GILLETTE MADISON PIPELINE PROJECT (GMPP)
TECHNICAL MEMORANDUM #5

TO: Mike Cole, P.E., City of Gillette

FROM: Darin Brickman, P.E., Burns & McDonnell
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DATE: July 20, 2010

JOB NO.: BMcD #54432, MMI #4776.001

RE: Water Quality and Blending Strategies

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ATTACHMENTS:

☐ **Urgent** ☐ **For Review** ☐ **Please Comment** ☐ **Please Reply** ☐ **For Your Use**

INTRODUCTION AND BACKGROUND

The purpose of this technical memorandum is to provide a general discussion of the water quality issues related to the expanded Gillette water system. The issues that will be presented include historic water quality, potential future water quality that may result from various blending approaches, and relative affect of the blending approaches and future demands on distribution system water quality. Mass balance water quality modeling of the physical facilities will be completed a later date.

The City of Gillette currently utilizes 26 groundwater wells to provide potable water to customers. Ten (10) of the wells are connected in the Madison aquifer and 16 wells are connected in the Fort Union and Fox Hills/Lance aquifers. The well water quality varies and as such, the City currently utilizes blending to meet the City's overall water quality objectives. These objectives can generally be defined as meeting the United States Environmental Protection Agency's (USEPA) enforceable primary regulations to control public health as well as

the non-enforceable secondary regulation for fluoride at 2 mg/L. Other secondary standards and aesthetic water quality parameters are considered in the current blending strategy and will be considered in future operational plans.

All in-town Fort Union and Fox Hills/Lance wells pump into raw water collection piping which ultimately discharges to Pump Station #1 (PS1) where the water is then air stripped, chlorinated, and discharged into the City's water distribution system via a transmission line. The Madison supply enters the city's system via a transmission line on the east side of the service area. The PS1 transmission line and the Madison transmission line connect near the intersection of US Highway 14/16 and S. Butler Spaeth Road. The combined or blended flow is then discharged via a transmission line to storage reservoir Z1R3 located on Dump Hill. Water subsequently enters the distribution system where all other storage reservoirs are supplied. Water quality is therefore currently dictated by the initial blended water quality at the blending point near US Highway 14/16 and S. Butler Spaeth Road. If any portions of the distribution system are unknowingly fed from transmission lines (e.g., well transmission lines that discharge to PS1), the connections would affect the water quality in the following analysis.

Technical Memorandum #3 presents a detailed discussion of the existing well field capacities as well as the required new system capacity for the study period. That document compares the findings of the 2007 City of Gillette Long-Term Water Supply, Level II Study by MMI/Burns & McDonnell (Level II) and the 2009 Gillette Regional Master Plan Level II Study by HDR (GRMP). Technical Memorandum #3 indicates that the existing groundwater source average and peak capacities are as indicated in Table 1.

Table 1. Existing Gillette Groundwater Source Production Capacity Summary

Groundwater Source	Average Day		Peak Day	
	Capacity (gpm)	Capacity (MGD)	Capacity (gpm)	Capacity (MGD)
Fort Union[1,2]	930	1.34	1,906	2.74
Fox Hills/Lance[3]	0	0	0	0
Madison[4]	6,565	9.45	6,565	9.45
Total	**7,495**	**10.79**	**8,471**	**12.19**

Notes:
1. Fort Union average capacity is limited by annual SEO cap, not system capacity.
2. Fort Union peak capacity is limited by firm capacity of the well system.
3. The Fox Hills/Lance source will not be used as a primary groundwater source.
4. Madison capacity is limited by the firm capacity of the well field

Technical Memorandum #3 also presents the required new system capacity which will be met by the firm capacity of the new Madison system. The proposed Madison well field expansion includes the addition of high-capacity Madison wells to meet projected water demands. As indicated in Technical Memorandum #3, the new Madison well field will require an additional 23.1 MGD, or 16,000 gpm, of firm capacity in order to meet the projected study period demands.

