Technical Memorandum

Prepared for: Lower South Platte Water Conservancy District

Project Title: South Platte Regional Water Development Concept Feasibility Study

Subject: Water Treatment Alternatives

Date: March 2020

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SPROWG Feasibility Study consulting team

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List of Abbreviations

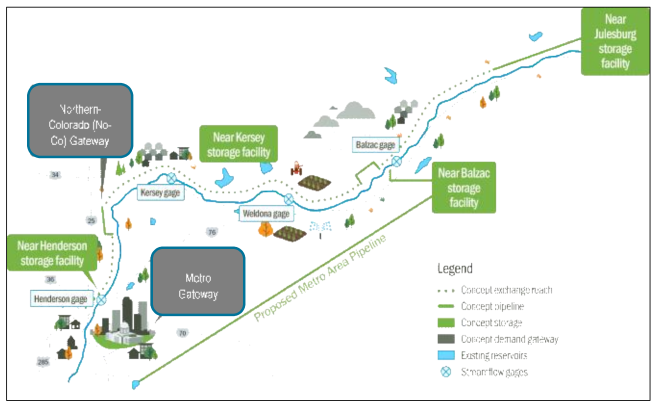
AFY	Acre-Foot per Year
ASR	Aquifer Storage and Recovery
AWTP	Advanced Water Treatment Plant
CDPHE	Colorado Department of Public Health and the Environment
CFS	Cubic Feet per Second
DBP	Disinfection By-Product
EDR	Electrodialysis Reversal
ES	Executive Summary
MCL	Maximum Contaminant Level
MGD	Million Gallons per Day
Mg/L	Milligrams per Liter
NDMA	N-Nitrosodimethylamine
NF	Nanofiltration
No-Co	Northern Colorado
O&M	Operation and Maintenance

pCi/L	Picocuries per Liter
PFAS	Per- and Polyfluoroalkyl Substances
RBF	Riverbank Filtration
RO	Reverse Osmosis
SPROWG	South Platte Regional Opportunities Working Group
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TM	Technical Memorandum
µg/L	Micrograms per Liter
US EPA	United States Environmental Protection Agency
WTF	Water Treatment Facility
WTP	Water Treatment Plant

Executive Summary

The South Platte Regional Opportunities Water Group (SPROWG) is currently investigating opportunities for the development of additional water from the South Platte River, downstream of Denver. The vision of SPROWG is to provide water for multiple users including municipal, industrial, agricultural as well as environmental and recreational users between the Denver metropolitan area and the Nebraska state line. The project has identified four alternatives for capturing, storing and delivering water to project participants. Municipal and industrial participants could choose to take raw or treated water. For the project to reach its full benefit, delivered treated water must meet appropriate water quality standards. The necessary water treatment will ultimately be determined by needs of the specific project participants and the water quality at the location of the final diversion points. For this study, simplifying assumptions were made to provide a conceptual understanding of the treatment needs and costs for providing water to municipal and industrial customers from the SPROWG Concept.

In general terms, the South Platte River's water quality continues to degrade as it progresses downstream. Thus, the treatment processes needed to address raw water quality will largely be determined by the location of the diversion. Conceptual locations of facilities and diversion points are shown in the adjacent figure. The SPROWG Concept considers the following four alternatives:



SPROWG Concept alternatives map

Alternative 1 –Refined Initial Concept (Three Storage Facilities). Storage at Henderson, Kersey and Balzac, with primary storage at Kersey.

Alternative 2 – Balzac First. Same storage concepts as Alternative 1 but with primary storage at Balzac.

Alternative 3 – Add Julesburg Storage. Same storage concepts as in Alternative 1 but add storage at Julesburg.

Alternative 4 – Additional Delivery. Same storage concepts as in Alternative 3 but enlarge storage options to increase deliveries.

Water Quality

Potable water delivered by a water utility must meet health related standards set by Colorado Department of Public Health and Environment (CDPHE) Regulation 11 Colorado Primary Drinking Water Regulations. Additional secondary or non-health related standards are also a consideration for water quality. The SPROWG Study assumed that those participants receiving finished water must meet primary drinking water standards, some secondary standards, and disinfection by-product (DBP) standards. The main secondary standard of concern is total dissolved solids (TDS); the SPROWG Study assumed a target TDS concentration for treated water deliveries at 400 milligrams per liter (mg/L).

The SPROWG Study utilized water quality data from the 2019 Historical Analysis of the South Platte River Salinity Study conducted by Nierbo Hydrogeology (Nierbo Study) (Nierbo, 2019). Data from the Nierbo Study included raw water quality for 13 parameters.

The SPROWG Study utilized the Nierbo Study water quality data for raw water quality at the approximate locations of South Platte River diversions for the four proposed alternatives: near Brighton, below the Poudre River confluence, and near Fort Morgan or Sterling. The SPROWG Study identified several water quality issues or considerations that may necessitate various levels of treatment.

- Turbidity, iron and manganese were found to be high
- Total dissolved solids exceed the secondary standard.
- Total organic carbon concentration is elevated enough to require 50% removal per regulations and to reduce DBP formation.
- Bromide levels are close to the trigger for bromate formation, if ozone is a desired treatment process.

Of the four alternatives, the best source water quality was found at the “near Brighton” location, which is the most upstream of the potential diversion points considered in this study. The data indicates this location provides the lowest TDS with sulfate and chloride levels near the maximum contaminant level (MCL).

Water Treatment Options

For each of the four alternatives, the SPROWG Study evaluated two treatment scenarios - riverbank filtration with a conventional treatment plant, and application of advanced treatment technology in an advanced water treatment plant. Each treatment scenario provides advantages and disadvantages. Considerations for water treatment scenarios included infrastructure costs, ability to meet primary and secondary standards, land requirements, and solids handling.

After an initial assessment, riverbank filtration was considered only as a pre-treatment option to reduce turbidity and total organic carbon. Conventional treatment would meet all required primary drinking water standards. This treatment option requires lower overall power demands relative to the advanced water treatment option. Additional advantages include ease of disposal of solids and lower water loss across the necessary processes. Disadvantages of riverbank filtration with conventional water treatment include increased chemical usage, some additional polishing processes or finished water blending to meet secondary standards for TDS. Additionally, this option may require additional processes or modifications to address future regulations.

The second water treatment scenario considered by the SPROWG Study was advanced water treatment. For the purpose of this study, the advanced water treatment process was assumed to consist of high-pressure membrane filtration, including reverse osmosis with mechanical evaporators for brine treatment. This option requires a smaller physical footprint and is more likely to meet future regulations with fewer modifications compared to the conventional water treatment scenario. However, advanced water treatment will require higher energy demands, have more maintenance requirements, and require additional source water flow to meet demands due to an increase in water loss across the processes. The reverse osmosis component of advanced treatment would be performed on a split-stream basis with back-blending to meet the target TDS concentration of 400 mg/L.

Brine disposal represents a significant cost and permitting challenge. Mechanical evaporators were selected for use in this study. They are the most expensive accepted practice for brine disposal but have more certainty of environmental approval than deep well injection and require significantly less land than evaporation ponds. It is possible that future regulations or specific project requirements may require a different alternative to be considered.

Capital, operation and maintenance (O&M), and life-cycle cost estimates were prepared for the treatment alternatives for each SPROWG alternative. Because the advanced water treatment option is more certain in terms of meeting water quality requirements, and is conservative in terms of cost, it was recommended for use in the overall SPWROWG Concept cost estimates. Table ES-1 presents the summary of costs for the advanced water treatment option. The total cost is the life-cycle cost including the present worth of 20 years of O&M.

Table ES-1. SPROWG Advanced Treatment Option Costs Comparison

Alternative	Design Flow (MGD)	Capital Cost[1] ($M)	*Annual Operating Cost[2] ($M/yr)*	Present Worth Operating Cost[3] ($M)	Engineering & Permitting Costs[4] ($M)	Land Acquisition Costs[5] ($M)	Legal & Administrative Costs[6] ($M)	Subtotal ($M)	Total ($B)
Alternative 1 – Refined Initial Concept									
Metro Gateway (Metro + NoCo-S)	74	$518	*$7.22*	$107	$78	$1.07	$41	$746	**$1.19**
NoCo Gateway (NoCo-N)	44	$308	*$4.29*	$64	$46	$0.64	$25	$444	
Alternative 2 - Balzac First									
Metro Gateway: Metro	57	$399	*$5.56*	$83	$60	$0.83	$32	$575	
Metro Gateway: NoCo-S	20	$140	*$1.97*	$29	$21	$0.29	$11	$202	**$1.22**
NoCo Gateway: NoCo-N	44	$308	*$4.29*	$64	$46	$0.64	$25	$444	
Alternative 3 - Add Julesburg Storage									
Metro Gateway: Metro	57	$399	*$5.56*	$83	$60	$0.83	$32	$575	
Metro Gateway: NoCo-S	20	$140	*$1.97*	$29	$21	$0.29	$11	$202	**$1.22**
NoCo Gateway: NoCo-N	44	$308	*$4.29*	$64	$46	$0.64	$25	$444	
Alternative 4 – Additional Delivery									
Metro Gateway: Metro	72	$504	*$7.02*	$104	$76	$1.04	$40	$726	
Metro Gateway: NoCo-S	20	$140	*$1.97*	$29	$21	$0.29	$11	$202	**$1.48**
NoCo Gateway: NoCo-N	55	$385	*$5.36*	$80	$58	$0.80	$31	$555	

Assumptions: [1] Capital ($M/mgd) = $7; [2]Annual operating costs (chemicals, equipment replacement, labor, power and miscellaneous); [3]Operating costs presented as 20-yr present worth ($M/mgd) = $1.45; [4]Engineering & Permitting = 15% Capital; [5]Land Acquisition ($10,000/ac) = 116 ac (using relative SF as the Binney WPF 80 mgd and ratio based on flow); [6]Legal and Administrative = 8% of Capital.

Conclusion and Recommended Future Studies

The necessary water treatment for any of the alternatives will ultimately be determined by the needs of the specific project participants and the water quality at the actual location of the diversions. High TDS is a challenge that must be addressed for all alternatives. The Brighton location has the lowest TDS. Additionally, this location provided sulfate and chloride levels near the MCL. As such, meeting as much of the Front Range municipal demand as possible from a diversion at this location could provide a relative advantage.

