrastructure considerations

Project Impact

- Qualitative ranking factors

The following criteria were not selected for this Phase of the siting study:

- **Habitat Concerns:** this criterion is more appropriate for site-specific implementation concerns (Phase 2 implementation). The nature of this investigation is to identify aquifers and surface water basins with favorable characteristics for the AR demonstration project. It is anticipated that critical habitat and wetlands would not comprise the entire selected area and specific sites could be identified for development of an AR facility within the scale of the investigation areas.

- **Waterlogging and Non-Beneficial Use:** this criterion can be addressed through the available storage capacity criterion. Alluvial aquifers will be the primary formations that could be influenced by this criterion, and thus the calculation of available storage will be modified to remove the subsurface zone that may be susceptible (approximately the upper 30 feet of subsurface).

- **Land Ownership/Use:** this criterion is more appropriate for site-specific implementation concerns. The nature of this investigation is to identify specific aquifers or portions of selected aquifers. Land ownership and use issues are appropriate for the site-specific selection process within the selected region.

- **Effects on Neighboring Streams:** this criterion shares common principles with the residence time criterion, and thus will not be evaluated separately.

- **Existing Aquifer Use:** this criterion shares common principles with the groundwater and source water quality, and effects on groundwater geochemistry criteria. Additionally, the operational issues associated with the demonstration AR facility would not be anticipated to produce excessive drawdown that would result in a loss of groundwater supply to current users.

- **End Use:** this criterion shares common principles with the groundwater quality and source water quality criteria and, and thus will not be evaluated separately

2.2 Application of Selected Criteria

As shown in Figure 1, potential AR demonstration project sites will go through a preliminary screening and a detailed ranking. The preliminary screening consists of a fatal flaw analysis and a threshold screening. Not all of the criteria identified in the previous section will be used in preliminary screening, but all are considered in the detailed ranking. This section describes the preliminary screening from the detailed analysis. In the detailed ranking analysis, the criteria will be weighted based on relative importance to determining the feasibility of the demonstration project.

Table 2 presents the criteria selected for the fatal flaw, threshold screening, and detailed ranking. These criteria were selected based on the recommendations of previous discussions within the SB1410 work group as well the recommended criteria from the Colorado SB06-193 study and the BOR report.

Table 2. Screening Levels and Criteria Weighting Factors

Category	Criteria	Screening Level		
		Fatal Flaw	Threshold	Detailed
Demand	Frequency	x	x	x
	Proximity	x	x	x
	Density			x
Source Water	Proximity	x	x	x
	Availability		x	x
	Quality for Non-Degradation		x	x
	Regulatory Challenges		x	x
Hydrogeologic Suitability	Available Storage Volume and Ability to Meet Local Demand		x	x
	Transmissivity		x	x
	Residence Time/Distance to Discharge		x	x
Groundwater Quality	Native Quality	x	x	x
	Geochemical Interactions with Source Water			x
Cost	Recharge Method (Capital and O&M)			x
Project Impact	Qualitative Considerations			x

The SB1410 work groups, the Colorado study, and the BOR report identified storage capacity, hydrogeologic suitability (transmissivity), and proximity to demand as having a high importance in evaluating AR locations. The SB1410 and the BOR report both identified source water quality and proximity/availability as important criteria. Several criteria were utilized in the Colorado SB06-193 study and/or recommended in the BOR report, but were not discussed in initial SB1410 work group meetings. These criteria include residence time, implementation costs, and effects on groundwater chemistry. Residence time and proximity to infrastructure were included as moderately-weighted criteria in the Colorado SB06-193 study. Residence time was highly weighted in the BOR report (included within the hydrogeologic considerations). All other criteria not included in the OWRB work group discussions received low weights in the SB06-193 study or were not included as weighted criteria in the BOR report.

Fatal Flaw Criteria

The fatal flaw analysis is the initial level of investigation intended to screen out several areas in the state located over aquifers based on relatively simple application of four criteria: annual or seasonal demand frequency; proximity of the AR site to demand; proximity of the AR site to a recharge source; and groundwater quality (based on TDS). This level of analysis is completed to answer a yes-or-no type question for each region under consideration for the AR demonstration project. At this level of analysis, the regions will likely consist of a surface water basin, groundwater aquifer, or combination as appropriate. The proximity criteria will be analyzed for each surface water basin, using the gap analysis tool for the OCWP to help assess demand and source data and geographic information system (GIS) mapping for physical distances. The water quality criterion will be analyzed for each major and minor aquifer within the State of Oklahoma as well as noting areas within each aquifer that may have poorer water quality. Failure at any one of the fatal flaw criteria indicates that a demonstration project at the potential AR site is most likely not feasible. Thus, any basin or aquifer that does not meet the recommendation for all fatal flaw analyses will be removed from further consideration. The portions of the surface water basins and groundwater aquifers that overlap (or are within close proximity) and produce a favorable response for all fatal flaw criteria will be retained for the threshold level analysis.

- **Demand Frequency:** Based on the discussion during the September 22, 2009 work group meeting, candidate recharge areas should have significant groundwater development and seasonal variability in the demand. Because Phase 2 is a pilot project, the work group concluded that the most appropriate demand to be met would be a seasonal demand, as the short-term effect of the pilot project would be seen. In the event that a long-term demand (such as storage for drought mitigation) were selected, it could be many years before the effect of the storage project would be observed. Thus, during fatal flaw analysis, only regions with short-term (seasonal) demands will be selected for further consideration.

- **Proximity to Demand:** For the fatal flaw analysis, the demand center should be within a set distance from the proposed AR site. Areas where no seasonally based demand exists should be screened from further consideration for the demonstration project.

- **Proximity of Source Water:** For the fatal flaw analysis, the proximity of source water to potential AR site should be less than a set distance. Alternatively, existing infrastructure, such as pipelines or ditches, may be able to provide an adequate source if they are present within the same radius. Only proposed AR sites with source water within the set distance will be considered for the demonstration project.

- **Groundwater Quality:** For the fatal flaw analysis, any groundwater aquifer or portion of the aquifer at the proposed AR site that has a TDS concentration above a specified limit will be excluded from further consideration due to the limited uses this water might have.

Threshold Screening Criteria

The threshold level of analysis is the second part of the preliminary screening and will be completed for each potential AR site that passes through the fatal flaw analysis. The purpose of the threshold screening is to further narrow the number of sites that will undergo the detailed ranking by applying several of the identified criteria in a relatively simple manner. The threshold screening is more involved than the fatal flaw analysis in that a value of high (good), moderate (fair), or low (poor) is assigned to the criteria. Those sites that have a low (poor) ranking will be eliminated from further consideration, and those sites that have the most moderate (fair) rankings may also be eliminated, depending on the final rankings of the potential sites. The goal of the threshold screening is to reduce the number of potential sites for the detailed analysis to 10 to 15 sites.

The criteria used in the fatal flaw analysis are used again in the threshold screening, but will be ranked as high (good), moderate (fair) or low (poor) rather than a simple yes/no type answer. In addition, the source water quality, regulatory issues, and hydrogeologic characteristics (available volume, transmissivity, and residence time) will also be ranked.