This technical memorandum discusses the water quality from each groundwater source and the future water quality resulting from expansion of the Madison groundwater supply as well as the reduced reliance on Fort Union and Fox Hills wells. Based on historically observed water quality and previous reports, the water quality parameters of concern are fluoride, hardness, total dissolved solids (TDS), and sulfate. Only fluoride is a concern for meeting the primary standard of 4.0 mg/L while all of the parameters require management to meet the secondary standard or city-specific water quality goals.

WATER QUALITY

As seen from the data in Table 2, the source water from the City of Gillette's Fort Union, Fox-Hills, and Madison wells vary in water quality.

Table 3 includes a summary of the different water sources with the weighted average water quality. Since the average sodium and iron from each water source are below the secondary standards they have been not considered in the following analysis. The analysis focuses on fluoride, TDS, hardness, and sulfate. For the purposes of this analysis, the new Madison wells are assumed to have the same water quality as the existing Madison wells.

The Fort Union well water quality is low in TDS, sulfate, and hardness in relation to the other wells. The Fox Hills well water quality is high in fluoride and TDS while it is low in hardness in relation to the other wells. The Madison well water quality is low in fluoride but is high in hardness and sulfate in relation to the other wells.

As indicated previously, based on historically observed water quality and previous reports, the water quality parameters of concern are fluoride, hardness, total dissolved solids (TDS), and sulfate. Table 4 summarizes the United States Environmental Protection Agency's (USEPA) enforceable primary regulations as well as the non-enforceable secondary regulations or water quality goals applicable to the City of Gillette water system.

The USEPA non-enforceable secondary regulations are only recommendations and are not enforceable. The regulations are in place to improve the water's aesthetic quality. The USEPA has not recently discussed changing any of the secondary water regulations discussed in this technical memorandum (TDS, sulfate, iron, sodium, and hardness) to primary water regulations. Although the secondary water regulations are not enforceable the USEPA has a requirement to report water constituents based on the unregulated contaminant monitoring requirement.

Table 2. Existing City of Gillette Well Water Quality

Number	Capacity[1] gpm	Fluoride[3] mg/L	TDS[3] mg/L	Hardness[3] mg/L as $CaCO_3$	Sulfate[2] mg/L	Sodium[2] mg/L	Iron[3] mg/L
Existing Wells – Fort Union designated as S-##							
S-9	250	1.10	346	49	0	114	0.13
S-12	250	1.37	359	14	1	105	0.20
S-17	250	3.90	875	15	0	399	0.04
S-18	200	1.30	322	2	1	97	0.14
S-19	200	1.10	262	2	1	96	0.06
S-20	400	1.10	450	43	0	150	0.17
S-21	90	3.00	655	19	ND	302	0.22
S-22	60	5.40	312	32	ND	143	0.43
S-23	70	2.40	490	13	ND	229	0.13
S-24	150	2.40	528	28	ND	238	0.11
S-25	86	4.00	746	16	ND	342	0.11
S-26	100	1.40	274	27	ND	129	0.87
S-27	200	2.80	558	20	ND	214	0.43
Total Capacity	**2,306**						
Weighted Average Water Quality		**2.03**	**471**	**24**	**0**	**185**	**0.20**
Existing Wells – Fox Hill/Lance designated as FH-#							
FH-3	650	9.40	1,280	ND	2	541	0.20
FH-4	500	7.00	1,240	ND	26	526	0.10
FH-5	500	6.00	1,030	ND	44	450	1.94
Total Capacity	**1,650**						
Weighted Average Water Quality		***7.64***	***1,192***	***0***	***24***	***506***	***0.75***
Existing Wells – Madison designated as M-##							
M-1	569	1.10	672	500	314	10	0.05
M-2	805	0.66	624	476	260	5	0.03
M-3	932	0.68	590	503	257	2	0.03
M-4	781	0.64	608	478	262	5	0.03
M-5	622	2.03	678	493	319	9	0.10
M-6	616	1.69	714	521	326	7	2.54
M-7	542	1.57	654	494	295	5	0.05
M-8	539	1.22	724	482	275	7	0.18
M-9	1,169	0.63	581	470	262	5	0.03
M-10	1,159	0.63	601	470	261	2	0.04
Total Capacity	**7,734**						
Weighted Average Water Quality		***0.97***	***632***	***486***	***278***	***5***	***0.25***

