Chapter 5

Multi-Barrier Approach Alternatives

The integration of source water protection and treatment technologies into multi-barrier water delivery approaches for BRWTF is detailed in this chapter. Additional conceptual improvements recommended in the Phase I Source Water Protection Study and Predesign Report including full containment from Carter Lake to BRWTF, UV light disinfection, membrane filtration, ozone, and GAC were considered here. Barriers for microbial pathogen control listed in the LT2ESWTR Microbial Toolbox (Table 3-4) were also considered in this study. *However, not all of the City's drinking water quality goals were fully satisfied by all multi-barrier water delivery alternatives evaluated, primarily due to compelling economic considerations.*

A. Conceptual Improvement Screening

Conceptual improvements that could be included in a multi-barrier water delivery alternative at BRWTF were screened for applicability based on several factors including integration with the existing treatment process train, probable performance, and economic considerations. Potential conceptual improvements were evaluated based on their ability to address one or more of the contaminant barriers identified in Chapter 3 including microbial pathogens, DBPs, organic micropollutants, manganese, taste and odor, and TDS and sulfate. The general strategy of the screening process was to give greater consideration to conceptual alternatives that where possible addressed more than one contaminant barrier, thereby minimizing the number of conceptual improvements and complexity of proposed multi-barrier water deliver alternatives.

1. Source Water Protection

Full containment from Carter Lake to BRWTF was the only source water protection improvement considered in this study. Other strategies such as large scale improvements to stormwater diversion along BFC or around Boulder

Reservoir, BFC road crossings, and hydraulic structures were not recommended in the Phase I source water protection study, and were beyond the scope of this study.

2. Prefiltration

Prefiltration options in the LT2ESWTR Microbial Toolbox, including pre-sedimentation, two-stage lime softening, and bank filtration, receive low inactivation/removal credit were not selected for inclusion in multi-barrier alternatives. These treatment processes could provide an additional minimal barrier for pathogens, but would not generally provide substantial additional barriers for other contaminant categories. Because of the mineralized soils that contribute to manganese and TDS increases while raw water is held in Boulder Reservoir, bank filtration could even lead to raw water quality degradation.

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3. Treatment Performance

Combined filter effluent and individual filter effluent performance credit was considered an effective component of any multi-barrier treatment alternative. These options assign additional *Cryptosporidium* log-inactivation/removal credit based on maintaining filter turbidity levels below target values, thus require no additional treatment processes. BRWTF has a treatment process optimization program in place, so additional contaminant barrier credit based on demonstration of further enhanced performance is likely, and was considered in this study.

4. Additional Filtration

Additional filtration technologies including bag or cartridge filters, second stage granular media filtration, and slow sand filtration were not included in multi-barrier water delivery alternatives evaluated in this study. As with the prefiltration options previously discussed, these additional filtration options would provide only marginally increased log-inactivation/removal credit for *Cryptosporidium*, and provide little in the way of additional barriers for other contaminant categories. The hydraulic profile of the existing BRWTF would also not accommodate additional filtration without substantial supplemental pumping, increasing O&M costs. The limited benefit of these additional filtration to finished

water quality of the well designed and operated full-conventional treatment provided by the existing BRWTF were not viewed as sufficient to justify the associated large capital cost, increased O&M costs, and additional filter backwash/cleaning requirements. However, due to the relatively high log-removal credit possible with low-pressure membrane filtration, it was included as a treatment process option in the BRWTF multi-barrier water delivery alternatives evaluated.

5. Oxidation/Inactivation

Chemical oxidation can potentially provide additional barriers for microbial pathogens, DBPs, organic micropollutants, manganese, and objectionable tastes and odors, depending on the oxidant used and its point of application. Addition of chlorine dioxide for DBP, manganese, and taste and odor control is included in the City's mid-term improvements plan, and is therefore assumed as part of the baseline treatment for the long-term improvements evaluated here. Ozone was also evaluated in this study because of its superior performance for taste and odor control, ability to oxidize many organic micropollutants, and additional pathogen inactivation. UV disinfection was also evaluated due to its superior disinfection performance for bacteria, viruses, and protozoan pathogens. These treatment processes result in relatively low headloss, simplifying their integration with the existing hydraulic profile at BRWTF.