- **Source Water Quality for Aquifer Non-Degradation:** Threshold analysis should initially rank sites based on TDS concentrations, with a tiered ranking for high, moderate, and low quality. If other water quality data are available to make reasonable comparisons across the state, those data should be utilized as well.

- **Source Water Availability:** The water available to the AR project should be sufficient to meet the demand, and could include various sources, such as precipitation capture systems or streamflow. Water rights are further evaluated within the regulatory challenges criterion to ensure legal availability.

- **Regulatory Challenges:** Many regulatory concerns will need to be addressed for any AR project, regardless of location. Some regulatory challenges, such as water rights, and their influence on source water availability, will be addressed in the source water proximity and availability criteria. Others regulatory challenges related to water quality

are encompassed in water quality criteria. The SB1410 work group indicated that regulatory concerns are very important and should be highlighted.

- **Storage Availability:** For the threshold evaluation, the available aquifer storage capacity should at a minimum meet the demand volume, which will result in a moderate score. Aquifers that more than meet the demand gap size should receive a high score. Additional consideration should be given to the possibility that injection or recharge of water could displace existing groundwater, resulting in no net storage gain. Small aquifer storage availability volume should not result in a lower score if the available storage could meet a nearby demand gap. Storage availability should allow for water to recharge without causing waterlogging or non-beneficial use by phreatophytes.

- **Transmissivity (T):** For the threshold evaluation, a tiered ranking should be established based on the range of transmissivities encountered for both alluvial and bedrock aquifers across the state. Lower T values could severely hinder the effectiveness of an AR project. Hydraulic conductivity (K) may be considered as a surrogate for T if the saturated thickness of the aquifer is unknown.

- **Residence Time/Distance to Discharge:** For the threshold evaluation, the residence time can be approximated by the distance to discharge points (e.g. streams, outcrops or bedrock aquifer contact with alluvial aquifers). Generally a longer residence time will ensure that water stored at the potential AR site would be available for extraction at a later date and should be ranked higher. More detailed estimates of residence times based on local groundwater gradients and comparisons to the time required based on the demand pattern are more appropriate for the detailed ranking and will be avoided in the threshold screening. Consideration should also be made that water injected into the AR project does not simply displace water from the aquifer, but adds to the total aquifer storage.

Detailed Ranking

The detailed ranking will be performed on the best 10 to 15 potential AR sites from the threshold screening stage of the preliminary screening and will apply each criteria on a more detailed and quantitative basis than was done through the preliminary screening. Each criterion will be scored on a one to five scale, with five being most favorable and one being unfavorable. Scores will be assigned based on a detailed analysis of existing data and professional judgment. The score will then be multiplied by a weighting factor that represents the relative importance of each criterion. Once each criterion score is multiplied by the weighting factor, the results are summed to generate a single potential AR site score. Higher scores indicated AR sites that are more feasible than lower scoring sites.

Several of the criteria that will be applied in the detailed ranking have already been discussed in the fatal flaw and threshold screening sections. The detailed ranking process will simply extend the application of the criteria based on other existing data, make comparisons relative to other potential AR sites and potential interactions with other

criteria. In addition, the detailed analysis will consider four other criteria not applied in the preliminary screening: demand density, geochemical interactions with source water, cost, and qualitative impact. The qualitative impacts could be used to distinguish otherwise quantitatively equal potential sites.

- **Demand Density:** This criterion will be utilized to evaluate the density of demands within a given area. For example, several demands that are located within close proximity to a recharge aquifer would result in a favorable ranking of that aquifer due to its potential to meet multiple demands depending on need. This criterion can also be used to select sites within a larger aquifer area identified in the preliminary screening. It is anticipated the state's well permit database can be used to quantify density of groundwater use.

- **Geochemical Interactions with Source Water:** For the detailed ranking, each potential AR site that passed the preliminary screening will be investigated for potential groundwater/surface water interactions and interactions with the aquifer matrix (e.g. mineral precipitate or leaching). Cases where recharge may result in water quality improvements will receive the highest score, while cases where recharge may result in poorer water quality or dissolution of the aquifer matrix will receive the lowest score. Interactions could lead to dissolution of undesirable metals or compounds into the groundwater, or aquifer clogging due to microbial interactions. On the contrary, recharge of aerobic (surface) water into an anaerobic aquifer could result in immobilization of elements such as arsenic, leading to an improvement in water quality, although this will need to be balanced with the potential clogging effects of precipitating iron.

- **Implementation Cost:** For the detailed ranking, each potential AR site that passed the preliminary screening will be evaluated for the anticipated method of recharge and groundwater extraction, as well as general land value. This criterion will be evaluated under the assumption that gravity-fed systems (such as recharge ponds) would be less expensive than the construction and operation of injection wells. Similarly, it is influenced by the method of extraction, such as supplementing stream baseflow versus using extraction wells. Cost for aquifers requiring well usage will also be influenced by the depth to the aquifer unit. An additional cost that may be incorporated is the cost of land; it can be assumed that the cost of land required to operate an AR project would be higher within the vicinity of metropolitan areas, and would result in a lower score.

  It is likely that alluvial aquifers will receive the highest scores, depending on location (locations near metropolitan areas receive lower scores due to price of land, while rural areas receive the higher scores). Bedrock aquifers will likely receive the lower scores due to the necessity of well usage; differentiation will also depend on the location (municipal versus rural). There is also the possibility that some bedrock aquifers may be able to utilize existing high capacity wells or could be recharged in areas of outcrops or shallow subcrops, which could increase their score to a moderate range.

- **Project Impact:** This qualitative criterion will be utilized to incorporate any additional information on a given aquifer that is available. This may include political or economic

reasons a specific aquifer should be given a higher or lower score. This criterion should be used to distinguish otherwise quantitatively equally feasible AR sites.

A scoring matrix was used for the detailed ranking and is presented in Section 4 of this report. All criteria were assigned a raw score from 1 to 5 with 1 being not favorable, and 5 being highly favorable. Criteria were assigned weights to indicate the relative importance the criteria. Final scores for each recharge site were determined by multiplying the raw score by the weight and summing the weighted scores for all criteria. At the January 2010 work group meeting, the relative importance of the criteria was surveyed through a voting exercise whereby each participant was given 14 votes to assign to the 14 criteria in Table 2. It should be noted that for this exercise, source water availability and proximity were considered as one criterion, and cost was divided into capital and operations and maintenance subcategories. The results of the voting are presented in Table 3. There were concerns that the participants present at the meeting may skew the voting results based on their particular professional backgrounds. During the final ranking, a sensitivity test was run on the weights to address these concerns (Section 4).