Notes:

1. Capacity for wells S-9, S-17, S-18, S-19, and S-27 are estimated future capacities after "re-drilling" activities. For the purposes of this analysis, the water quality of these wells is assumed to be the same after re-drill as before the re-drill.
2. Data Source: December 2004 City of Gillette Water Master Plan Report
3. Data Source: August 2007 City of Gillette Long Term Water Supply Level II Study

Table 3. Summary of Well Water Quality Data

Well Identification	Total Capacity (gpm)	Fluoride (mg/L)	TDS (mg/L)	Hardness (mg/L as $CaCO_3$)	Sulfate (mg/L)
Fort Union	2,306	2.03	471	24	0
Existing Fox Hill/Lance	1,650	7.64	1,192	0	24
New/Existing Madison	23,987	0.97	632	486	278

Table 4. Gillette Water Quality Standards or Goals

Parameter	Primary Standard (mg/L)	Secondary Standard (mg/L)	Water Quality Goal (mg/L)
Fluoride	4.0	2.0	2.0
Hardness	--	--	500
TDS	--	500	500
Sulfate	--	250	250
Iron	--	0.3	0.3
Sodium	--	250	250

WATER DEMAND

The system water demand during the different time periods will dictate the water sources that will be utilized to provide customers with an adequate supply of water. The GRMP projected various demands. For the purposes of this analysis, various interim demands were used for water quality comparison purposes. Table 5 shows the source water demand projections for the City of Gillette between 2010 and 2040.

Table 5. Projected Water Demand

Year	Minimum Day Demand (gpm)	Average Day Demand (gpm)	Peak Day Demand (gpm)
2010[2]	2,200	4,500	14,000
~2020[2]	2,700	5,400	17,500
~2030[2]	3,200	6,400	21,000
2040[1]	3,717	7,155	24,500

Source:
1. Technical Memorandum #3
2. 2007 City of Gillette Long-Term Water Supply, Level II Study

As the water demand increases and given the fixed capacity of the Fort Union wells, the City of Gillette will be required to increase reliance on the Madison source. Reviewing the 2007 through 2009 well pumping data, the City typically operates the Fort Union and Fox Hills wells at approximately 700 gpm throughout the year. Further, the Fox Hills wells were operated very little compared to the Fort Union wells. The analysis contained herein assumes that the Fort

Union wells are operated at 700 gpm at the minimum day demand and the Fox Hills wells will not be operating during any demand scenarios. It is assumed that the remaining demand would be provided by the Madison source.

Given that the existing hydraulic firm capacity of PS1 is 2,620 gpm (1,750 gpm process firm capacity) and considering the overall water quality of the Fort Union supply, the demand supplied by PS1 will effectively be provided by the Fort Union source. The maximum water production from the Fort Union supply is approximately 930 gpm on an average day basis and 1,906 gpm on a peak day basis. This is due to the 1500 ac-ft/year restriction placed on the Fort Union maximum productions by the State Engineer's Office. This is discussed in Technical Memorandum 3. It is assumed that the remaining demand would be provided by the Madison source.