6. GAC Adsorption

Granular activated carbon was evaluated in this study based on additional barriers for DBPs, organic micropollutants, and objectionable tastes and odors that it may provide. Although GAC adsorption has headloss restrictions similar to the filtration technologies previously considered, the multiple potential finished water quality benefits that it may provide were viewed as sufficient to warrant the added complexity and cost of integrating this process into the existing BRTWF hydraulic profile.

B. Grouping Conceptual Improvements into Alternatives

Candidate multi-barrier approaches were developed for BRWTF by combining conceptual improvements that address identified drinking water quality

vulnerabilities in source water conveyance to and treatment at BRWTF. Only those conveyance and treatment barriers that were selected in the screening process previously described were included in BRWTF multi-barrier alternatives. The combination of conceptual improvements selected for each delivery alternative was based on providing process redundancy and operational continuity at BRWTF.

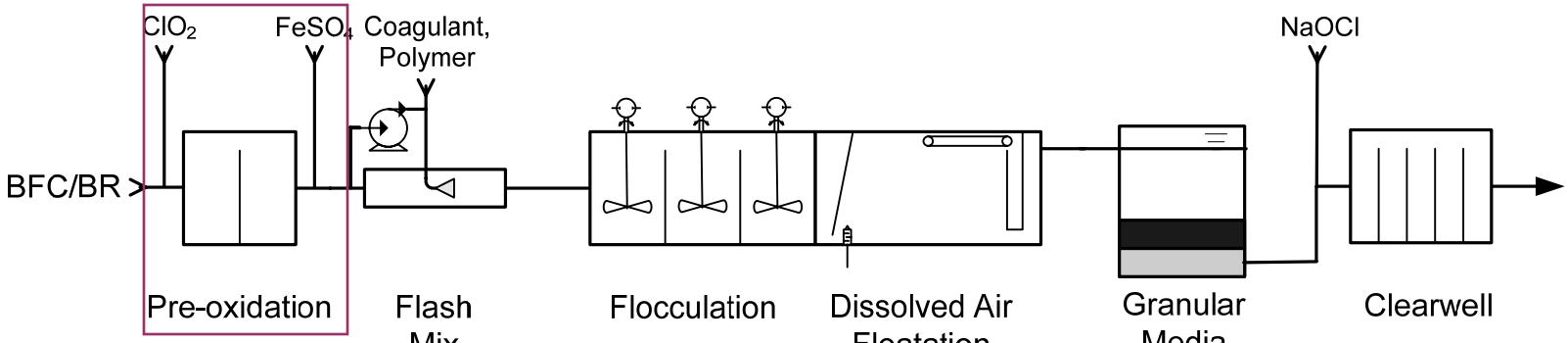
Not all possible combinations of screened barriers were included in alternative evaluations, but each screened barrier was incorporated in at least one water delivery alternative. The multi-barrier delivery alternatives developed for this study would produce finished water that meets all current state and federal drinking water standards; however, it is important to note that not all of these alternatives continuously meet the City's drinking water goals as discussed below.

1. BFC and Boulder Reservoir Seasonal Delivery Alternatives

Five water delivery alternatives that provide seasonal raw water delivery to BRWTF through BFC or by pumping from Boulder Reservoir were developed, as shown schematically on Figures 5-1 through 5-5. Each of these delivery alternatives is based on the existing conventional treatment at BRWTF and residual disinfection with free chlorine. In addition, chlorine dioxide preoxidation added as part of the ongoing mid-term improvements program was also assumed.

- Alternative 1: This water delivery alternative incorporates preoxidation with chlorine dioxide followed by full conventional treatment and free chlorine disinfection. A centralized contact basin for preoxidation contact time is included to allow use of both BFC and Boulder reservoir raw water sources. Presedimentation for turbidity and suspended solids control would also be provided by the preoxidation contact basin, but because no coagulant would be added prior to basin contact no credit towards *Cryptosporidium* treatment would be provided. Residual chlorine dioxide and chlorite would be quenched by ferrous sulfate addition prior to coagulation.