Table 3. Criteria Weight Voting Results

Category	Criteria	Votes
Source	Quality for Non-Degradation	27
Hydrogeologic Suitability	Available Storage Volume and Ability to Meet Local Demand	25
Groundwater Quality	Native Quality	20
Groundwater Quality	Geochemical Interactions with Source Water	20
Demand	Proximity	19
Source	Proximity and Availability	19
Hydrogeologic Suitability	Transmissivity	16
Hydrogeologic Suitability	Residence Time/Distance to Discharge	14
Demand	Frequency	10
Demand	Density	10
Cost	Operations and Maintenance (O&M)	10
Cost	Capital	8
Source	Regulatory Challenges	7
Project Impact	Qualitative Considerations	5

Weighting factors were utilized in the Colorado SB06-193 study, and the BOR study. Table 4 presents various criteria in each and compares the relative importance placed on each criteria in the studies. The table shows that although each study has a unique scoring system, there are several criteria that are agreed to be more important than others. There are also significant deviations in the work group ranking from other studies. This can be explained in part that the voting occurred after the preliminary screening identified sites that likely have at least adequate levels of available supply and hydrogeologic suitability. These criteria were ranked lower than other studies, but were implicitly ranked higher since they were selected for the preliminary screening. The sensitivity test on weightings allowed analysis with more importance on the criteria used in the preliminary screening.

Table 4. Comparison of Relative Importance of Criteria

Criteria	OWRB Work Group Weighting	Colorado SB06-193	BOR
Source Water Quality for Non-Degradation	1	NA	NA
Suitable Storage Volume	2	1	1
Native Groundwater Quality	3	4	NA
Geochemical Interactions with Source Water	4	4	NA
Proximity to Demand	5	1	NA
Proximity to Source	6	NA	NA
Hydrogeologic - Transmissivity	7	2	1
Hydrogeologic - Residence Time/Distance to Discharge	8	3	1
Demand Frequency	9	NA	NA
Demand Density	10	NA	NA
Cost/Recharge Method	11/12	4	2/3/5
Source Water Regulatory Challenges	13	NA	4/5
Project Impact/ Qualitative Considerations	14	3	NA
Land Ownership/Use	NA	4	NA
Existing Infrastructure	NA	3	NA
Engineering Feasibility	NA	NA	4
Monitoring Plan	NA	NA	4
Rehabilitation Plan	NA	NA	5
Environmental Issues	NA	4	5
Uniqueness	NA	NA	4

Note: 1 indicates highest weighting

2.3 Data Requirements

Data requirements for analysis of the various criteria relied on multiple sources of data, including GIS data files. The following presents a summary of the data sources used for evaluation of each criterion. Data used for each recharge region in the detailed analysis are presented in the appendices. Refer to the references section for proper citations.

- **Demand Frequency:** Tables and figures and original data from the OWRB Gap Analysis project were utilized to determine seasonality of demands.
- **Proximity to Demand:** GIS maps of public water supply (PWS), aquifer footprint and surface water sources were utilized to determine distances and spatial relationships.
- **Proximity and Availability of Source Water:** Data from the OWRB Gap Analysis project were utilized to determine the amount and frequency of available source water. Additional data, including precipitation and streamflow gage data were used to supplement the evaluation in the detailed screening. Distances from surface water sources to recharge areas were determined from GIS maps.
- **Storage Availability:** The availability of storage volume, or freeboard, within an aquifer was analyzed using depth to water, ground surface elevation and groundwater elevation contours Grid surfaces of the groundwater contours were generated and compared against ground surface digital elevation models (DEM) to determine depth to water. Storage coefficients were used to compute available storage.

- **Groundwater Quality:** Groundwater quality data were obtained from OWRB, USGS, and EPA online databases.
- **Source Water Quality for Non-Degradation:** Data were gathered for the OWRB Marginal Quality study, as well as the OCWP, Plentiful data were obtained from the USGS and EPA online databases.
- **Regulatory Challenges:** Data from the OWRB Gap Analysis work in progress, as well as information from the OWRB were utilized to assess the magnitude of regulatory challenges, including legal availability.
- **Transmissivity:** The AWI preliminary screening report provided a summary of transmissivity data for the major aquifers.
- **Residence Time/Distance to Discharge:** The Glover equation was used in conjunction with hydrogeologic parameters and GIS maps to estimate residence time and losses.
- **Demand Density:** Demand density information was available from the OWRB Gap Analysis and from the groundwater permit database.
- **Geochemical Interactions with Source Water:** Groundwater and surface water quality data from the online USGS and EPA databases were utilized to assess geochemical interaction and Langelier indices.
- **Implementation Cost:** Relative costs (both capital and operations and maintenance [O&M]) were estimated based on recharge type (e.g., spreading basins, retrofit of existing wells, new wells), treatment needed due to source water quality, and conveyance method.
- **Project Impact:** Data from the OCWP were utilized to help determine the magnitude of an impact a pilot project would make relative to the local demand.

Section 3
Preliminary Screening

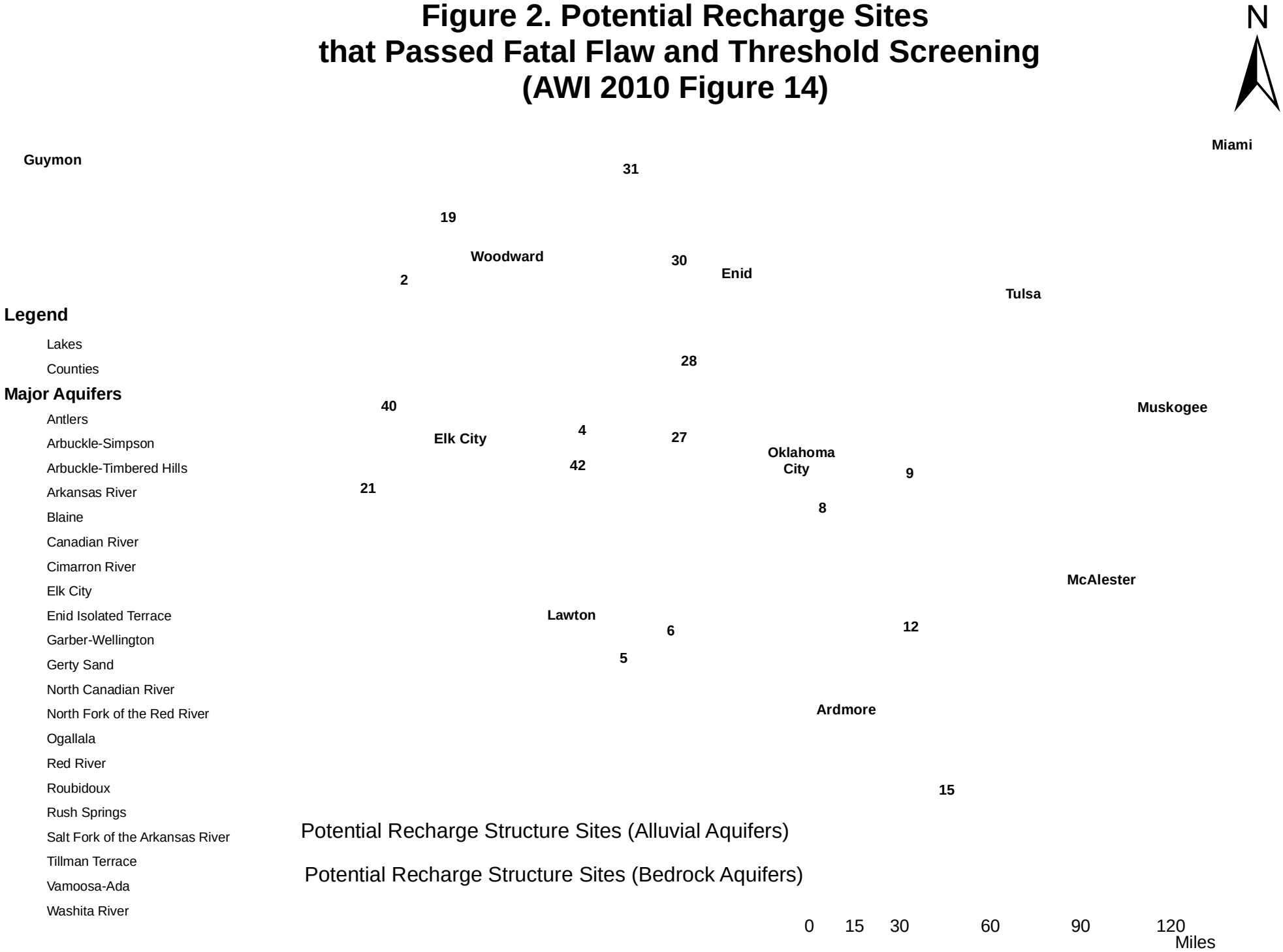
The preliminary screening was performed by Wayne Kellogg with the AWI using the criteria identified in Table 2 for a fatal flaw and threshold screening analysis (AWI 2010). The purpose of the preliminary screening is to eliminate many areas from further consideration based on relatively simple application of a small number of the criteria. All sites that are not eliminated through the preliminary screening would likely be suitable for an AR demonstration project. Sites that passed through the fatal flaw and threshold screening were considered in the detailed ranking. Only basic results of the AWI 2010 report are presented here. The reader should refer to the AWI 2010 report for detailed discussion of methods, analyses, and results.