FUTURE WATER QUALITY

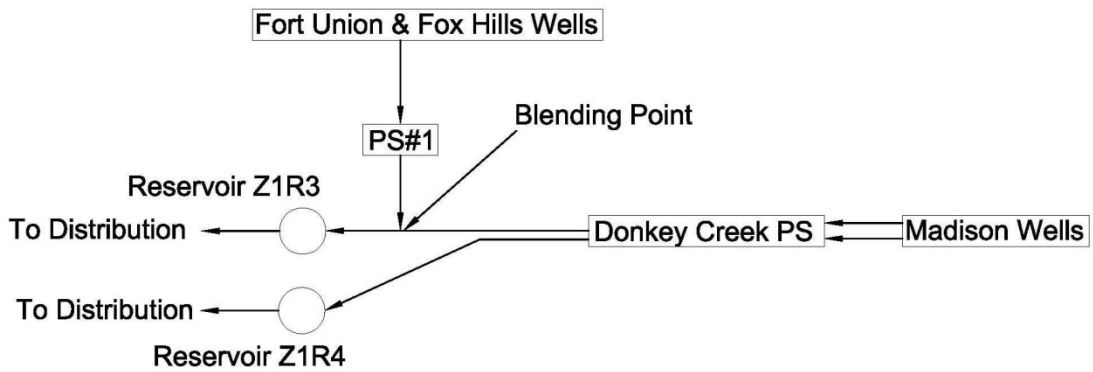
Depending on the method of supplying water to the distribution system, the water quality in the distribution system will vary. Two alternatives were analyzed using a mass-balance approach to determine the water quality at the end of the transmission lines and prior to entering the distribution system. A spreadsheet-type model was prepared and it contains detailed water quality and capacity information for each well. In the model the flow contributions are adjusted from each well and a resulting water quality is calculated.

Note that if water from other sources not analyzed in this technical memorandum such as Sleepy Hollow or Antelope Valley is ever introduced into the system, the overall water quality would be affected depending on the connection point of these additional sources. The following two scenarios would need to be considered if additional water sources are incorporated in the overall system:

- The City of Gillette could choose to allow the introduction of these water sources near their source (e.g., Sleepy Hollow wells discharge into transmission line near the location of the Sleepy Hollow wells) knowing that changes in water quality would result.
- The City of Gillette could choose to bring the water source to whichever blending point results from this project via new pipeline facilities. This would require additional capital expense but would again provide consistent water quality throughout the system.

Alternative 1 assumes that Reservoir Z1R4 (Southern) will be supplied solely by Madison water and that Reservoir Z1R3 (Dump Hills) will be supplied by a blend of Madison water and Fort Union water (i.e., in-town wells). The existing blending point at US Highway 14/16 and S. Butler Spaeth Road would be maintained as it currently exists and the new Madison parallel transmission line would follow the proposed routing and discharge to Z1R4. See Figure 1 for Alternative 1 layout.

Figure 1. Alternative 1 Layout



The transmission line to Reservoir Z1R4 is currently anticipated to be a 42-inch diameter pipeline while the existing pipeline to the blending point is a 30-inch diameter pipeline. For reasons discussed in technical memorandum #8, a design capacity of 8,000 gpm will be used for the existing 30-inch diameter pipeline. The new transmission line will be designed to provide the difference between the Madison supply and the existing Madison 30-inch diameter transmission line capacity of 8,000 gpm. There is the possibility that the existing 30-inch diameter transmission line could be operated at reduced flow rates.

For the purposes of this technical memorandum, it is assumed that 35% of the Madison water will be routed to the existing blend point and 65% of the Madison water will be routed to Reservoir Z1R4 to proportion the flow as discussed in Technical Memorandum #8. Once further modeling is performed in Technical Memorandum 7, the percentage of flows may be revised accordingly.

The water quality in Reservoir Z1R4 will be the same as the Madison wells as indicated in Table 6. The water quality in the Reservoir Z1R3 will depend on the water demand. Table 7 presents the water quality in Reservoir Z1R3 at different water demands.

Table 6. Alternative 1 - Water Quality in Reservoir Z1R4

Year	Fluoride mg/L	Hardness mg/L as $CaCO_3$	TDS mg/L	Sulfate mg/L
All Demands				
2010	0.97	486	632	278
2020	0.97	486	632	278
2030	0.97	486	632	278
2040	0.97	486	632	278