Additional investigations are recommended to determine the raw water quality and treatment requirements for a project like the SPROWG Concept.

- **Additional sampling program for better data.** The water quality data used in this Study is a compilation of water quality sampling data collected from multiple sample points in each reach of the South Platte River. These sampling points could be upstream or downstream of the actual proposed intake for the SPROWG Concept and represented different seasons and flow conditions. As such, the SPROWG participants should perform additional analysis of currently available data as well as additional sampling at desired diversion points to determine raw water quality and necessary treatment.
- **Evaluation of potential blending supplies.** The SPROWG Study was conducted under the assumption that SPROWG Concept water would not be blended with other lower TDS sources. A blending supply,

depending on its quality, could reduce or eliminate the need for expensive membrane treatment and brine disposal to reach a desired water quality.

- **Better definition of the desired quality of delivered water supplies from a future SPROWG Project.** The SPROWG Study was conducted under the assumption that treated water deliveries would meet all primary and secondary drinking water standards, including a TDS concentration of approximately 400 mg/L. However, the project could deliver supplies at lower quality if the participants are able to provide additional treatment to meet their specific needs.
- **Nonpoint source treatment opportunities.** Nonpoint source treatment measures at a watershed scale could have benefits in improving South Platte River water quality and reducing treatment costs. This SPPROWG Study included a separate analysis of nonpoint source approaches. Further exploration of those options should be part of future treatability studies for SPROWG concepts.

Section 1: Introduction

1.1 SPROWG Overview

The South Platte Regional Opportunities Water Group (SPROWG) is performing a feasibility study (Study) of regional water development concepts in the South Platte Basin downstream of Denver. The SPROWG concept could provide water for multiple municipal, agricultural and environmental/recreational users between the Denver Metro area and the Nebraska state line.

Specific project participants have yet to be identified. As such, the SPROWG Concept is being evaluated at a conceptual level using assumptions including participant water user categories (municipal, agricultural and industrial), water supply demands to be met, and the location of raw or treated water delivery. The objective of this Study is to identify the potential magnitude and operational aspects of a regional water concept. The results of this study will be provided to potential participants for independent assessment of the Concept's applicability to their current and future needs.

One of the objectives of the SPROWG Study is to evaluate the ability of different alternatives to provide water to municipal entities located in the greater Denver metropolitan area and the North Front Range. A survey, conducted as part of the SPROWG Study, collected information from potential participants on their water needs. This is described in the Outreach and Education Technical Memorandum (TM) prepared for the Study. Information collected included participants' identified water quality needs. Results from the survey show that while some municipal entities prefer to accept raw water from SPROWG for treatment in their own water treatment plants, others would prefer to receive treated water from the concept that meets drinking water standards. These preferences had a geographical distribution, with municipal entities in the Denver Metro area and the North Front Range area indicating a preference to receive treated water from the project, while municipal entities in the lower portion of the basin indicated a preference to receive raw water. This is likely due to the intended use of the water from SPROWG. While upstream municipal entities in the Denver Metro and North Front Range area desire treated water that can go directly into their systems, downstream entities are likely to use their allocation of SPROWG to augment depletions associated with their other water supplies.

To meet the needs of these and other diverse participants, this technical memorandum (TM) provides an assessment of the necessary water treatment facilities and costs to provide treated water to municipal participants in the Denver Metro and North Front Range areas for each SPROWG alternative concept.

1.2 SPROWG Alternatives

The SPROWG Study developed four alternatives for capturing, storing, and delivering water to project participants. These alternatives are listed below and described in the Concept Refinement Alternatives Memorandum (January 2020). Figure 1 shows locations of key concepts in the SPROWG alternatives. The SPROWG alternatives are:

- Alternative 1 –Refined Initial Concept (Three Storage Facilities). Storage at Henderson, Kersey and Balzac, with primary storage at Kersey.
- Alternative 2 – Balzac First. Same storage concepts as Alternative 1 but with primary storage at Balzac.
- Alternative 3 – Add Julesburg Storage. Same storage concepts as Alternative 1 but adding storage at Julesburg.
- Alternative 4 – Additional Delivery. Same storage concepts as Alternative 3 but enlarge storage options to increase deliveries.

Figure 1. SPROWG Alternative Conceptual Facilities and Diversion Points

All alternatives had the same two locations to which water would be delivered for Denver Metro and North Front Range municipal customers: the Metro Gateway (Henderson) in the vicinity of Brighton and the Prairie Waters North Campus, and the Northern Colorado (No-Co) Gateway west of Greeley. Water delivered to the Gateways could come from direct diversions from the South Platte River or from SPROWG reservoir storage. These source water locations would determine the quality of water to be treated at SPROWG water treatment facilities (WTFs).

For purposes of this phase of the SPROWG analysis, each alternative was assumed to be capable of delivering all raw water or all treated water to municipal project participants. In that way all the other conceptual alternative infrastructure components (storage reservoirs, conveyance facilities, diversion locations) would be the same with or without water treatment. This provides simplified metrics for comparing the cost of delivering treated water verses delivering raw water.

Section 2: Water Treatment Scenarios

2.1 Water Treatment Strategies

The SPROWG feasibility study scope of work specified consideration of two main water treatment strategies: advanced water treatment (AWT), and riverbank filtration (RBF) followed by conventional water treatment (RBF +WTP) similar to the Aurora Prairie Waters treatment strategy. Each of these strategies was applied to the SPROWG water delivery alternatives.

In addition, the SPROWG feasibility study scope of work included a task to review nonpoint source treatment options due to the potential for reducing treatment costs using typical processes. This review is presented in a separate technical memorandum.

2.2 Locations and Sources

Conceptual points of diversion from the South Platte River that would supply municipal water treatment facilities are shown on Figure 1 and include: (1) near Brighton or the Henderson gage; (2) below the Poudre River confluence or near the Kersey gage; and (3) near Fort Morgan/Sterling or the Balzac gage. It was assumed that water treatment would be provided primarily near the Prairie Waters North Campus for the Metro Gateway and at a "No-Co" site west of Greeley for the No-Co Gateway. For this Study the No-Co site is assumed to be the Gold Hill site identified previously by Northern Colorado Water Conservancy District (Farnsworth 2016). For alternatives with a Metro Area Pipeline from Balzac storage to Henderson, desalination could occur near the Balzac storage reservoir to facilitate brine disposal and minimize the volume of water to be pumped.

Some SPROWG alternatives include use of an aquifer storage and recovery (ASR) option in place of surface water storage near Henderson. For planning purposes, ASR storage in the Upper Lost Creek groundwater basin was assumed for SPROWG alternatives. Prior to recharge to the aquifer, SPROWG water would have to be treated to a level meeting drinking water standards in order to satisfy Colorado water quality regulations for protecting groundwater quality. Conducting ASR also requires compliance with the United States Environmental Protection Agency's (US EPA) Underground Control Program which requires receiving a Class V permit.

2.3 Water Treatment Scenarios

SPROWG water treatment scenarios developed to match infrastructure alternatives considered: (1) the infrastructure delivering the water to the municipal Gateways, (2) the source water to be treated, and (3) the method of treatment. The water treatment scenarios covering the SPROWG alternatives are summarized in Table 1.

The scope of work for the SPROWG water treatment evaluation included RBF as a stand-alone process. However, when used alone it is not capable of meeting water quality objectives for municipal uses. SPROWG water users would have to provide their own finished water treatment processes in this case. To have a manageable number of treatment options, the RBF-only option was not considered. This still allows for a comparison between the bookends of fully treated and raw water SPROWG concepts.

Table 1. SPROWG Water Treatment Scenarios

Gateway	South Platte River Diversion Location	Source Water to be Treated	Treatment Scenarios
Metro Gateway	Near Brighton	South Platte River at Brighton (Henderson gage)	AWTP near Brighton RBF + WTP near Brighton
Metro Gateway	Near Fort Morgan/Sterling	Balzac Reservoir via Metro Area Pipeline	AWTP at intake to Metro Area Pipeline RBF + WTP near Brighton
NoCo Gateway	Below Poudre Confluence	South Platte River near Greeley (Kersey gage)	AWTP at No-Co Site RBF near Greeley + WTP at No-Co site
ASR	Near Brighton	South Platte River at Brighton (Henderson gage)	AWTP at ASR site RBF near Brighton + WTP at ASR

2.4 Planning Criteria

2.4.1 Flow Analysis

The WTF required at each treatment location is sized based on the assumptions from the SPROWG point flow operations model, presented in the Concept Refinement Alternatives Modeling TM (January 2020). For the purpose of this TM the assumptions used in determining treatment plant hydraulic capacities are:

- Annual Demand is split 60/40 for indoor/outdoor uses.
- Indoor demand is constant through the year.
- Maximum outdoor demand is 21.4 percent (%) of annual demand.
- Design flow is based on the maximum monthly delivery requirement for normal or dry years and storage is available to smooth out daily fluctuations.

The design flow for each treatment location and each SPROWG alternative with the corresponding water treatment scenario is summarized in Table 2.

Table 2. SPROWG WTF Sizing

Alternative/Gateway	Design Flow (AFY)	Design Flow (MGD)	Design (CFS)	Link to Water treatment Scenarios
Alternative 1 – Refined Initial Concept				
Metro Gateway (Metro + NoCo-S)	6,780	74	114	AWTP; RBF + WTP[1]
NoCo Gateway (NoCo-N)	4,068	44	68	AWTP; RBF + WTP[1]
Alternative 2 - Balzac First				
Metro Gateway (Metro + NoCo-S)	6,780	74	114	AWTP; RBF + WTP[1]
NoCo Gateway (NoCo-N)	4,068	44	68	AWTP; RBF + WTP[1]
Alternative 3 - Add Julesburg Storage				
Metro Gateway (Metro + NoCo-S)	6,780	74	114	AWTP; RBF + WTP[1]
NoCo Gateway (NoCo-N)	4,068	44	68	AWTP; RBF + WTP[1]
Alternative 4 – Additional Delivery				
Metro Gateway (Metro + NoCo-S)	8,475	92	142	AWTP; RBF + WTP[1]
NoCo Gateway (NoCo-N)	5,085	55	85	AWTP; RBF + WTP[1]

[1]RBF + WTP only feasible for a portion of the flow up to 20 MGD

2.4.2 Regulations

2.4.2.1 Current Regulations

As it pertains to water quality, both federal and state governments can have jurisdiction. Where both entities exist, to have jurisdiction the state regulations must be more stringent than the federal regulations. The treatment alternatives were designed to meet Colorado Department of Public Health and the Environment (CDPHE) Regulation 11 Colorado Primary Drinking Water Regulations (health-related). Additionally, the treatment alternatives were selected to meet the secondary (non-health related) standards. The primary standards are summarized in Table 3. The primary standards also include the Radionuclide Rule standards. The secondary standards are summarized in Table 4.