Initially, 57 sites throughout the state were identified for the preliminary screening based on aquifer location, existing use, and demands (AWI 2010, Figure 5 and Table 1). Several sites were screened out through the fatal flaw analysis, resulting in 15 alluvial aquifer sites, and 15 bedrock sites. The threshold analysis screened out an additional 15 sites, resulting in 6 alluvial sites and 9 bedrock sites (AWI 2010, Figure 14, reproduced on the next page). The 15 sites that passed the fatal flaw and threshold screening were considered in the detailed ranking presented in Section 4. Table 5 presents the site number, surface water basin, aquifer and nearby municipality of the 15 sites identified for the detailed screening.

Table 5. Sites Identified through Preliminary Screening.

Site	Surface Water Basin	Aquifer	Nearby Municipality
2	Upper North Canadian River	Ogallala	Woodward
4	Upper Canadian River	Rush Springs	Weatherford
6	Beaver Creek	Rush Springs	Marlow
8	Little River	Garber Wellington	Norman
9	Lower North Canadian River	Ada Vamoosa	Shawnee and Seminole
12	Blue River	Arbuckle Simpson	Ada (Byrd's Mill Spring)
15	Red River	Antlers	Durant and Calera
19	Upper North Canadian River	Alluvial	Woodward
21	Upper North Fork Red River	Alluvial	Elk City
27	Middle North Canadian River	Alluvial	El Reno
28	Middle Cimarron River	Alluvial	Kingfisher and Hennessey
30	Lower Cimarron River	Alluvial	Enid
31	Upper Salt Fork of Arkansas River	Alluvial	Cherokee
40	Washita Headwaters	Ogallala	Reyden
42	Upper Washita	Rush Springs	Eakly

Figure 2. Potential Recharge Sites that Passed Fatal Flaw and Threshold Screening (AWI 2010 Figure 14)



Section 4
Detailed Ranking and Scoring

Fifteen recharge sites were identified through the preliminary screening that met certain minimum criteria and are all likely suitable locations for a recharge pilot study (Section 3). The purpose of the detailed ranking is to determine the most suitable of the sites for the pilot project through an objective scoring process. All sites were re-evaluated in more detail using each of the criteria used in the preliminary screening and additional detailed analysis criteria as described in Section 2 (Table 2). A 'site' from the preliminary screening is defined as an approximately township (6 miles by 6 miles) located in a favorable area of an aquifer that is proximal to an appropriate source and demand. The preliminary screening 'site' is referred also referred to as a 'recharge region' in the detailed ranking. In the detailed ranking, the size of a site is narrowed to an approximately 1-square-mile 'recharge area'. The exact design-level location of the project remains undetermined to allow for site specific evaluation, such as coordination with local landowners and other environmental factors.

The first step in the detailed screening was to evaluate each recharge region (preliminary screening 'site') to determine the best recharge area (approximately 1- square-mile area within a recharge region). Recharge areas were identified based on locations of PWS wells, recharge source water, available aquifer freeboard (depth to water), and general groundwater flow direction. This initial step resulted in minor shifts in the locations of some recharge regions identified in the preliminary screening to encompass a more favorable area. Some of the larger recharge regions contained more than one possible location for a recharge project. In such instances, the recharge area with the closest source and demand proximities, with sufficient aquifer freeboard and located upgradient from the demand and groundwater discharge areas was selected for the ranking and scoring process. It was assumed that a pilot project would not exceed 1,000 acre-feet per year (AFY), and criteria were scored based on that assumption.

Detailed results for each recharge area are presented in the appendices. The detailed ranking methods summarized results and recommended pilot project recharge areas are presented below.

4.1 Detailed Ranking Methods

Based on the information gathered for each recharge area, individual criteria were compared among all recharge areas, and an appropriate score (high, moderately high, moderate, moderately low, low) was assigned to each recharge area for each criterion. Table 6 presents the criteria that were evaluated for the detailed screening, and presents the scoring guidelines for each criterion. In some cases, further differentiation was deemed appropriate, and a moderately high or moderately low score was assigned for a given recharge region. Detailed justification for the scoring of recharge area is presented in its appendix. A description of the methods used to assign the scores for each criterion follows Table 6.