Notes:
3. Refer to Table 5 for the projected water demand

Table 7. Alternative 1 - Water Quality in Reservoir Z1R3

Year	Total Demand	Madison Supply	Fort Union Supply	30-inch Line Demand	42-inch Line Demand	Fluoride	Hardness	TDS	Sulfate
	gpm	gpm	gpm	gpm	gpm	mg/L	mg/L as $CaCO_3$	mg/L	mg/L
Minimum Demand									
2010	2,200	1,500	700	525	975	1.58	222	540	119
2020	2,700	2,000	700	700	1,300	1.50	255	551	139
2030	3,200	2,500	700	875	1,625	1.44	280	560	154
2040	3,717	3,017	700	1,056	1,961	1.39	302	568	167
Average Demand									
2010	4,500	3,570	930	1,250	2,321	1.42	289	563	159
2020	5,400	4,470	930	1,565	2,906	1.37	313	572	174
2030	6,400	5,470	930	1,915	3,556	1.32	335	579	187
2040	7,155	6,225	930	2,179	4,046	1.29	348	584	195
Peak Demand									
2010	14,000	12,094	1,906	4,233	7,861	1.30	342	582	191
2020	17,500	15,594	1,906	5,458	10,136	1.25	366	590	206
2030	21,000	19,094	1,906	6,683	12,411	1.21	383	596	216
2040	24,500	22,594	1,906	7,908	14,686	1.18	396	600	224

Notes:
1. Refer to Table 5 for the projected water demand

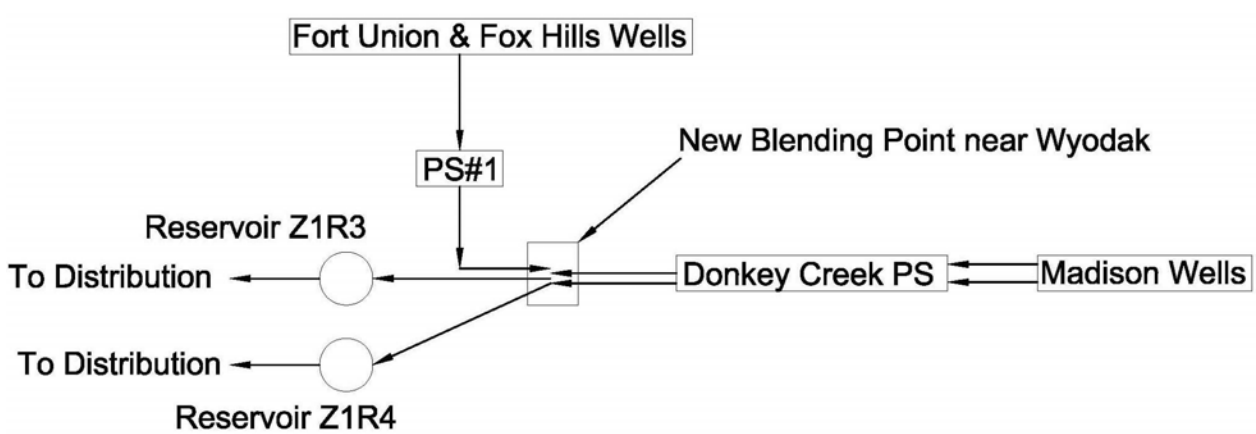
Table 8 shows the difference between the water quality in the two reservoirs at the minimum, average, and maximum demand. As seen from Table 8, as the water demand increases, the difference in water quality between reservoirs will start to decrease due to a greater reliance on the Madison aquifer water supply. From the minimum demand in 2010 to the maximum demand in 2040, the difference in fluoride concentration decreases from 0.60 to 0.20 mg/L and the difference in hardness decreases from 264 to 90 mg/L as $CaCO_3$.

Table 8. Alternative 1 – Difference in Water Quality between Reservoirs.

Year	Fluoride	Hardness	TDS	Sulfate
	mg/L	mg/L as $CaCO_3$	mg/L	mg/L
Minimum Demand				
2010	0.60	264	92	158
2020	0.53	231	80	139
2030	0.47	205	71	123
2040	0.42	184	64	111
Average Demand				
2010	0.45	197	68	118
2020	0.39	172	60	103
2030	0.34	151	52	91
2040	0.32	138	48	83
Maximum Demand				
2010	0.33	144	50	86
2020	0.27	120	42	72
2030	0.23	103	36	62
2040	0.20	90	31	54

Alternative 2 assumes that transmission modifications would be completed to facilitate the blending of in-town well water into the new parallel transmission line at a location near the Wyodak Power Plant. Reservoirs Z1R3 and Z1R4 would be supplied by a blend of Madison water and Fort Union water. Refer to Figure 2 for an illustration of Alternative 2.