Table 3. Primary Standards			
Parameter	**MCL**	**Parameter**	**MCL**
Turbidity	0.3 NTU	trans-1,2-Dichloroethylene	0.1
Cryptosporidium	Treatment technique[1] 2-log removal required)	Dichloromethane	0.005
Giardia	Treatment technique[1] (3-log removal required	1,2-Dichloropropane	0.005
Virus	Treatment technique[1] (4-log removal required)	Di(2-ethylhexyl) adipate	0.4
Total Organic Carbon	Remove 50% to meet disinfection by-product rule	Di(2-ethylhexyl) phthalate	0.006
Arsenic	0.010 as of 01/23/06	Dioxin (2,3,7,8-TCDD)	0.007
Asbestos (fiber > 10 micrometers)	7 Million fibers per liter (MFL	Diquat	3E-08
Barium	2	Endothall	0.02
Beryllium	0.004	Endrin	0.1
Cadmium	0.005	Epichlorohydrin	0.002
Chromium (total)	0.1	Ethylbenzene	TT -0.01% dosed at 20 mg/L (or equivalent)
Copper	Action Level=1.3	Ethylene dibromide	0.7
Cyanide (as free cyanide)	0.2	Glyphosate	0.00005
Fluoride	4	Heptachlor	0.7
Lead	Action Level=0.015	Heptachlor epoxide	0.0004
Mercury (inorganic)	0.002	Hexachlorobenzene	0.0002
Nitrate (measured as Nitrogen)	10	Hexachlorocyclopentadiene	0.001
Nitrite (measured as Nitrogen)	1	Lindane	0.05
Selenium	0.05	Methoxychlor	0.0002
Thallium	0.002	Oxamyl (Vydate)	0.04
Heterotrophic plate count (HPC)	Treatment technique[1]	Polychlorinated biphenyls (PCBs)	0.2
Legionella	Treatment technique	Pentachlorophenol	0.0005
Total Coliforms (including fecal coliform and E. Coli)	5%	Picloram	0.001
Acrylamide	TT - 0.05% dosed at 1 mg/L (or equivalent)	Simazine	0.5
Alachlor	0.002	Styrene	0.004
Atrazine	0.003	Tetrachloroethylene	0.1
Benzene	0.005	Toluene	0.005
Benzo(a)pyrene (PAHs)	0.0002	Toxaphene	1
Carbofuran	0.04	2,4,5-TP (Silvex)	0.003
Carbon tetrachloride	0.005	1,2,4-Trichlorobenzene	0.05
Chlordane	0.002	1,1,1-Trichloroethane	0.07

Table 3. Primary Standards			
Parameter	**MCL**	**Parameter**	**MCL**
Chlorobenzene	0.1	1,1,2-Trichloroethane	0.2
2,4-D	0.07	Trichloroethylene	0.005
Dalapon	0.2	Vinyl chloride	0.005
1,2-Dibromo-3-chloropropane (DBCP)	0.0002	Xylenes (total)	0.002
o-Dichlorobenzene	0.6	Radium (226 & 228)	5 picocuries per liter (pCi/L)
p-Dichlorobenzene	0.075	Uranium	30 micrograms per liter (ug/L)
1,2-Dichloroethane	0.005	Alpha	15 pCi/L
1,1-Dichloroethylene	0.007	Beta particles and photon emitters	4 millirems per year
cis-1,2-Dichloroethylene	0.07		

[1]*Treatment Technique (TT) - A required process intended to reduce the level of a contaminant in drinking water*

Table 4. Secondary Standards	
Parameter	**Maximum Contaminant Level (MCL)**
Chloride	250 mg/L
Color	15 color units
Copper	1.0 mg/L
Corrosivity	Non-corrosive
Fluoride	2.0 mg/L
Foaming agents	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Odor	3 TON (threshold odor number)
pH	6.5 - 8.5
Silver	0.1 mg/L
Sulfate	250 mg/L
Total Dissolved Solids (TDS)	500 mg/L
Zinc	5 mg/L

In addition to the primary and secondary standards, finished water quality must also meet DBP standards. These standards are presented in Table 5.

Table 5. Disinfection By-Product Standards	
Parameter	**MCL**
Bromate	0.010 mg/L
Chlorite	1.0 mg/L
Haloacetic Acids (HAA_5)	0.060 mg/L
Trihalomethanes (TTHMs)	0.080 mg/L

The alternatives that use ASR will also be subject to the CDPHE groundwater classification and standards (Regulations 41, 42 and 43). The regulations note specific levels for radionuclides, organics, and TDS. For these regulations, the main difference between drinking water standards and groundwater standards pertains to TDS. The TDS water quality standard is provided in Table 6.

Table 6. Groundwater TDS Water Quality Standards	
Background TDS Value (mg/L)	**Maximum Allowable TDS Concentration**
0-500	400 mg/L or 1.25 times the background level, whichever is least restrictive
501 – 10,000	1.35 times the background value
10,0001 or greater	No limit

Impending Regulations

The US EPA contaminant candidate list monitors contaminants that are found in public water systems but are not currently regulated under the Safe Drinking Water Act. For example, Per- and Polyfluoroalkyl Substances (PFAS) are on this list where no national regulation has been established. Currently, CDPHE is regulating PFAS in El Paso County only where elevated levels have been found. For the purpose of this TM, the treatment scenarios assessment will discuss meeting future regulations from the standpoint of ease to modify treatment to accommodate potential for future treatment, if needed.

Section 3: Raw Water Quality

Raw water quality is used to determine appropriate treatment methods and size treatment processes. Data for the following raw water quality parameters was examined:

- Turbidity
- Total Dissolved Solids
- Calcium
- Magnesium
- Sulfate
- Chloride
- Total Organic Carbon
- Alkalinity
- Iron and Manganese

- Nitrogen-Nitrate
- Bromide
- pH
- Temperature

The data was provided by Nierbo Hydrogeology (2019), a third-party entity, that collected the data as part of the Historical Analysis of South Platte River Salinity Study to evaluate the South Platte River water quality. This study was conducted in parallel with this SPROWG Study and collected and analyzed water quality data for the South Platte River from 1995 to 2019. For the purposes of this analysis, the water quality data compiled under the Nierbo study was correlated to match the SPROWG alternative diversion points as shown in Figure 1. A map of the assumed locations from which source water would be provided for SPROWG alternatives is shown in Figure 2. The Brighton diversion draws water from Nierbo Reach 3, the Poudre Confluence diversion draws water from Nierbo Reach 7, and the Fort Morgan/Sterling diversion draws water from Nierbo Reach 8.

The data provided by Nierbo is a compilation of water quality sampling data collected from multiple sample points in each reach shown in Figure 2. These sampling points could be upstream or downstream of the actual proposed intake for the SPROWG Concept. In addition, water quality data collected by Nierbo represents different years and different seasons. As a result, there is a significant spread in the available data for most of the constituents evaluated in this analysis. The mean, 10 percentile, and 90 percentile values from the available datasets are listed in this section. It is recommended that a water quality sampling program be developed to characterize source water quality for the proposed SPROWG Concept intake sites. This is discussed further in the Conclusions section.

The following sections summarize water quality data evaluated by constituent.

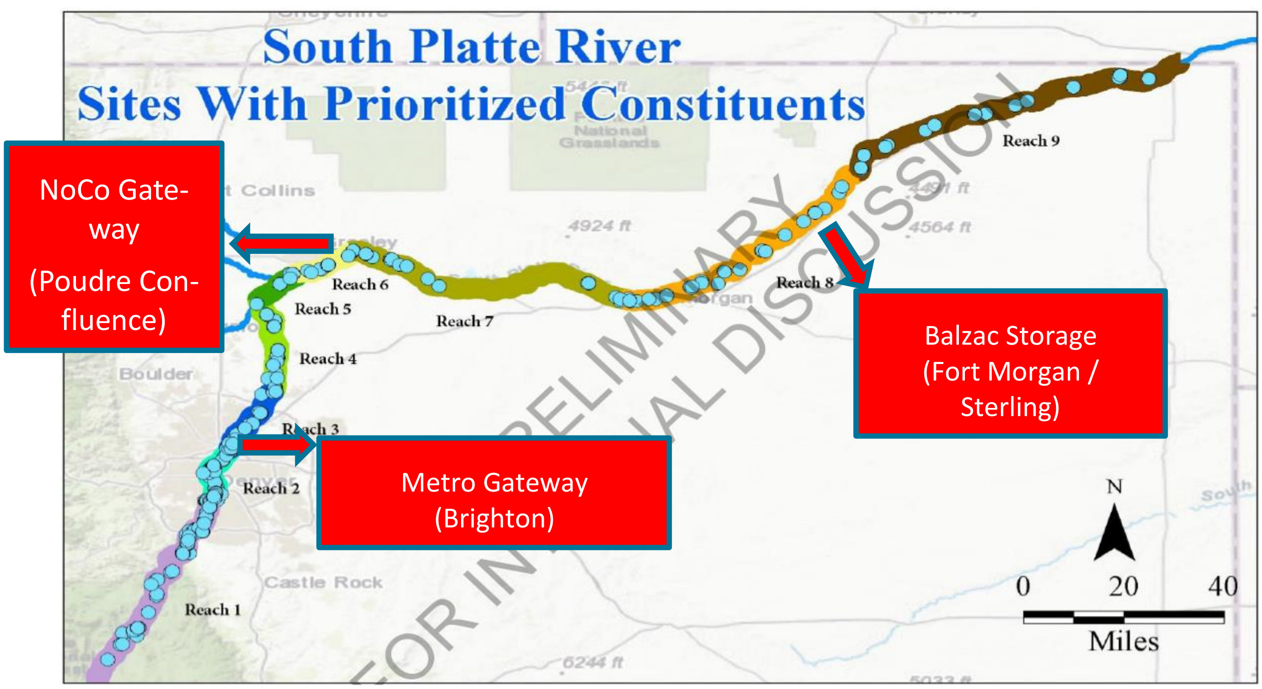


Figure 2. South Platte River Reaches and Sampling Sites for Prioritized Constituents

(Source: Nierbo, 2019)

3.1 Turbidity

Turbidity is a measure of light penetration through a water sample and is indicative of the relative amount of particulate matter in the sample. Turbidity is typically used to select pre-treatment clarification processes and impacts solids handling. The finished water quality goal for turbidity is 0.3 nephelometric turbidity units (NTU). The resultant turbidity expressed in NTU is presented in Table 7.