Table 6. Scoring Guidelines for Detalied Ranking

Criteria	Factors for High Score	Factors for Moderate Score	Factors for Low Score
Demand Proximity (distance from recharge area)	Within 1 mile	Approximately 1.5 miles	Greater than 2 miles
Source Proximity (distance from recharge area)	Within 1 mile	Approximately 1.5 miles	Greater than 2 miles
Available Freeboard and Ability to Meet Demand	Plentiful volume for meeting the associated demand; no areas will raise water level to less than 15 feet bgs	Likely sufficient volume for associated demand, but uncertainty exists	Not enough volume to meet the associated demand; may raise the water level to less than 15 feet
Demand Density (number of wells)	Greater than 10 PWS wells within 1 mile	5 to 10 PWS wells within 1 mile	Less than 5 PSW wells within 1 mile
Source Quality for Non-degradation	Similar concentrations as groundwater or lower concentrations that will improve groundwater; no MCL exceedences; low TDS	Borderline TDS; few exceedences of MCLs	Quality will degrade groundwater; high TDS; many MCL exceedences
Native Groundwater Quality	Low TDS (<500 mg/L); no exceedences of MCLs	Borderline TDS; few exceedences of MCLs	High TDS (>500 mg/L); many exceedences of MCLs
Geochemical Interactions of Source and Groundwater	Similar Langelier Indices (source and groundwater within 0.5 units); similar pH values	Langelier index unable to be computed, but similar pH and hardness values	Langelier indices that are greater than 0.5 units different; largely different pH or hardness values
Transmissivity	T>1,000 ft2/d	T>500 ft2/d, but less than 1,000 ft2/d	T<500 ft2/d
Residence Time	Less than 10% loss in 180 days, >480 days to 25% loss	10 to 25% loss in 180 days, 180 to 480 days to 25% loss	>25% loss in 180 days
Cost (O&M)	No pretreatment required; gravity flow delivery; spreading basin use	Combination of some more expensive and less expensive components	Pretreatment required; ASR wells utilized; force mains required
Cost (capital)	Gravity flow delivery; ASR well retrofit	Spreading basin in rural area	Spreading basin near municipality; ASR well construction; pipeline construction
Qualitative Considerations	Project size meets 100% of demand	Project size meets 25% of demand	Project size meets <10% of demand

Source Availability

The source availability included an analysis of the available water from a given source for each recharge area. Availability of source water was evaluated in the preliminary screening using basin-wide availability data. For the detailed ranking, a finer level of source availability was investigated using both the basin water availability from the Draft OCWP (CDM 2009), and gaged flow data from the listed source when available. The period of record of gaged streamflow data in the different recharge areas varies significantly. To evaluate all recharge areas on a common basis and to ensure the pilot project would have sufficient water in most years, long-term precipitation records for different OCS's precipitation regions were used to identify years with precipitation well below average (approximately the 25th percentile or less). Only sites with gage data with a period of record overlapping a low precipitation year were considered as representative of a low-year flow, representing a conservative estimate of source water availability for a recharge project.

Gage data on the source stream for the most recent low-precipitation year was chosen to represent a reasonable lower-end estimate of flow availability for the recharge area. The daily gage flows for that year were then utilized to determine the seasonal total flows. Each source was also evaluated to determine whether source availability could be adversely affected by upstream or downstream influences, such as legal availability constraints or reservoir releases. Additionally, an analysis of whether high-yield irrigation wells had been installed in the vicinity of the source since the selected year was completed to determine whether less water may be available. It was assumed that if a large number of wells had been installed after the representative year, the source availability would likely be less than predicated by the gaged data prior to the well installations. Stormwater runoff was not considered in the evaluation of source availability due to limited data on storm runoff flows; also, a continuous source is desirable for a pilot project. In addition, streamflow is an indicator of runoff potential at some sites and further investigation into the availability of stormwater runoff could be used to augment the project.

For scoring of this criterion, sources that have plentiful water available during the spring season received the highest scores, as it is anticipated that the water utilized for the recharge pilot project would be diverted during the spring. However, sources that have additional water available throughout the year received higher scores than those where only spring flows were available. Also, sources with gage data older than approximately 1990 received lower scores due to uncertainty in current availability due to potential land water use changes. Additionally, gages that were present downstream of the probable diversion resulted in a lower score due to uncertainty associated with downstream gains and tributary inflows.

Aquifer recharge regions 27 and 40 (El Reno and Reyden) were identified as having legal availability constraints based on existing permits and reservoirs in the basin and likely regulatory challenges in obtaining a permit to divert surface water. Information on the legal availability was obtained after the preliminary screening was complete.

The maximum volume of water needed for a pilot recharge project is estimated at 1,000 AF. Thus, the available water required for each recharge area was at most 1,000 AF. Some demands were less than 1,000 AF; in these cases the desired volume of water was equivalent to the demand. Scoring of source water availability resulted in the following recharge areas receiving high scores: 9, 28.

Available Storage Capacity

The available storage and ability to meet the demand criterion was assessed using depth to water maps generated for each recharge region. These maps were created using digitized groundwater elevation contours from the USGS (2009), and were gridded. The gridded groundwater elevation data were subtracted from the gridded surface elevation data (DEM). Three recharge regions (Site numbers 12, 21 and 31) did not have groundwater contours, so wells with water level data were plotted on the appropriate maps. The wells utilized were all available in the groundwater permit database, and had a measured water level value. The value plotted on the figures was the shallowest water level measurement over the period of record to generate a conservative depth to water estimate.

For scoring, it was assumed that the pilot AR project size was the smaller of the local demand or the assumed upper pilot project size of 1,000 AF. Specific yield (or storativity for confined bedrock aquifers) was used to calculate the area required to store the specified volume of water with an increase in water level of either 25 or 10 feet. The required area was then compared to the depth to water in the vicinity of the recharge area to determine whether a decrease in depth to water to less than 15 feet bgs would occur. A depth to water of less than 15 feet bgs is undesirable due to potential flooding of underground structures or non-beneficial losses due to evapotranspiration. Recharge regions that had depths to water of less than 25 or 10 feet in the vicinity received lower scores due to the likelihood of these issues. Generally, recharge areas located in areas with greater than 50 feet of available freeboard were given the highest scores. Confined aquifers were generally rated lower due to the small storage available per unit area. It should be noted that multiple successful Aquifer Storage and Recovery (ASR) projects have been implemented in highly confined aquifers. Recharge regions that received a high score include: 2, 4, 6, 12, 15, 19, 30, 42.

Proximity to Demand

The proximity to demand analysis included an assessment of the approximate distance from a recharge area to the demand points. For this analysis, the demand points were assumed to be at or near the location of PWS wells for the selected demand (town or city) that was identified during preliminary screening. The majority of demand points were located very close (within 1 mile) of the recharge area. Recharge areas were located within a recharge region based on locations of demands, as discussed previously. This ensures that a recharge project would have an observable impact to a known demand. The highest ranking recharge regions had demand points located within a 1 mile radius of the recharge area. Two towns that did not have PWS wells (recharge regions 9 and 15) were scored based on the distance from the recharge region to the outer proximity of the town. Since there are no existing wells that could be retrofitted for recharge, there would be

additional costs at these locations. The recharge regions that received a high score included: 2, 4, 6, 8, 12, 19, 21, 28, 30, 31, 42.

Demand Density

Areas with existing groundwater development are better candidates for a recharge project than areas without groundwater development due to the existing infrastructure and proven use of the groundwater source. Higher density of wells indicates heavier development of the aquifer and results in a more favorable ranking. The demand density criterion was assessed by counting the number of PWS wells for the given demand at a recharge region within a 1- and 2-mile radius of the recharge area. Recharge regions that had a density of greater than 10 wells within 1 mile received high scores, while recharge regions with fewer than five PWS wells within 1 mile received moderately low or low scores. The recharge regions that received high scores included: 4, 6.