  This barrier combination serves as the baseline BRWTF multi-barrier water delivery alternative. *This baseline alternative would not meet the City's water quality goals with respect to*



Mid-term Improvement

Primary MCL	Microbial Pathogens	✓	✓	✓	✓
	Disinfection Byproducts	✓	✓	✓	
	Micro-Pollutants				
Secondary MCL	Manganese	✓		✓	
	Taste and Odor	✓			
	TDS and Sulfate				

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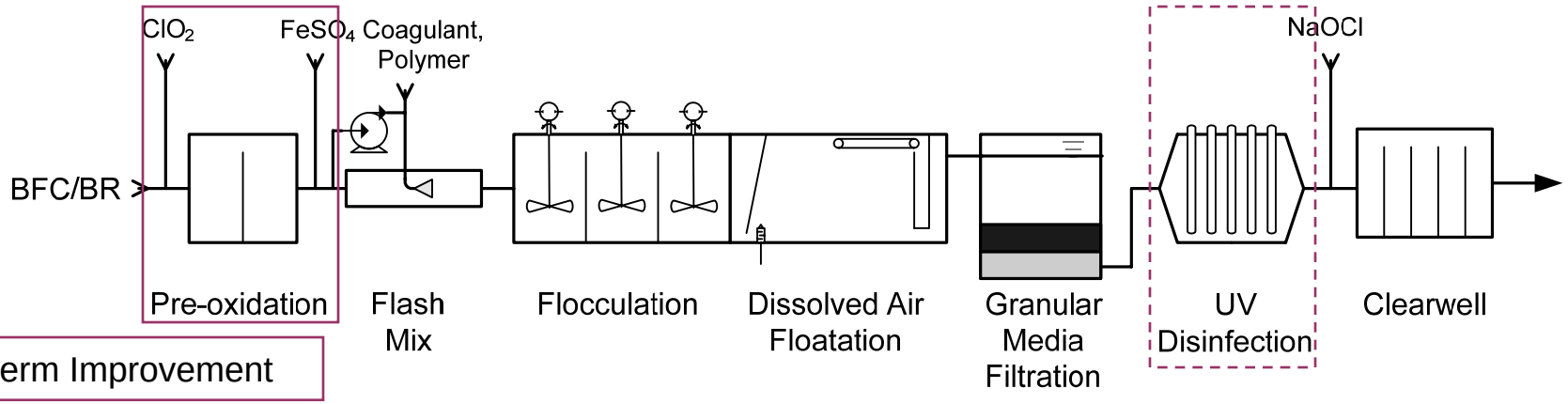
Alternative 1: Boulder Feeder Canal/Boulder Reservoir Seasonal Delivery with ClO_2 Pre-oxidation

Figure 5-1



Mid-term Improvement

Long-term Improvement

Primary MCL	Microbial Pathogens	✓	✓	✓	✓	✓
	Disinfection Byproducts	✓	✓	✓		
	Micro-Pollutants					
Secondary MCL	Manganese	✓		✓		
	Taste and Odor	✓				
	TDS and Sulfate					