Table 7. Turbidity

	Brighton	Poudre Confluence	Fort Morgan/Sterling
Mean	25 NTU	30 NTU	34 NTU
10th Percentile	3 NTU	5 NTU	1.9 NTU
90th Percentile	42 NTU	68 NTU	99 NTU

[1]*Historical Analysis of South Platte River Salinity (Nierbo 2019)*

Data indicates a turbidity range typical for a river source having periods of high turbidity that occur as a result of runoff. Turbidity is also increasing further downstream so water diverted at the Fort Morgan/Sterling location may have increased water treatment operation and maintenance costs relative to water from the Brighton and Poudre Confluence locations due to an increase in chemical usage and solids production.

3.2 Total Dissolved Solids

Total dissolved solids (TDS) is a secondary contaminant and is the measurement mainly of inorganic salts (calcium, magnesium, sulfates, and chloride). The main concern with elevated TDS in the raw water is aesthetics with the noticeable effects typically being salty taste, hardness, deposits, and discoloration. The secondary MCL for TDS is 500 mg/L. The total dissolved solids concentrations at SPROWG source water locations are presented in Table 8. Because TDS is a critical constituent for water treatment assessments, the Nierbo plots of TDS data collected for their study are reproduced in Attachment A.

Conventional filtration treatment will not substantially remove these secondary contaminants. Where TDS exceeds the MCL a either a desalination treatment method (e.g., reverse osmosis) is needed or the source water must be blended with a lower TDS supply to reduce the combined TDS to below 500 mg/L.

Table 8. Total Dissolved Solids

	Brighton	Poudre Confluence	Fort Morgan/Sterling
Mean	596 mg/L	755 mg/L	901 mg/L
10th Percentile	310 mg/L	417 mg/L	472 mg/L
90th Percentile	844 mg/L	973 mg/L	1217 mg/L

[1]*Historical Analysis of South Platte River Salinity (Nierbo 2019)*

Even though there are times when the levels are under the MCL, the mean TDS concentration at all proposed source water locations is above the MCL. It is noted that data used to calculate the water quality statistics in Table 8 include samples collected during high runoff periods when TDS concentrations are typically low, and low flow periods when TDS concentrations are typically high. Because water rights for SPROWG could include a combination of water rights that allow diversions at different times of year to achieve the desired yield, it may not be possible to selectively divert SPROWG water only during periods of low TDS. In addition, most SPROWG water delivered to water treatment plants would come from reservoir storage in which water diverted at different times of year would be blended. For purposes of this water treatment analysis it was assumed the data in Table 8 represent the range of TDS that may have to be treated for SPROWG participants.

The data shows that the TDS levels increase moderately in the downstream direction. This could impact the selection of treatment processes necessary to meet the MCL for water derived from lower reaches of the river.

3.2.1 Calcium

Calcium concentration is an indication of the raw water's hardness. Water is considered soft with calcium concentrations between 60 to 120 mg/L, moderately hard between 120 to 180 mg/L, and hard at levels greater than 180 mg/L. Calcium concentrations at the proposed intake sites are presented in Table 9. There is no specific MCL for calcium but removing it will help reduce the total TDS.

Table 9. Calcium

	Brighton	Poudre Confluence	Fort Morgan/Sterling
Mean	72 mg/L	98 mg/L	113 mg/L
10th Percentile	44 mg/L	58 mg/L	20 mg/L
90th Percentile	99 mg/L	125 mg/L	209 mg/L

[1]*Historical Analysis of South Platte River Salinity (Nierbo 2019)*

The data is showing concentrations near the threshold for hard water at the Brighton and Poudre confluence sites and very hard water at the Fort Morgan/Sterling location. Though not necessarily to meet MCL, treatment processes for calcium through lime softening or high pressure membranes (i.e. reverse osmosis (RO) are included at all three locations.

3.2.2 Magnesium

Magnesium is also an indication of the raw water's hardness, but the concentration is typically less than calcium. As such, in making water treatment process determinations treatment for calcium is more of a driver than magnesium. Similar to calcium there is no MCL for magnesium. The magnesium results are presented in Table 10.

Table 10. Magnesium

	Brighton	Poudre Confluence	Fort Morgan/Sterling
Mean	16 mg/L	41 mg/L	46 mg/L
10th Percentile	9 mg/L	23 mg/L	26 mg/L
90th Percentile	20 mg/L	52 mg/L	58 mg/L

[1]*Historical Analysis of South Platte River Salinity (Nierbo 2019)*

The magnesium results are lower than calcium; therefore, treatment for hardness will be selected based on the calcium results.

3.2.3 Sulfates

The presence of sulfate in the water is not only an aesthetic concern which presents with a salty taste, but it also provides challenges with scaling, specifically chemical scaling of high-pressure membranes. The sulfate MCL is 250 mg/L. Concentrations at the SPROWG source water locations are presented in Table 11.

Table 11. Sulfates			
	Brighton	Poudre Confluence	Fort Morgan/Sterling
Mean	159 mg/L	336 mg/L	631 mg/L
10th Percentile	86 mg/L	140 mg/L	430 mg/L
90th Percentile	200 mg/L	465 mg/L	776 mg/L

[1]*Sulfate results were not included the Nierbo study; however, data pulled from similar water quality databases*
[2]*Databases include STORET from EPA and NWIS from US Geological Survey*

The data shows South Platte River 90th percentile sulfate concentrations at Brighton are under the MCL and Poudre confluence and Sterling sites are above the MCL. The Brighton levels are not significantly under the MCL so sulfate treatment should be considered.

3.2.4 Chloride

When present in water, chloride, like sulfate, is an aesthetic concern and may indicate elevated levels of sodium. Additionally, high chloride can increase the potential for corrosion. The secondary standard for chloride is 250 mg/L. The chloride data at SPROWG source water locations are presented in Table 12.

Table 12. Chloride			
	Brighton	Poudre Confluence	Fort Morgan/Sterling
Mean	69 mg/L	62 mg/L	61 mg/L
10th Percentile	48 mg/L	35 mg/L	47 mg/L
90th Percentile	86 mg/L	86 mg/L	74 mg/L

[1]*Sulfate results were not included the Nierbo study; however, data pulled from similar water quality databases*
[2]*Databases include STORET from EPA and NWIS from US Geological Survey*

The chloride levels are below the MCL for all three locations.

3.3 Total Organic Carbon

Organic matter in the raw water can affect its treatability as well as other water quality characteristics, including chlorine demand and decay, DBP formation, and tastes and odors. Organic content can be derived from the natural decay of plant life, as in humic and fulvic acids, or the presence of algae. High organic content also triggers additional treatment compliance requirements. The compliance trigger for total organic carbon (TOC) is 2 mg/L. The TOC concentration data at SPROWG source water locations is presented in Table 13.

Table 13. Total Organic Carbon			
	Brighton	Poudre Confluence	Fort Morgan/Sterling
Mean	9 mg/L	4.8 mg/L	5 mg/L
10th Percentile	5 mg/L	5 mg/L	3 mg/L
90th Percentile	12 mg/L	9 mg/L	6 mg/L

[1]*Historical Analysis of South Platte River Salinity (Nierbo 2019)*

Reported TOC concentrations at the SPROWG intake sites indicate that additional treatment to reduce TOC will be required for compliance with the DBP Rule. The TOC concentration and the associated alkalinity results will require a 50 percent reduction in the raw water TOC through treatment. Treatment options to remove TOC include enhanced coagulation or advanced treatment such as high-pressure membranes. Treatment scenarios discussed in Section 4 will accomplish this purpose.

3.4 Alkalinity

Alkalinity has an impact on coagulation performance, corrosivity, pH stability, and TOC removal requirements (depending on raw water organic concentrations) but has no MCL. A value above 20 mg/L is generally considered adequate for alum coagulation and for improved pH stability in the distribution system. However, alkalinity over 150 mg/L can cause scaling. The alkalinity data for the South Platte near the SPROWG source water locations are presented in Table 14.

Table 14. Alkalinity			
	Brighton	Poudre Confluence	Fort Morgan/Sterling
Mean	150 mg/L	188 mg/L	218 mg/L
10th Percentile	98 mg/L	111 mg/L	130 mg/L
90th Percentile	185 mg/L	228 mg/L	260 mg/L

[1]*Historical Analysis of South Platte River Salinity (Nierbo 2019)*

Data shows alkalinity levels above the 150 mg/L limit can occur at all intake sites. These high alkalinity levels may have an operational impact on water treatment and necessitate high chemical dosages for adequate treatment. Bench-scale testing for determining proper chemical dosages is recommended.

3.5 Iron and Manganese

Iron (Fe) and Manganese (Mn) are secondary contaminants associated with colored water, staining and sometimes taste and odor issues. In stratified lakes and reservoirs, precipitates (solid forms) of these metals contained within the sediments may be reduced in the lower anoxic layer to a soluble form . In aerobic waters, these metals are oxidized and form a precipitate. An oxidizing process, such as chlorination or ozonation, will also result in formation of precipitates, which can then be settled and/or filtered in a treatment plant. The MCL for iron is 0.30 mg/L and for manganese is 0.05 mg/L. The iron and manganese concentration data near SPROWG source water intakes is presented in Tables 15 and 16, respectively.