Source Water Proximity

The source water proximity analysis included an assessment of the approximate distance from the identified source to the chosen recharge area for each recharge region. Generally, the recharge areas were located closer to the demands to utilize existing infrastructure (PWS wells and pipelines) for the demand. The proposed recharge area for recharge regions with towns without PWS wells was located approximately halfway between the town limits and the source water location to minimize the length of pipelines that would be required for a pilot project. Recharge areas without existing PWS would incur higher costs for construction of new recharge project wells. Highest scoring recharge regions had sources located within 1 mile of the recharge area. The recharge regions that had a high score included: 28, 12.

Effects on Groundwater Chemistry and Clogging

This criterion was assessed by analyzing differences in the geochemistry parameters that were included in surface and groundwater sampling by the USGS and EPA; data were compiled from USGS and EPA online databases (USGS 2010; EPA 2010). For this criterion, the wells located in close proximity to the recharge areas were selected for data presentation. Source water data included for the analysis was generally available from the gage location used for source availability; additional data points were also utilized as available. Analysis included evaluation of geochemistry parameters such as hardness and pH. An additional analysis that was completed was a comparison of Langelier indices, or Langelier Saturation Indices (LSI), which indicate the potential for geochemical interactions. The Langelier index is calculated using hardness values to determine the potential for water to precipitate or dissolve calcium carbonate, a common component of groundwater aquifers. Overall, the highest scoring recharge regions had similar concentrations for parameters such as hardness and pH, and similar values for the Langelier index. The highest scoring recharge regions include: 12, 28.

Groundwater Quality

The groundwater quality criterion was assessed using the data available from USGS and EPA. The water quality within the aquifer is important to consider; both for how it could

impact the quality of the source recharged water and how it might be affected by it. For this criterion, data were utilized from the same wells that were utilized for the groundwater chemistry and clogging analysis. Water quality parameters evaluated included nutrients, bacterial contamination, high salinity or TDS, and any other common water quality parameter that could have a negative effect on the implementation of an AR project. Potential contaminants (compounds with a regulated drinking water maximum contaminant level or MCL) were also evaluated when data were available. As a conservative assumption, if a compound was not detected in the sample, the detection limit value was used in the analysis. The highest scoring recharge regions had similar groundwater and surface water parameter concentrations, and did not exceed MCLs. Recharge regions that received a high score included: 12, 19.

Source Water Quality

Source water quality analysis included an assessment of water quality data that was available for the recharge water source. Data were compiled from USGS and EPA online databases. Sample locations utilized in the analysis were the same as used for the groundwater chemistry and clogging analysis. The surface water quality analysis utilized the same suite of parameters that was utilized for groundwater quality. The highest scoring recharge regions had concentrations of parameters that closely matched that of the groundwater, and did not contain large concentrations of effluent or MCLs. The highest scoring recharge regions included: 9, 12, 15.

Hydrogeologic Suitability - Transmissivity

The transmissivity and hydraulic characteristics of an aquifer are important to a recharge project, as they provide an estimate of an aquifer's ability to receive or yield water. Characteristics such as hydraulic conductivity (K) and transmissivity (T), and storage coefficients (S, Sy) are important aspects to consider. Well yields are also important to consider for this criterion. Different criteria are necessary for alluvial and bedrock aquifers since hydraulic properties vary widely between alluvium and bedrock. However, unconfined bedrock aquifers behave similarly to alluvial aquifers, and thus are scored in the same manner. Transmissivity values between unconfined aquifers and alluvial aquifers were comparable. Only two recharge regions were present within confined bedrock aquifers. Scoring was completed by comparing the hydraulic characteristics among all of the recharge areas. Highest scoring recharge regions included: 2, 4, 6, 12, 15, 19, 21, 28, 30, 31, 42.

Residence Time

The residence time criterion is important to this analysis for determining the length of time recharged water can be stored prior to natural discharge or loss. If an aquifer is not capable of containing the recharged water for a long enough time period, losses to streams may negatively impact the project's success. Similar to transmissivity, residence time differs between alluvial and bedrock aquifers. For alluvial aquifers, the residence time is a function of aquifer properties and distance to discharge areas, such as a large stream or lake. For bedrock aquifers, the residence time differs between confined and unconfined areas. For the unconfined portions of bedrock aquifers, the proximity of

contact with alluvial aquifers or other discharge areas was analyzed. However, for confined portions, the residence time relies on distance to discharge areas or unconfined areas of the aquifer. The residence time for alluvial aquifers and unconfined bedrock aquifers was calculated using the Glover equation. Recharge regions that received a high score for residence time include: 2, 4, 12, 15, 19, 30, 42.

Cost – Capital

This criterion included an assessment of the ability to convey source water to a recharge region, as well as the likely method of recharge. Conveyance differences include use of pipelines to pump water to a recharge region versus ability to use gravity-fed ditches. This is determined by differences in elevation of the recharge region versus the location of the potential diversion; locations where the recharge area is higher in elevation than the source would require force main pipelines to transfer the water, leading to a higher cost. Another cost associated with construction is use of spreading basins versus existing wells. For this project it was assumed that existing wells could be retrofitted for use in the recharge pilot project. Spreading basins would likely be cheaper to install than new wells, although land acquisition may be a major factor in development of spreading basins and could drive the cost higher. It is anticipated that land costs away from municipalities would likely be lower. Based on these factors, spreading basins located far from municipalities received the highest scores, followed by retrofitted wells, spreading basins closer to municipalities, and finally installation of new wells. The recharge regions that received a high score include: 2, 8, 12, 30, 31.

Cost – O&M

This criterion included an assessment of the likely O&M costs associated with implementing a project at each recharge region. Key O&M costs would be associated with maintenance of wells or spreading basins, and pretreatment of water to be recharged. It is assumed that operation of spreading basins would likely be less costly than operation of wells, thus, higher scores were assigned to projects that would likely be able to utilize spreading basins. Recharge areas with high total suspended solids (TSS) concentrations in the source water would require filtration prior to injection and would negatively impacted project costs. The recharge regions that received a high score included: 30, 31.

Qualitative Factors

The qualitative considerations were most heavily influenced by the impact of the project on the total demand. This was evaluated by determining what portion of the local water provider's demand a pilot project could meet. Other factors include the desire of individual towns or cities to support recharge project, and any other information gathered that indicate a specific location may be better supported by the public. Work group feedback indicated local support and interest could be one of the most important factors in selecting a site, but would be difficult to assess without first evaluating potential sites on the other criteria. Scoring for this criterion was primarily based on the percent of demand that is met by the project, and highest scoring recharge regions included: 31, 42.

Demand Frequency

This criterion was intended to be used for determining whether an area's demand is primarily during the summer season versus over an entire year, and whether the hydrology of the recharge region matched the demand frequency. The preliminary screening identified seasonal demands, and all sites that were passed onto the detailed analysis have a seasonal component. Further analysis of demand frequencies for various towns in the 15 recharge regions indicated that there was very little variance between towns. This suggests that all recharge regions would have received the same score; thus, no analysis was completed for this criterion.