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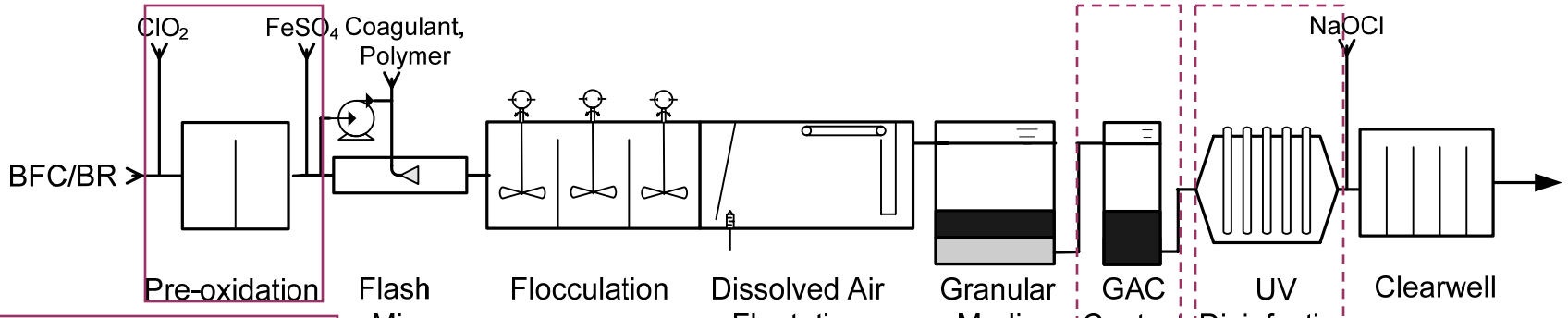
Alternative 2: Boulder Feeder Canal/Boulder Reservoir Seasonal Delivery with ClO_2 Pre-oxidation and UV Disinfection

Figure 5-2



Primary MCL	Microbial Pathogens	✓	✓	✓		✓	✓
	Disinfection Byproducts	✓	✓	✓	✓		
	Micro-Pollutants				✓		
Secondary MCL	Manganese	✓		✓			
	Taste and Odor	✓			✓		
	TDS and Sulfate						

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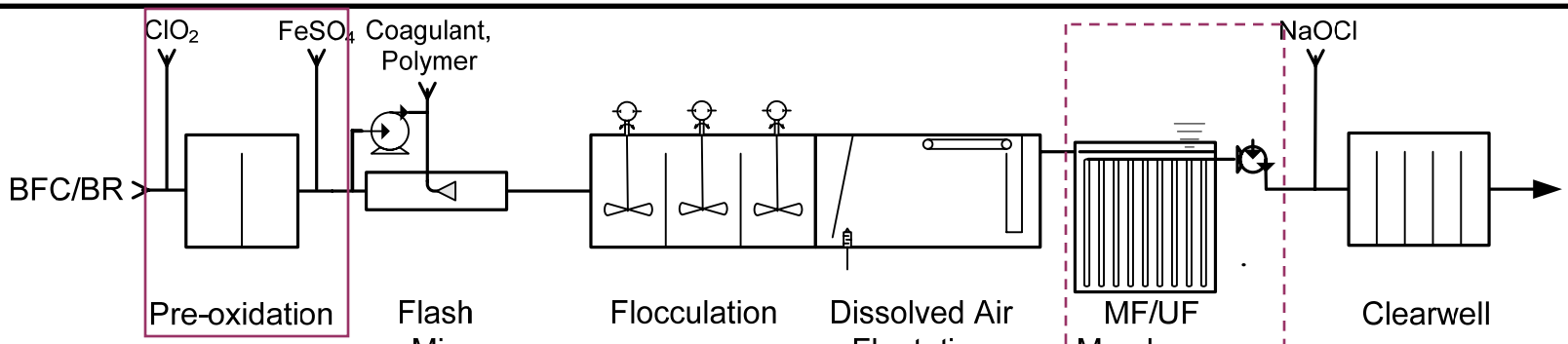
Alternative 3: Boulder Feeder Canal/Boulder Reservoir Seasonal Delivery with ClO_2 Pre-oxidation, GAC Adsorption and UV Disinfection

Figure 5-3



Mid-term Improvement

Long-term Improvement

Primary MCL	Microbial Pathogens	✓	✓	✓	✓
	Disinfection Byproducts	✓	✓	✓	
	Micro-Pollutants				
Secondary MCL	Manganese	✓		✓	
	Taste and Odor	✓			
	TDS and Sulfate				