Table 15. Iron			
	Brighton	Poudre Confluence	Fort Morgan/Sterling
Mean	0.93 mg/L	0.95 mg/L	0.70 mg/L
10th Percentile	0.27 mg/L	0.19 mg/L	0.04 mg/L
90th Percentile	2.5 mg/L	1.86 mg/L	1.3 mg/L

[1]*Historical Analysis of South Platte River Salinity (Nierbo 2019)*

Table 16. Manganese			
	Brighton	Poudre Confluence	Fort Morgan/Sterling
Mean	0.17 mg/L	0.07 mg/L	0.14 mg/L
10th Percentile	0.06 mg/L	0.01 mg/L	0.02 mg/L
90th Percentile	0.26 mg/L	0.16 mg/L	0.26 mg/L

[1]*Historical Analysis of South Platte River Salinity (Nierbo 2019)*

The concentrations for iron and manganese are above the MCL at all locations; thereby, treatment will be required to meet secondary standards.

3.6 Nitrogen-Nitrate

Nitrogen is a nutrient found in naturally, urban runoff, agriculture, and commercial fertilizer. High concentrations (i.e., greater than 10 mg/L) of nitrogen-nitrate in water can have adverse health effects, especially for babies and pregnant women. Nitrogen is regulated under primary drinking water standards. The MCL for nitrogen-nitrate is 10 mg/L. Data for the South Platte River near SPWOWG intakes is presented in Table 17.

Table 17. Nitrogen-nitrate			
	Brighton	Poudre Confluence	Fort Morgan/Sterling
Mean	4.5 mg/L	4.9 mg/L	4.4 mg/L
10th Percentile	1.5 mg/L	2.2 mg/L	2.2 mg/L
90th Percentile	5.6 mg/L	7.2 mg/L	6.7 mg/L

[1]*Historical Analysis of South Platte River Salinity (Nierbo 2019)*

At all proposed intake sites, nitrate levels are under the primary drinking water MCL. Therefore, no additional treatment is required for nitrate when the raw water is sourced directly from the river. However, most of the water will be stored in surface reservoirs where nitrate could accumulate, especially in the larger reservoirs water could be stored for several years. As a result, the nitrate concentration could increase compared to the river, possibly to the point where treatment would be needed. Treatment options to reduce nitrate is to include reservoir management to keep nitrate concentrations below the MCL or include advanced treatment such as high pressure membranes.

3.7 Bromide

Bromide has impacts on the feasibility of using ozone for disinfection due to the reaction between bromide and ozone to form bromate. Bromate is a disinfection by-product and has a MCL of 0.010 mg/L. Raw water bromide concentration greater than 0.04 mg/L would trigger additional evaluation to determine bromate potential. The bromide data for the South Platte River is minimal presented in Table 18.

Table 18. Bromide			
	Brighton	Poudre Confluence	Fort Morgan/Sterling
Mean	0.03 mg/L	N/A	N/A
10th Percentile	0.02 mg/L	N/A	N/A
90th Percentile	0.06 mg/L	N/A	N/A

[1]*Historical Analysis of South Platte River Salinity (Nierbo 2019)*

The bromide levels are low; however, further evaluation is recommended to determine the feasibility of ozone as a treatment process.

3.8 pH

pH is a measurement of the acidic or basic nature of water and can also be indicative of water corrosiveness. A pH of less than 7.0 usually indicates corrosivity; pH above 8 indicates basic water which can impact the amount of chemicals required for some forms of treatment. The pH data for the South Platte River are presented in Table 19.

Table 19. pH			
	Brighton	Poudre Confluence	Fort Morgan/Sterling
Mean	7.5	8.1	8.1
10th Percentile	7.1	7.8	7.8
90th Percentile	7.9	8.4	8.4

[1]*Historical Analysis of South Platte River Salinity (Nierbo 2019)*

3.9 Temperature

Temperature is important to water treatment because it affects the rate of chemical reaction including disinfection and formation of DBPs, floc formation and settling, and filter performance. Higher temperature typically requires lower chemical doses and offers better floc formation, settling, filtration, and disinfection characteristics. The temperature data for the South Platte River presented in Table 20.

Table 20. Temperature			
	Brighton	Poudre Confluence	Fort Morgan/Sterling
Mean	57 deg. F	60 deg. F	60 deg. F
10th Percentile	45 deg. F	42 deg. F	41 deg. F
90th Percentile	69 deg. F	76 deg. F	75 deg. F

[1]*Historical Analysis of South Platte River Salinity (Nierbo 2019)*

3.10 Design Raw Water Quality

Water treatment plant design for SPROWG alternatives is based on the more challenging water quality conditions, unless a secondary source is available when the plant is off. The design raw water quality to be treated at each source water location was based on the 90th percentile of the data presented in the previous sections. This is conservative, and accounts for the fact that concentrations of some constituents may increase in the future as land use and water operations in the South Platte basin change. The Nierbo data from 1995 to 2019 shows modest upward trends in TDS concentration over the period of data evaluated for reaches upstream of the Poudre River confluence, and lack of a trend downstream of the confluence. Note the effect of the September 2013 flood can be seen in this data set. The design water quality assumptions used for water treatment assessments in this Study are summarized in Table 21.

Table 21. Design Raw Water Quality

	Brighton	Poudre Confluence	Fort Morgan/Sterling
Turbidity	42 NTU	68 NTU	99 NTU
Total Dissolved Solids	844 mg/L	973 mg/L	1217 mg/L
Calcium	99 mg/L	125 mg/L	209 mg/L
Magnesium	20 mg/L	52 mg/L	58 mg/L
Sulfate	200 mg/L	465 mg/L	776 mg/L
Chloride	86 mg/L	86 mg/L	74 mg/L
Total Organic Carbon	12 mg/L	9 mg/L	6 mg/L
Alkalinity	185 mg/L	228 mg/L	260 mg/L
Iron	2.5 mg/L	1.86 mg/L	1.3 mg/L
Manganese	0.26 mg/L	0.16 mg/L	0.26 mg/L
Nitrogen-Nitrate	5.6 mg/L	7.2 mg/L	6.7 mg/L
Bromide	0.06 mg/L	N/A	N/A
pH	7.9	8.4	8.4
Temperature	69 deg. F	76 deg. F	75 deg. F

As a result of the water quality evaluation the following treatment issues or considerations were identified.

- The turbidity values are high and indicate that clarification or RBF pre-treatment would be beneficial prior to filtration or membrane separation.
- TDS exceeds the secondary standard. Unless finished water blending is an option, the TDS concentration will need to be reduced to meet the secondary MCL. It is unlikely that removing the calcium and magnesium using a lime softening process would sufficiently reduce the TDS to below the secondary MCL. However, membrane processes such as nanofiltration (NF), reverse osmosis (RO), or electrodialysis/electrodialysis reversal would be effective. Sulfate levels are elevated and chemical scaling maybe a concern for membrane processes.
- Iron and manganese concentrations should be reduced. Reducing iron and manganese concentrations is typically accomplished with oxidation and filtration. As a result of the potential for disinfection by-product formation, pre-chlorination should not be performed. Ozone may be a feasible option with the low bromide concentrations; however, future piloting or bench work to identify ozone dose and design characteristics should also consider potential for bromate formation. The more likely oxidation candidates include sodium/potassium permanganate or chlorine dioxide.

- Total organic carbon concentration is elevated enough to require 50% removal per regulations and to reduce disinfection byproduct formation. Additionally, ammonia may be needed to halt DBP formation after primary disinfection with chlorine. Organic removal would be by coagulation or advanced treatment. Additionally, the two largest water users in the Metro area are the City of Aurora and Denver Water and both utilities use chloramines. This would require other entities that are not on chloramines to convert to minimize blending compatibility issues.
- Bromide levels are close to the trigger for bromate formation potential if ozone is a desired treatment process.

Section 4: Treatment Process Alternatives

The SPROWG treatment scenarios proposed in Section 2 are riverbank filtration with a conventional water treatment plant (RBF + conventional water treatment plant (WTP) and application of advanced treatment technology in an advanced water treatment plant (AWTP). This section describes the selected treatment processes for each scenario needed to meet the finished water requirements. The proposed main process schematic is the same for all treatment locations; however, the Fort Morgan/Sterling source water location will require additional TDS removal due to the higher TDS concentrations further downstream in the South Platte River. The alternative that includes only RBF assumes each participant will blend the raw water with their individual systems to meet regulation requirements.

4.1 Riverbank Filtration and Water Treatment Plant

The process for the conventional treatment of raw water in projects like those contemplated in SPROWG include pretreatment with RBF or another process to reduce turbidity and solids concentrations, pre-oxidation with chlorine dioxide, some variation of lime softening with coagulation and plate sedimentation, granular media filtration, chlorine disinfection, and chloramination with ammonia. The RBF process is a natural pretreatment process that uses the filtration properties of riverbed and riverbank sediments to remove solids and certain other constituents. It usually involves a system of shallow horizontal or vertical wells beneath streambeds and constructed recharge basins in adjacent areas to draw water from alluvial sediments. Even with RBF pretreatment additional solids removal is necessary in the conventional treatment process via mechanical dewatering with recycle. Figure 3 is a graphical representation of the process schematic.