Regulatory Concerns

Regulatory concerns such as legal availability of water and constraints due to water quality were already considered through the availability of source water and water quality criteria. Thus, regulatory concerns did not receive a separate score. At the April 2010 work group meeting, it was brought up that regulatory concerns could impede the pilot project and the ODEQ was asked to provide their input into requirements they might have for permitting a pilot project. In addition, Wayne Kellogg noted that while the Ada water board was interested in such a project, there was concern that current permitting would not allow credit of recharged water, such that water withdrawn from the aquifer under the recharge program would count against existing groundwater permits. While not considered as a discriminator between recharge sites evaluated in this study because of the applicability to all sites, regulatory concerns remain an important aspect to consider before proceeding with a pilot project.

4.2 Scoring and Ranking

A raw score of 1 to 5, with 1 being not favorable and 5 being favorable were assigned to each recharge area for each of the criteria described above. Each score was then multiplied by the criteria weighting factor and summed to arrive at a final score. The scoring matrix is presented in Table 7. Details of the raw scoring are provided in a detailed appendix for each region. The weightings presented in Table 7 are proportional to the number of votes received at the January work group meeting (see Section 2.2) and scaled such that a maximum score is 100.

Table 7. Scoring Matrix (Sorted by Rank)

Recharge Region Number	Nearby Municipality	Source Availability	Demand Proximity	Source Proximity	Available Storage Volume	Demand Density	Source Water Quality	Native GW Quality	Geochemical Interactions	Transmissivity	Residence Time	Cost - O&M	Cost - Capital	Qualitative Considerations	Weighted Score
	weighting factor	*1.8*	*1.8*	*1.8*	*2.4*	*0.9*	*2.5*	*1.9*	*1.9*	*1.5*	*1.3*	*0.9*	*0.8*	*0.5*	
12	**Ada**	3	5	4	5	3	4	5	5	5	5	3	3	1	**85**
42	**Eakly**	3	5	3	5	2	3	4	3	5	5	3	2	5	**75**
19*	**Woodward**	3	5	2	5	4	1	5	3	5	5	3	1	2	**70**
2	**Woodward**	3	5	1	5	3	3	3	3	5	5	3	3	1	**69**
15	**Durant and Calera**	3	2	2	5	1	5	3	2	5	5	3	1	2	**66**
30*	**Enid**	3	5	1	5	4	1	3	2	5	5	5	3	1	**65**
4	**Weatherford**	2	5	3	5	5	1	2	3	5	5	2	1	3	**65**
28*	**Kingfisher and Hennessey**	4	5	5	1	2	1	3	4	5	1	3	1	4	**59**
6	**Marlow**	1	5	1	5	5	1	2	2	5	3	2	1	3	**55**
8	**Norman**	1	5	3	1	4	3	4	2	3	1	3	3	1	**53**
31*	**Cherokee**	3	5	1	1	2	2	1	2	5	3	4	3	5	**51**
21*	**Elk City**	2	5	1	1	1	1	2	3	5	1	3	1	2	**43**
9	**Shawnee and Seminole**	4	1	1	1	1	4	4	2	1	1	3	1	2	**43**

Note: sites 27 and 40 were not evaluated due to legal water availability constraints

Asterisk (*) denotes alluvial aquifer

As described in Section 2.2, the relative weights of the criteria were determined through the voting process at the January work group meeting. The weights are potentially biased by the participants at the work group meeting and by the fact that the voting was done after the preliminary screening identified recharge sites that had available water and preliminary level of hydrogeologic suitability. As a check on the sensitivity to the weightings determined through the voting process, the weightings were modified in several different ways, including weightings similar to those used in the Colorado Study and BOR study as presented in Table 4. Modifying the weights had little influence on the top ranked sites. Sites 12, 42 were the top two rated sites in all of the tested permutations of the weightings. Site 19 was the third ranked site in all but one of the tested permutations, in which it ranked fourth.

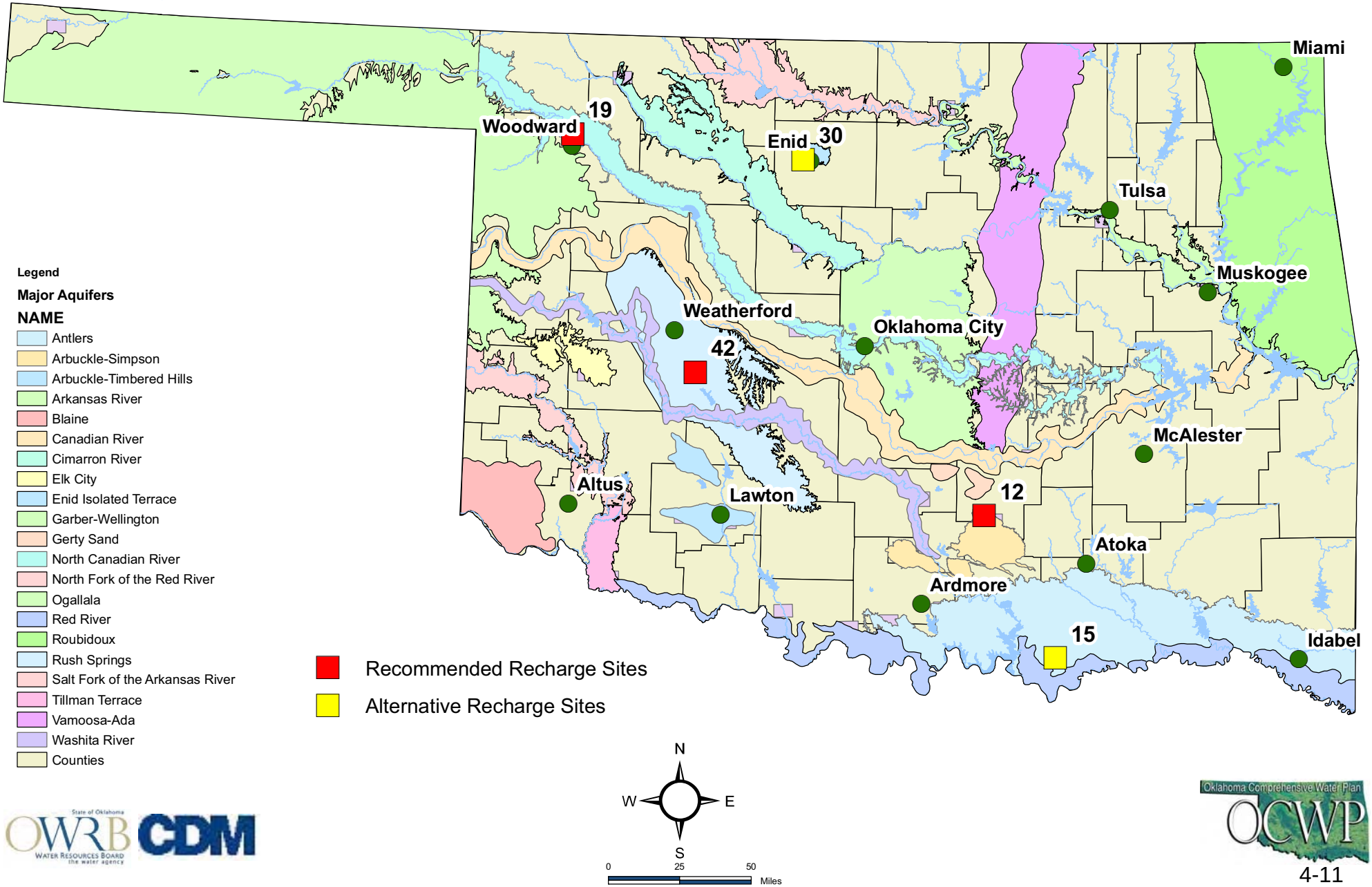
At the April 2010 work group meeting, CDM presented three short-listed sites (site 12, Ada; site 42, Eakly; site 19, Woodward). The meeting participants recommended expanding the recommended number of sites to include two alternates in case local interest is low or new information from follow-up investigations at the recommended sites reveals a limiting factor. The work group selected site numbers 15 (Durant) and 30 (Enid). These sites were added as alternatives because they were consistently in the top group of sites in the rankings under various criteria weightings tested at the work group meeting, and one is a bedrock aquifer (Site 15, Durant, Antlers aquifer) and the other is an alluvial aquifer that can utilize a lower-cost spreading basin (Site 30, Enid, Isolated Terrace Aquifer). The selected sites are shown in Figure 3.