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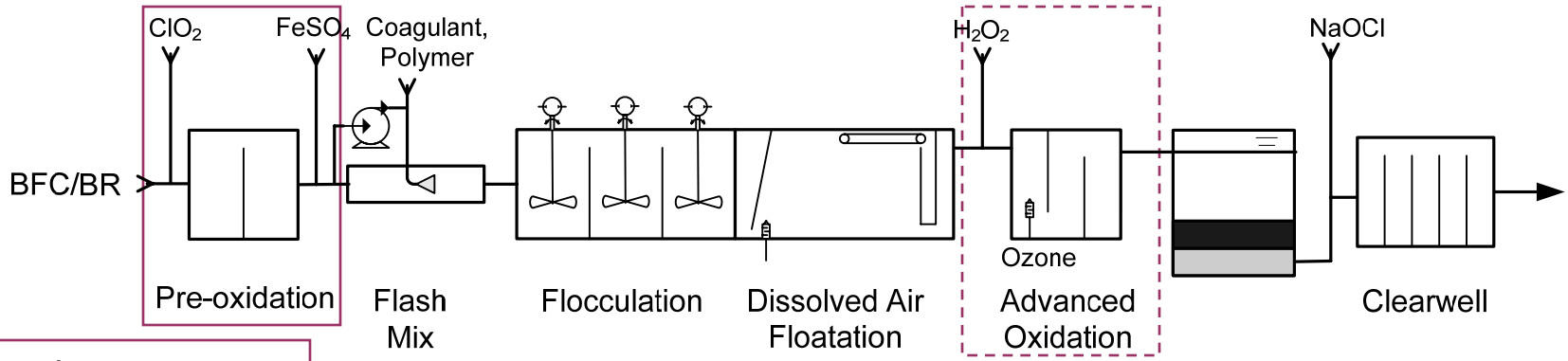
Alternative 4: Boulder Feeder Canal/Boulder Reservoir Seasonal Delivery with ClO_2 Pre-oxidation and Submerged MF/UF

Figure 5-4



Mid-term Improvement

Long-term Improvement

Primary MCL	Microbial Pathogens	✓	✓	✓	✓	✓
	Disinfection Byproducts	✓	✓	✓	✓	
	Micro-Pollutants			✓		
Secondary MCL	Manganese	✓		✓	✓	
	Taste and Odor	✓		✓		
	TDS and Sulfate					

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Alternative 5: Boulder Feeder Canal/Boulder Reservoir Seasonal Delivery with ClO_2 Pre-oxidation and Advanced Oxidation

Figure 5-5

pathogen control, nor would it meet finished water TDS and sulfate goals when raw water is provided from Boulder Reservoir. No effective barrier for organic micropollutant control is provided by this alternative.

- Alternative 2: This alternative incorporates UV disinfection with the barriers provided by Alternative 1. *This delivery alternative would not meet the City's TDS and sulfate water quality goals when Boulder Reservoir was online, nor would it provide an effective barrier for organic micropollutant control.*

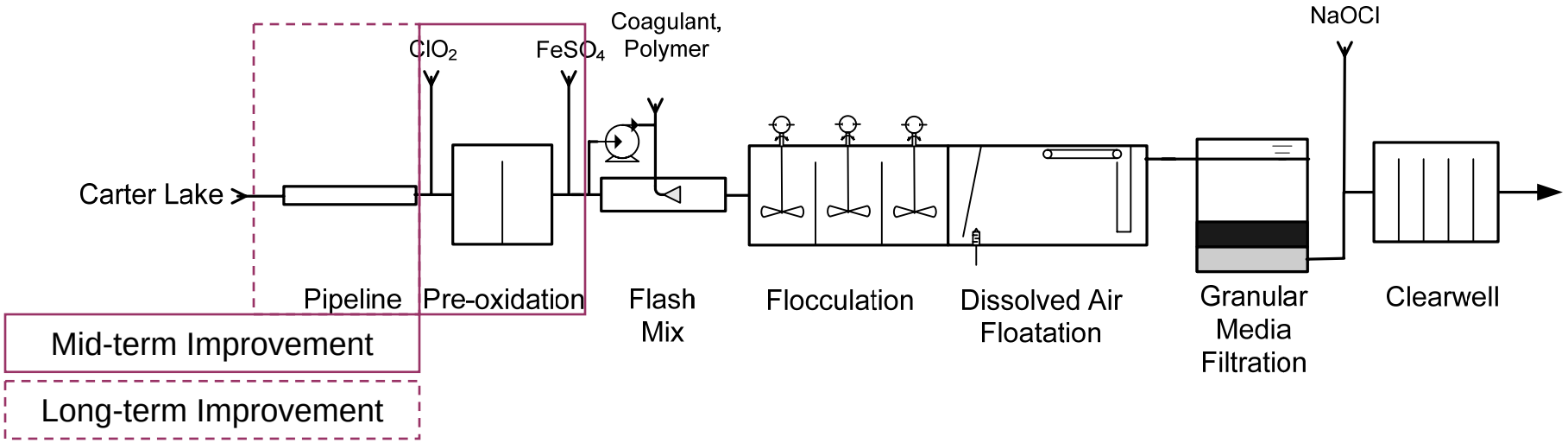
- Alternative 3: This alternative adds both GAC adsorption and UV disinfection to the contaminant barriers provided by baseline Alternative 1. *This delivery alternative would not meet the City's TDS and sulfate water quality goals when raw water was supplied from Boulder Reservoir.*