Figure 2. Alternative 2 Layout



If the water is blended before the water splits to the reservoirs a substantial amount of additional pipelines and a new blending structure will be required since the existing transmission system does not provide this capability. The new blending point would be located where the water

splits between Reservoir Z1R3 and Z1R4, near Wyodak and HWY 51. This blending alternative would require an additional 18" PVC pipeline for approximately five miles and the capital and maintenance cost of the blending structure. This cost would be substantial, as such, Alternative 2 would require additional capital funds that are not currently within the identified capital plan. Table 9 presents the water quality in the reservoirs if the water is blended before splitting to the reservoirs.

Table 9. Alternative 2 – Water Quality throughout the City

Year	Total Demand	Madison Supply	Fort Union Supply	Fluoride	Hardness	TDS	Sulfate
	gpm	gpm	gpm	mg/L	mg/L as $CaCO_3$	mg/L	mg/L
Minimum Demand							
2010	2,200	1,500	700	1.31	339	580	189
2020	2,700	2,000	700	1.25	366	590	206
2030	3,200	2,500	700	1.20	385	596	217
2040	3,717	3,017	700	1.17	399	601	225
Average Demand							
2010	4,500	3,570	930	1.19	389	598	220
2020	5,400	4,470	930	1.16	405	604	230
2030	6,400	5,470	930	1.13	418	608	237
2040	7,155	6,225	930	1.11	425	611	242
Peak Demand							
2010	14,000	12,094	1,906	1.12	421	610	240
2020	17,500	15,594	1,906	1.09	434	614	247
2030	21,000	19,094	1,906	1.07	443	617	252
2040	24,500	22,594	1,906	1.06	449	619	256

Hardness is the primary water quality concern related to blending, accordingly, Table 10 shows the difference in hardness between Alternative 1 and 2 at the minimum, average, and maximum demand. As seen from Table 10, as the water demand increases, the difference in water quality between reservoirs will decrease due to a greater reliance on the Madison aquifer water supply.

Table 10. Comparison of Hardness (mg/L as $CaCO_3$) between Alternatives

Year	Alternative 1		Alternative 2	Difference between Alternative 1 & 2	
	Z1R4	Z1R3	Z1R4 & Z1R3	Z1R4	Z1R3
Minimum Demand					
2010	486	222	339	-147	117
2020	486	255	366	-120	111
2030	486	280	385	-101	104
2040	486	302	399	-87	97
Average Demand					
2010	486	289	389	-97	101
2020	486	313	405	-81	92
2030	486	335	418	-68	83
2040	486	348	425	-61	77
Maximum Demand					
2010	486	342	421	-65	79
2020	486	366	434	-52	68
2030	486	383	443	-43	59
2040	486	396	449	-37	53

Note: Negative numbers indicate a reduction in hardness from Alternative 1 to Alternative 2

As seen from Table 10, if Alternative 2 is chosen compared to Alternative 1, the hardness in reservoir Z1R4 would be decreased by 60 to 100 mg/L during average demand and the hardness in reservoir Z1R3 would be increased by 70 to 100 mg/L during average demand.

CONCLUSIONS

The following are the conclusions of the analysis of blending the Fort Union and Madison wells:

- As seen in Table 8, as the water demand increases, the difference in water quality between reservoirs will decrease due to a greater reliance on the Madison aquifer water supply.
- As seen from the tables throughout this technical memorandum, the primary and secondary water quality standard are being met with Alternative 1 and Alternative 2 except for sulfate which is over the secondary standard for both alternatives
- If Alternative 2 is chosen, the project would require a significant amount of funding for design and construction of an additional 18" PVC pipeline for approximately five miles and the capital and maintenance cost of the blending structure. As such, Alternative 2 would require additional capital funds that are not currently within the identified capital plan.
- The difference in hardness achieved by adjusting the blending location is negligible when considering these levels of hardness. As such, consideration should be taken to determine if a significant amount of funds should be used for such a negligible change in hardness for the customers.