4.3 Recommended Sites for Recharge Pilot Project

Recharge Region 12 (near Ada)

Recharge region 12 is located near the Town of Ada, with the Blue River providing a water source and the Arbuckle Simpson aquifer providing storage. The Blue River appears to provide adequate source, although the nearest gage is located approximately 17 miles downstream of the probable diversion location for a project. There are no upstream gages to help better quantify source availability, but based on basin size, the source location appears to have an adequate supply. The Town of Ada has existing PWS wells in the vicinity of the recharge region, making it a good candidate for a recharge project. Additionally, there is plentiful storage, and the residence time is appropriate for a pilot project. Given the channelized nature of the karst aquifer, specific site investigations would be required to ensure the recharged water could be recovered. The Blue River had minimal MCL exceedences, and low TDS concentrations, suggesting that pretreatment would not be required. Also, the Langelier indices for the Blue River and Arbuckle Simpson aquifer provided one of the closest pairings of all recharge regions. Perhaps the most negative aspect of Recharge Region 12 is the requirement of a pipeline to convey water from the source to the project site. However, the majority of recharge regions included this requirement, and most would require a longer pipeline than Recharge Site 12.

Figure 3. Recommended and Alternate Recharge Sites



Recharge Region 42 (near Eakly)

Recharge region 42 is located near the Town of Eakly, with Lake Creek providing a water source and the Rush Springs aquifer providing storage. Demand for the entire town is approximately 250 AFY, so a pilot project could potentially meet the entire demand for the town. Flows in Lake Creek are subject to regulation due to nearby Fort Cobb Reservoir, which may limit the supply availability; however the relatively small amount of water required for the project may be negligible compared to the reservoir yield requirements. Overall, Lake Creek appears to provide adequate source, even during drought years. The Town of Eakly has two existing PWS wells in the vicinity of the recharge region, making it a good candidate for a recharge project. Additionally, there is plentiful storage, and the residence time is appropriate for a pilot project. There was limited water quality data available from Lake Creek, but nearby Cobb Creek exceeded MCLs infrequently. Only one sample was collected from Cobb Creek for TDS, and it slightly exceeded the MCL. Thus, it is strongly recommended that further water quality characterization be completed prior to implementing a pilot project at this recharge region to help determine the need for pre-treatment. Pat Billingsley, representing the OCC, provided oil and gas well locations in the area. The nearest wells were over a mile from the recharge region and so were not considered to be detrimental to the site. Recharge Region 42 would also require a pipeline to convey water from the source to the project, and the pipeline is longer than that of Recharge Region 12.

Recharge Region 19 (near Woodward)

Recharge region 19 is located near the Town of Woodward, with the North Canadian River providing a water source, and the North Canadian alluvial terrace aquifer providing storage. The hydrogeologic characteristics of this site are very favorable for a recharge project, and this region is the only alluvial site of the three recommended sites, allowing for use of spreading basins instead of injection wells. Woodward provides an appropriate level of demand for a pilot project. In a representative low-precipitation year, there was approximately 90,000 AF a downstream gage. Supply for a pilot project scale (maximum of 1,000 AF) is most likely available, but could be tempered by Canton Reservoir's yield requirement. Native groundwater quality is good, but source water quality has exceeded MCL for several parameters in the past.

At the April work group meeting, it was suggested that the high TDS levels in the source water were isolated events from nearby oil and gas operations and water source quality may be better than the annual analysis indicated, especially during the high flow times of year when a recharge project would be operating. TDS measurements were examined on a monthly basis, and showed that TDS decreases in the higher flow months, but still exceeds the MCL in those months. Almost none of the TDS measurements for the site were below the MCL. The source water quality data thus indicate pre-treatment would be required before recharging the aquifer. A pipeline approximately 2 miles long would be required to bring water from the North Canadian River to the recharge location.

Alternate Recharge Region 15 (near Durant)

Recharge region 15 is located near the Town of Durant, with the Blue River providing a water source and the Antlers aquifer providing storage. The Blue River appears to provide adequate source, although the nearest gage is located approximately 8 miles downstream of the probable diversion location for a project. There are several tributary streams that enter the Blue River between the probable point of diversion and the downstream gage, but the majority of the basin lies upstream of that point, suggesting that flows associated with those tributaries likely do not have a large impact on the river. The representative low-precipitation year had flows greater than 120,000 AF, suggesting there is plentiful water for a project. Water quality data for both source and groundwater are generally good, although the geochemistry was unable to be effectively compared due to a lack of hardness data. One of the largest hindrances to a project is the proposed location and lack of infrastructure. There are no existing high-capacity wells in the vicinity of the proposed location, and the area is approximately 2 miles from both the Blue River and Durant. Thus, this location will require installation of ASR wells and construction of transfer pipelines.

Alternate Recharge Region 30 (near Enid)

Recharge region 30 is located near the Town of Enid, with Skeleton Creek providing a water source, and the Enid isolated terrace aquifer providing storage. The hydrogeologic characteristics of this site are very favorable for a recharge project, with injection wells nearby or the potential to use spreading basins instead of injection wells. The nearest gage is 7 miles downstream, and annual flow during the representative low-flow year was only approximately 16,000 AF. There may be issues with supplying the project during low-flow seasons. No surface water data was available for Skeleton Creek, suggesting that a monitoring program should be implemented prior to selection of the area for a project. Groundwater quality was relatively good, with few MCL exceedences. Skeleton Creek is located greater than 2 miles from the potential project location, but gravity flow ditches may be usable for water delivery, and the presence of nearby wells and potential for spreading basin use may lower project costs.

Section 5
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