- Alternative 4: This alternative utilizes the contaminant barriers in baseline Alternative 1 with granular media filtration replaced by submerged low-pressure membrane filtration retrofitted into the existing filter boxes. *This delivery alternative would not meet the City's TDS and sulfate water quality goals, nor would it provide an effective barrier for organic micropollutant control.*

- Alternative 5: This alternative adds ozone oxidation to the contaminant barriers provided by baseline Alternative 1. *This water delivery alternative would not meet the City's water quality goals with respect to pathogen control during cold weather operation at BRWTF, nor would it meet finished water TDS and sulfate goals.*

2. Carter Lake Pipeline Delivery Alternative

Because a dedicated pipeline from Carter Lake for raw water delivery to BRWTF provides barriers for each contaminant category except DBP control, only one water alternative using this delivery method was developed, as shown schematically on Figure 5-6. This alternative utilizes the existing conventional treatment at BRWTF and residual disinfection with free chlorine. In addition, chlorine dioxide preoxidation added as part of the ongoing mid-term improvements program was also assumed.



Primary MCL	Microbial Pathogens	✓	✓	✓	✓	✓
	Disinfection Byproducts		✓	✓	✓	
	Micro-Pollutants	✓				
Secondary MCL	Manganese	✓	✓		✓	
	Taste and Odor	✓	✓			
	TDS and Sulfate	✓				

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Alternative 6: Carter Lake Pipeline Delivery with ClO_2 Pre-oxidation

Figure 5-6

- Alternative 6: Carter Lake pipeline for turbidity, suspended solids, manganese, taste and odor, organics, DBP, and inorganics control followed by chlorine dioxide pre-oxidation for additional pathogen, taste and odor, organics, and DBP control. *This water delivery alternative meets all the City's water quality goals, and provides at least one barrier for each contaminant category evaluated.*

3. Water Delivery Alternatives Summary

The candidate water delivery alternatives outlined here integrate a range of conceptual improvements with existing treatment processes to provide multi-barrier approaches for drinking water treatment at BRWTF. Table 5-1 summarizes the barriers provided in each alternative for identified water quality vulnerabilities.

As indicated in Table 5-1 BRWTF candidate water delivery Alternatives 1, 2, and 4 do not provide effective barriers for organic micropollutants and, and the degree of organic micropollutant control provided by Alternative 3 varies with GAC age. Only Alternative 3 provides TDS and sulfate in finished water that is consistent with City drinking water goals. Alternatives 1, 2, and 5 also do not satisfy the City's finished water quality goals for *Cryptosporidium* control, as shown in Table 5-2.