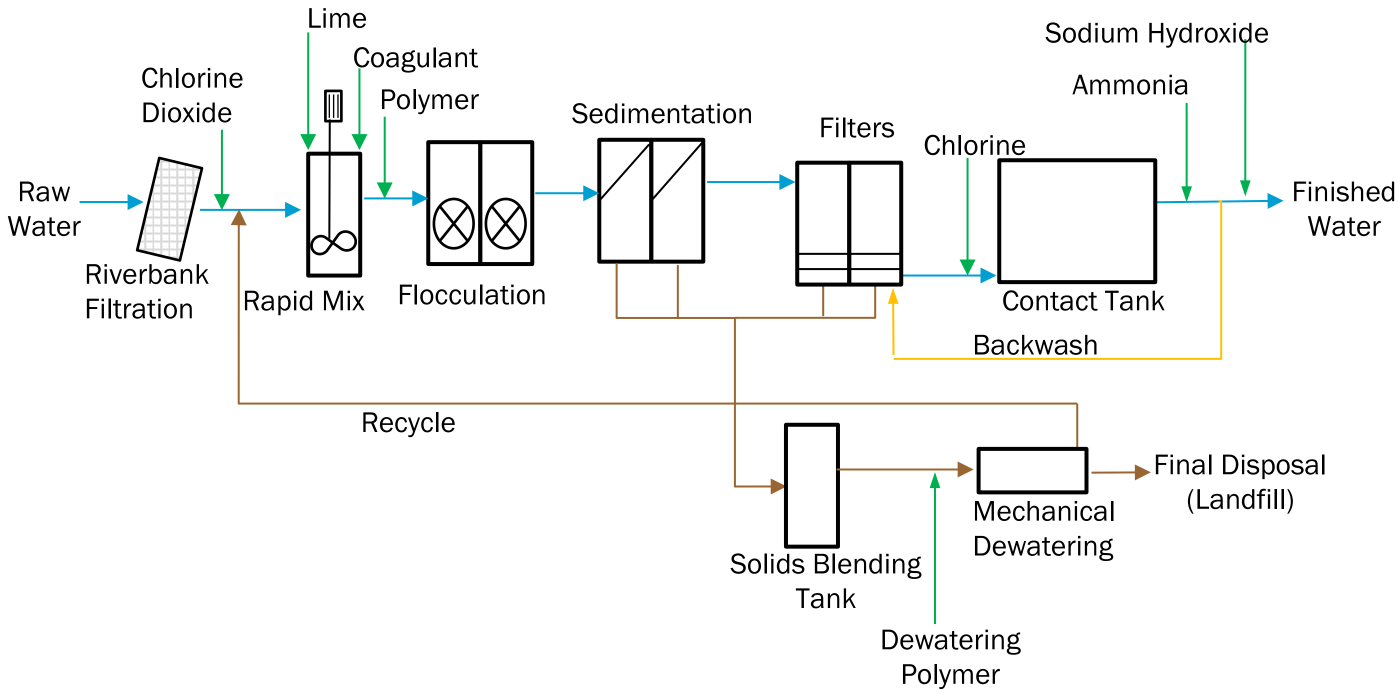


Figure 3. RBF + Conventional Treatment Process Schematic

A brief description of the RBF + Conventional WTP processes, reasons to justify selection of this process, and key design criteria of each process component included in the schematic are summarized in Table 22. Table 23 presents relative advantages and disadvantages for the RBF + Conventional WTP scenario.

Table 22. Conventional WTP Processes			
Process	**Description**	**Selection Reasoning**	**Design Criteria Considerations**
Riverbank Filtration	The natural pretreatment process that uses the riverbed and a nearby sand and gravel aquifer as a filter. Used as pretreatment to reduce raw water turbidity. On a case by case basis the reduction of TOC, iron, and manganese have been observed.	The source water has a high potential for swings in turbidity, RBF can provide pre-treatment to reduce the elevated turbidity and minimize impact to the WTF.	Minimum of 25-feet from river to receive log inactivation credit
Pre-oxidation with Chlorine Dioxide	Chlorine dioxide is a strong oxidant used for disinfection and oxidation. Used to oxidize iron and manganese ahead of filtration. It can also react with TOC and provide contact time for disinfection log removal credit.	The source water has elevated TOC, iron, and manganese.	Bench-scale testing conducted to determine chlorine dioxide demand and decay.
Lime Softening	The addition of chemicals of calcium hydroxide, lime water, to soften the water. Used to remove calcium and magnesium	Reduce the elevated levels of calcium and magnesium to overall reduce the total dissolved solids.	Chemical feed point must be directly into rapid mix.
Coagulation (Rapid Mix)	The addition of chemicals, coagulants and polymer, followed by rapid mix to quickly dissolve and disperse the chemicals. Use to disperse chemicals into the water.	Condition the water for downstream treatment and is the first step in conventional treatment.	Provide mixing energy to meet a velocity gradient of 500 per seconds (s^{-1}) and minimum of two trains.
Flocculation	The formation of larger-settleable particles. Used to provide contact time to form the large particles and condition the water.	Condition the water for downstream treatment and is the second step in conventional treatment.	Hydraulic residence time of 30 minutes at a minimum and mechanical agitation used and minimum of two trains.
Sedimentation	The settling of solids by gravity. A tank with plates installed to enhance the settling process is plate-sedimentation. Used to remove the larger particles.	Condition the water for downstream treatment and is the third step in conventional treatment	Lime-softening facility minimum of 2-hours of settling time, sludge collection equipment required, and minimum of two trains.
Dual-Media Filtration	The removal of particles through a filter comprised of gravel, sand, and anthracite. Used to remove smaller particles not removed through sedimentation.	Required process to meet regulation.	Dependent on the type of filtration used. Dual media filters have a must have minimum of 30-inches of sand and anthracite, backwash and filter-to-waste system, minimum of two trains. Filtration with a conventional plant provides required 2-log inactivation credit for cryptosporidium, 1-log inactivation of giardia and 2-log inactivation of viruses.
Disinfection with Chlorine	The addition of chlorine either chlorine gas solution or sodium hypochlorite to post-filter water. Used to provide primary disinfection.	Required process to meet regulation.	Sizing is based on flow, temperature, pH, baffle factor and chlorine residual to provide adequate contact time to meet additional 1-log needed for giardia and 2-log for viruses. Must provide primary disinfection at all times.
Chloramination	The addition of ammonia to form chloramines. Used to provide secondary disinfection and reduce the potential for disinfection by-production formation.	As a result of the elevated raw water TOC, chloramination will stabilize the finished water and reduce the potential for disinfection by-products.	Sizing is based on chlorine residual and decay demand. Consideration to distribution system with storage tanks such that water doesn't get stagnant and nitrogen forms.
Mechanical Dewatering	Mechanical unit to remove water content from the solids. The water removed is collected and recycled to the head of the WTF and the solids are disposed to a landfill.	The addition of lime softening coagulation will increase the number of solids such that dewatering equipment may be more economical to other solids management options.	Sized based on the influent solids load and the desired percent solids required for land fill disposal.

Table 23. Advantages and Disadvantages of RBF + Conventional WTP	
Advantages	**Disadvantages**
No advanced treatment technologies	Retrofit generally more challenging
Use gravity to minimize pumping needs	Increase chemical usage
Lower overall power demand	Additional processes or significant modifications may be needed to meet future regulations
Ease of disposal of solids	Additional polishing process or finished water blending needed to meet secondary and ASR standards for TDS.
Less water loss across processes	Larger footprint

Feasibility of RBF + Conventional WTP

Conventional WTP will meet primary water treatment regulations. However, it will not meet secondary standards. To address TDS and meet ASR recharge water quality requirements, finished water blending or a polishing process would be needed. Also, chlorimination is not required to meet finished water quality, but would be necessary for some potential participants including Denver Water and the City of Aurora. Additionally, processes such as advanced oxidation process and granular activated carbon (GAC) may be needed to remove constituents such as PFAS, N-Nitrosodimethylamine (NDMA), or other emerging contaminants to meet future regulations .

The RBF process can have limitations on capacity due to the large area required for the wellfield and recharge basins. RBF effectiveness is strongly dependent on local geologic conditions that can be high variable. Aurora's experience with the Prairie Waters North Campus facility has shown the benefits and challenges of using RBF as a pretreatment strategy. There are practical limits to the capacity of this type of system in a segment of the South Platte river corridor that can be managed as a treatment unit. Although this limit is likely less than the treatment capacity required for the SPROWG alternatives, RBF has been considered as a pretreatment option for any of the alternatives at this level of conceptual evaluation. Additional limitations to consider are operational and maintenance needs and seasonal start-up and shutdown. Conventional WTP alone is not feasible to meet the finished water quality objectives of the SPROWG Concept.

4.2 Advanced Water Treatment

Advanced water treatment (AWT) would be necessary should the raw water quality exceed the capability of conventional treatment to meet primary and secondary drinking water standards. The process considered for this study as AWT is high pressure membrane filtration which include reverse osmosis (RO), nanofiltration and electrodialysis reversal (EDR), and process description, advantages and disadvantages are summarized in Table 24. All three processes will require brine disposal. Currently, deep well injection, evaporation ponds and mechanical evaporator are the three general industry methods for brine disposal. Evaporation ponds require a lot of land and deep well injection triggers additional permitting requirements. Therefore, the brine disposal method proposed is a mechanical evaporator.

For the purpose of this study, RO is assumed for AWT and mechanical evaporators are assumed for brine treatment. Therefore, the proposed AWT process schematic includes pre-oxidation with chlorine dioxide, coagulation, plate sedimentation, microfiltration, RO, chlorine disinfection, and chloramination with ammonia. Additionally, the pretreatment solids will be treated using mechanical dewatering and mechanical evaporators for the RO brine.

Table 24. High Pressure Membrane Filtration Processes			
Process	Description	Typical Removal	Advantages/Disadvantages
Reverse Osmosis	Reverse osmosis uses a partially permeable membrane to remove dissolved constituents like the small monovalent ions (i.e. sodium chloride) from drinking water.	Salts and low molecular weight organics	High finished water quality/ High feed pressure, water loss across the membranes, and pretreatment required,
Nanofiltration	Nanofiltration membranes are used to remove larger divalent ions such as calcium and sulfate while the smaller monovalent ions pass through.	Divalent ions/hardness, limited monovalent ions, dissolved organic ions, and color	Used for softening and TOC removal, lower energy requirement than RO and EDR/ membranes fouling from sulfate can occur
Electrodialysis Reversal	Electrodialysis reversal uses electricity applied to electrodes to remove naturally occurring dissolved salts through an ion exchange membrane to separate the water from the salts.	Salts	Relatively low energy consumption/elaborate controls required and keeping membranes at optimum conditions is challenging, manufacturing is key component to ensure compatibility with the feed system, few manufacturers

A graphical representation of the AWT process schematic is illustrated in Figure 4. The AWT will meet finished water quality requirements at any of the SPROWG source water locations; however, there may be differences in operation costs at each location as a result of differences in chemical demands and site layout characteristics.

As indicated in Figure 4, the RO process is a split-stream process in which only a portion of the flow is treated for TDS removal. This minimizes the size and cost of this portion of the treatment train. In sizing the RO portion of the AWT process, the proportion of the flow stream to be treated is a function of the raw water TDS concentration. To be conservative, a finished water TDS concentration of 400 mg/L was assumed for sizing the RO treatment component. Based on the 90th percentile TDS raw water quality, the percentage of the flow stream to be treated in the RO portion of the treatment train at each WTF is summarized in Table 25.

Table 25. RO Split-Stream Flow Rates		
Diversion Location	Source Water TDS Concentration (mg/L)	Percentage of Flow to be Treated in RO Process
Brighton	800	50
Poudre Confluence	900	56
Fort Morgan/Sterling	1,200	67

A brief description of the AWTP process, reasons to justify selection of this process, and key design criteria of each process component included in the schematic are summarized in Table 26. Table 27 presents relative advantages and disadvantages of AWTP scenario.

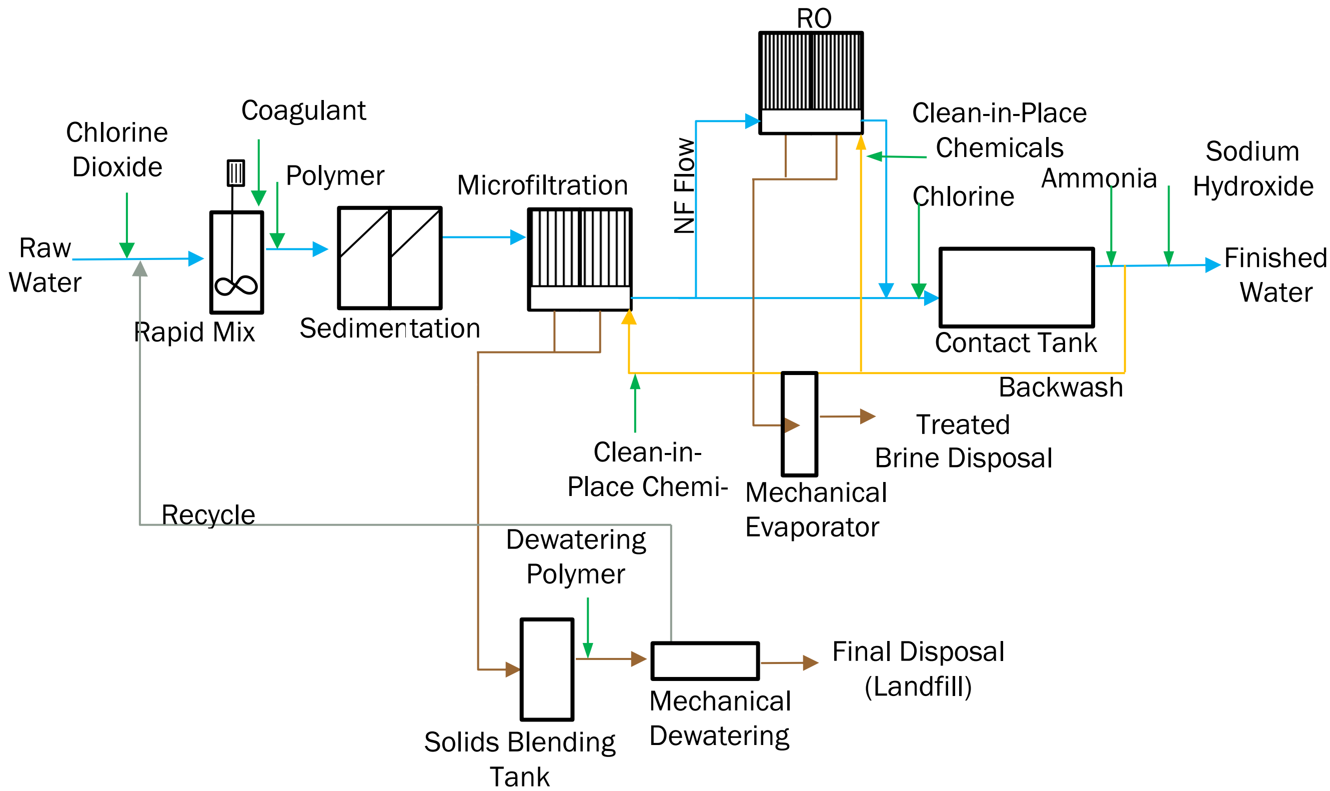


Figure 4. Advanced Water Treatment Process Schematic

Table 26. Advanced Water Treatment Processes			
Process	Description	Selection Reasoning	Design Criteria Considerations
Pre-oxidation with Chlorine Dioxide	Chlorine dioxide is a strong oxidant used for disinfection and oxidation. Used to oxidize iron and manganese ahead of filtration. It can also react with TOC and provide contact time for disinfection log removal credit.	The source water has elevated TOC, iron, and manganese.	Onsite generators design based on chemicals used and bench-scale testing conducted to determine chlorine dioxide demand and decay.
Coagulation (Rapid Mix)	The addition of chemicals, coagulants and polymer, followed by rapid mix to quickly dissolve and disperse the chemicals. Use to disperse chemicals into the water.	Condition the water for downstream treatment and is the first step in conventional treatment.	Provide mixing energy to meet a velocity gradient of 500 per seconds (s^{-1}) and minimum of two trains.
Flocculation	The formation of larger-settleable particles. Used to provide contact time to form the large particles and condition the water.	Condition the water for downstream treatment and is the second step in conventional treatment.	Hydraulic residence time of 30 minutes at a minimum and mechanical agitation used and minimum of two trains.
Sedimentation	The settling of solids by gravity. A tank with plates installed to enhance the settling process is plate-sedimentation. Used to remove the larger particles.	Condition the water for downstream treatment and is the third step in conventional treatment	Minimum of 4-hours of settling time, sludge collection equipment required, and minimum of two trains.
Microfiltration	The removal of particles through a low pressure membrane. There are two types of membranes submerged and pressure. Membrane filtration includes additional chemicals for membrane cleaning.	Meets the filtration process requirement and is a pre-treatment step ahead of nanofiltration.	Microfiltration meets the required 2-log inactivation credit for cryptosporidium , 3-log inactivation of giardia and 2-log inactivation of viruses.
Reverse Osmosis	The removal of particles through a semi-permeable membrane. Membrane filtration includes additional chemicals for membrane cleaning.	Removal of total dissolved solids. An option as shown is to split the flow to the RO for blending to reduce TDS to below the limits.	RO design criteria are dependent on finished water goals. The sulfate concentration is elevated that there is a potential for chemical scaling. Additional water quality testing to determine sulfate limit prior to design.
Disinfection with Chlorine	The addition of chlorine either chlorine gas solution or sodium hypochlorite to post-filter water. Used to provide primary disinfection.	Required process to meet regulation.	Sizing is based on flow, temperature, pH, baffle factor and chlorine residual to provide adequate contact time to meet additional 1-log needed for giardia and 2-log for viruses. Must provide primary disinfection at all times.
Chloramination	The addition of ammonia to form chloramines. Used to provide secondary disinfection and reduce the potential for disinfection by-production formation.	As a result of the elevated raw water TOC, chloramination will stabilize the finished water and reduce the potential for disinfection by-products.	Sizing is based on chlorine residual and decay demand. Consideration to distribution system with storage tanks such that water doesn't get stagnant and nitrogen forms.
Mechanical Dewatering	Mechanical unit to remove water content from the solids. The water removed is collected and recycled to the head of the WTF and the solids are disposed to a landfill.	The addition of lime softening coagulation will increase the number of solids such that dewatering equipment may be more economical to other solids management options.	Sized based on the influent solids load and the desired percent solids required for land fill disposal.
Brine Disposal	The disposal of the reject water from the nanofiltration system. Brine disposal may require additional treatment and is dependent on the final disposal option.	Required to treat reject of the nanofiltration system.	Meet quality based on final disposal like groundwater injection or discharge to wastewater treatment system, if available.

Table 27. Advantages and Disadvantages of Advanced Water Treatment	
Advantages	**Disadvantages**
Smaller footprint	Higher power demand.
Meet future regulations with less process modifications	Increase maintenance requirements
Ease of retrofit	Additional consideration required for brine disposal
Can meet secondary MCLs	Additional source water flow required to meet demand due to increase in water loss across the processes.

4.2.1 Feasibility of Advanced Water Treatment

An AWTP process is necessary when a high level of finished water quality is required and challenging raw water quality such as elevated levels of TDS and sulfate is present. AWTP also is advantageous when space for a new WTF is limited. The AWT option including pretreatment with conventional WTP meets primary and secondary standards. If the SPROWG Concept is to deliver individual participants finished water fully in compliance with primary and secondary standards, then AWTP is necessary. As with conventional water treatment, chloramination is not required to meet finished water quality, but will be necessary for some potential participants including Denver Water and the City of Aurora.

Additional limitations to consider are similar to conventional WTP option such as operational and maintenance needs and seasonal star-up and shutdown. Brine disposal with AWTP will be a technical and permitting challenge. The AWTP is feasible to meet the finished water quality objectives of the SPROWG Concept; however, the cost implications are significantly higher than the conventional WTP option.

Section 5: Alternative Cost Assessment

In order to standardize the comparison of treatment costs for the four SPROWG alternatives, the following assumptions were adopted based on the foregoing comparison of the various treatment options.

- All RBF concepts were similar to Prairie Waters North Campus. The possible practical limit of RBF hydraulic capacity was not considered at this level.
- Conventional treatment processes did not include brine removal. It was assumed operational programs or blending water would be available to reduce TDS concentrations to acceptable levels.
- All AWT concepts included RO and mechanical evaporation for brine disposal. RO processes were sized for split-stream operations.
- Treatment prior to ASR recharge includes all treatment processes except disinfection.
- Treatment for water conveyed in the Metro Area Pipeline was performed in two stages. RO treatment was performed at the pipeline intake at the Balzac storage facility so make brine disposal more practical and reduce the volume of water to be pumped and piped to the Henderson area. Conventional treatment was performed at the Henderson WTF in combination with water from Henderson storage.
- Figures 5, 6 and 7 illustrate the treatment scenario schematic for Alternative 1, Alternatives 2 and 3, and Alternative 4, respectively.