Table 5-1

Barriers for Water Quality Vulnerabilities at BRWTF

Alternative	Pathogens	DBPs	Organic Micro-pollutants	Mn	Taste & Odor	TDS/ Sulfate
1	ClO_2[(2)] Conv. treat. NaOCl	ClO_2[(2)] Conv. treat.	NB	ClO_2[(2)] Conv. treat.	ClO_2[(2)]	NB
2	ClO_2[(2)] Conv. treat. UV NaOCl	ClO_2[(2)] Conv. treat.	NB	ClO_2[(2)] Conv. treat.	ClO_2[(2)]	NB
3	ClO_2[(2)] Conv. treat. NaOCl	ClO_2[(2)] Conv. treat. GAC[(3)]	GAC[(3)]	ClO_2[(2)] Conv. treat.	ClO_2[(2)] GAC[(3)]	NB
4[(1)]	ClO_2[(2)] Conv. treat. NaOCl	ClO_2[(2)] Conv. treat.	NB	ClO_2[(2)] Conv. treat.	ClO_2[(2)]	NB
5	ClO_2[(2)] Conv. treat. AOP NaOCl	ClO_2[(2)] Conv. treat. AOP	AOP	ClO_2[(2)] Conv. treat. AOP	ClO_2[(2)] AOP	NB
6	Pipeline ClO_2[(2)] Conv. treat. NaOCl	ClO_2[(2)] Conv. treat.	Pipeline	Pipeline ClO_2[(2)]	Pipeline ClO_2[(2)]	Pipeline

Abbreviations:
ClO_2 – chlorine dioxide, Conv. treat. – conventional treatment (coagulation, flocculation, plate assisted sedimentation, filtration), NaOCl – free chlorine, NB – no barrier, UV – ultraviolet light disinfection, GAC – granular activated carbon adsorption, AOP – advanced oxidation process (ozone/H_2O_2).

[(1)]Low pressure membrane filtration (MF/UF) instead of granular media filtration.
[(2)]Partial barriers for pathogen and taste and odor control and robust barriers for DBP and manganese control.
[(3)]Partial barriers for organic micropollutants and taste and odor and robust barrier for DBP control.

Table 5-2

Microbial Pathogen Barriers for BRWTF Delivery Alternatives

Barrier	*Cryptosporidium*	*Giardia*	Viruses
Conventional Treatment	3.0	2.5	2.0
Combined Filter Performance	0.5	0.5[(1)]	–
Individual Filter Performance	0.5	0.5[(1)]	–
Chlorine Dioxide[(2)]	0.02/0.06	0.67/1.58	0.96/2.39
Ozone[(3)]	0.52/1.60	12.49/31.55	26.64/66.60
Free Chlorine[(4)]	–	0.54/1.21	12.33/30.15
UV Disinfection[(5)]	4.0	4.0	0.5
Pipeline[(6)]	1.5	1.5	–
Alternative	***Cryptosporidium***	***Giardia***	**Viruses**
1	*4.02/4.06*	4.71/6.29	15.29/34.54
2	8.02/8.06	8.71/10.29	15.79/35.04
3	8.02/8.06	8.71/10.29	15.79/35.04
4	5.52/5.56	6.71/8.29	15.29/34.54
5	*4.54*/5.66	17.20/37.84	41.93/101.1
6	5.52/5.56	6.21/7.79	16.79/36.04
City Goal	5.0	4.0	5.0

[(1)]Assumes same log-removal as for *Cryptosporidium* because *Giardia* is substantially larger.

[(2)]LT2ESWTR log-inactivation credit: 1 mg/L chlorine dioxide residual, 10 min. contact.3°C and 15°C.

[(3)]LT2ESWTR log-inactivation credit: 1 mg/L ozone residual, 10 min. contact, 3°C and 15°C.

[(4)]LT2ESWTR log-inactivation credit: 1 mg/L free chlorine residual, 10 min. contact, 3°C and 15°C.

[(5)]LT2ESWTR log-inactivation credit, UV dose 40 mJ/cm^2, no temperature dependence.

[(6)]*Cryptosporidium* and *Giardia* log-removal set equal to equivalent log-removal based on ratio of historical bacterial concentrations in BFC and Carter Lake.