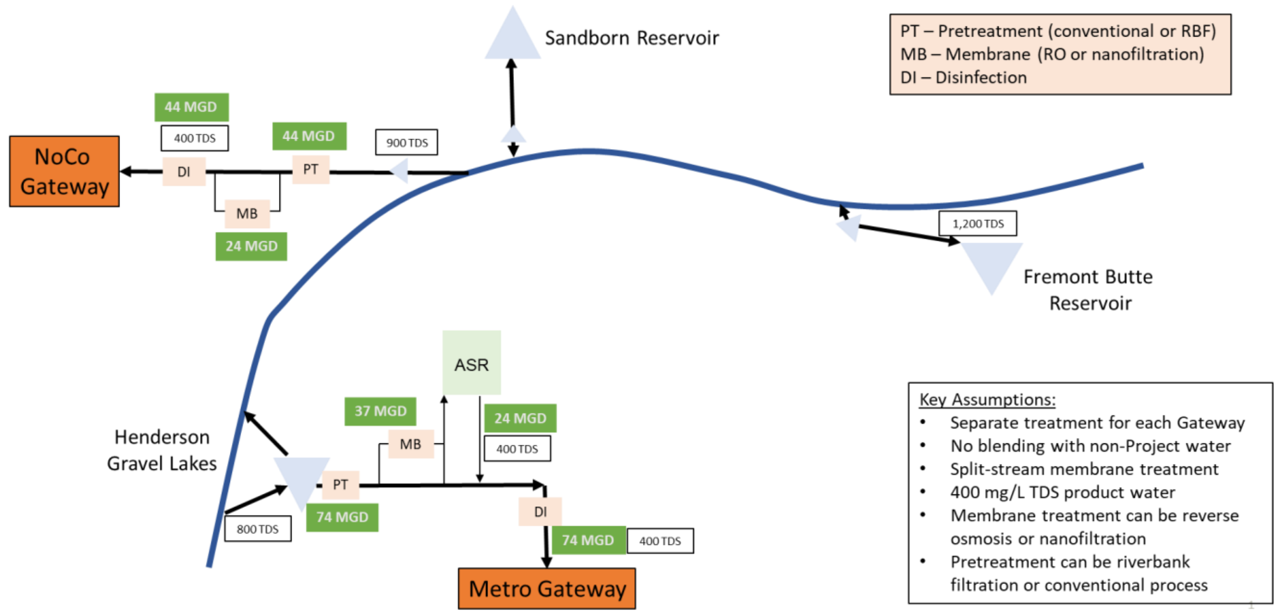


Figure 5. South Platte Regional Water Treatment Facility Treatment Scenario Schematic - Alternative 1

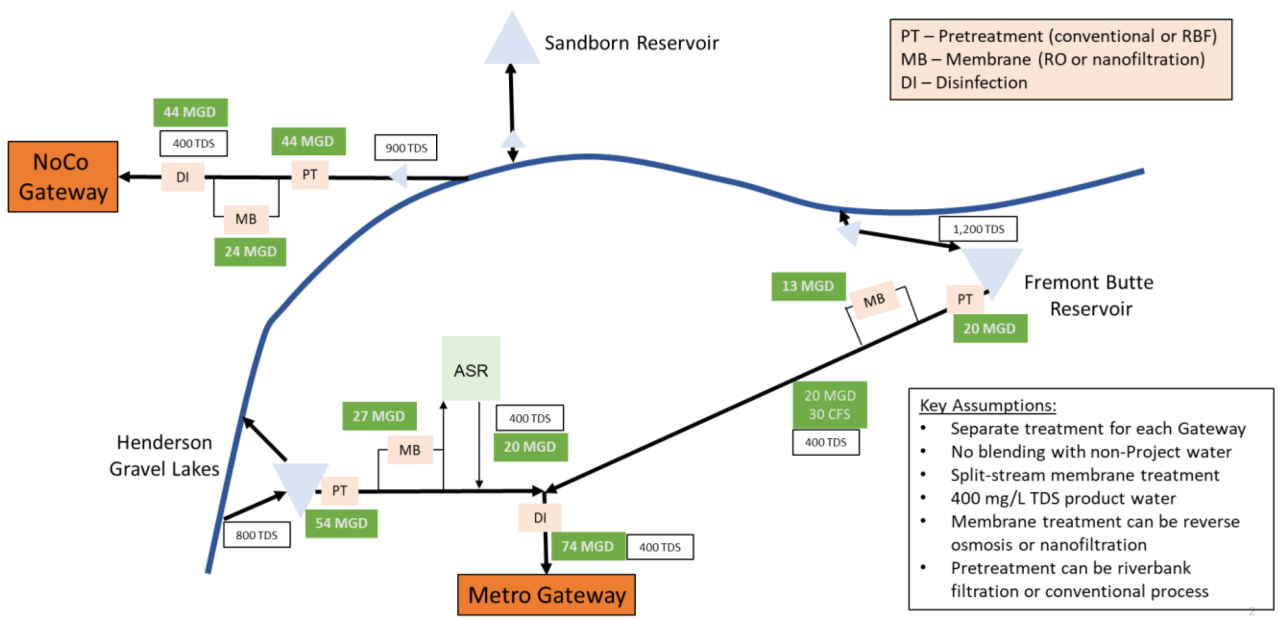


Figure 6. South Platte Regional Water Treatment Facility Treatment Scenario Schematic - Alternatives 2 and 3

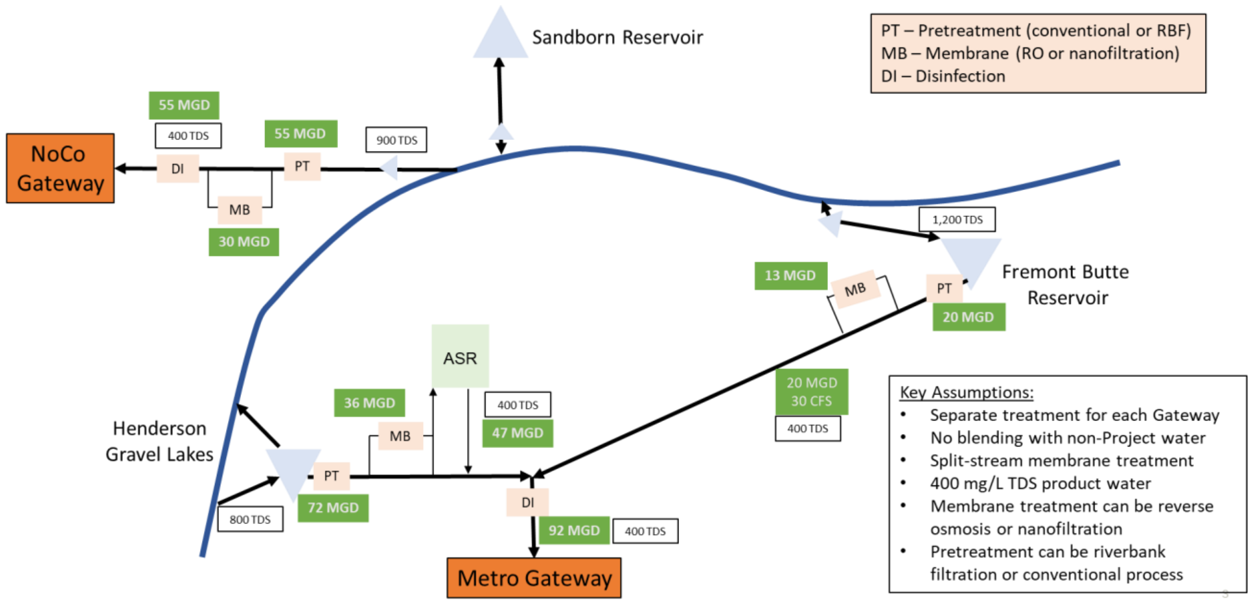


Figure 7. South Platte Regional Water Treatment Facility Treatment Scenario Schematic - Alternative 4

The capital and operational costs vary with each alternative. Table 28 and Table 29 provide a comparison of the total project costs for each alternative. For planning purposes, capital and operating costs were derived using a unit cost per million gallons (mg) of treated water. The engineering, legal, land acquisition, and administrative costs are based on typical percentages of the capital costs. AWTP costs include the cost of brine removal and disposal. These cost estimates were derived from construction and operating cost data from similar projects completed by Stantec or by other entities for which data was available. The capital costs cover treatment facility costs only and do not include the expense for conveyance of raw and finished water to and from the treatment facility. Also included in the cost estimates is the net present worth of 20 years of operation and maintenance costs. O&M cost estimates were based on experience operating similar scales of water treatment facilities. An O&M period of 20 years is representative of the time before major mechanical equipment must be replaced or significant process improvements could be implemented based on new technology, treatment regulations or other factors.

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Table 28. SPROWG Riverbank Filtration + Conventional WTP Option Costs Comparison									
Alternative	Design Flow (MGD)	Capital Cost[1] ($M)	*Annual Operating Cost[2] ($M/yr)*	Present Worth Operating Cost[3] ($M)	Engineering & Permitting Costs[4] ($M)	Land Acquisition Costs[5] ($M)	Legal & Administrative Costs[6] ($M)	Subtotal ($M)	Total ($M)
Alternative 1 – Refined Initial Concept									
Metro Gateway (Metro + NoCo-S)	74	$222	*$5.2*	$78	$33	$1.16	$18	$353	**$563**
NoCo Gateway (NoCo-N)	44	$132	*$3.1*	$47	$20	$1.16	$11	$210	
Alternative 2 - Balzac First									
Metro Gateway: Metro	57	$171	*$3.8*	$60	$26	$0.83	$14	$272	**$578**
Metro Gateway: NoCo-S	20	$60	*$1.4*	$21	$9	$0.29	$5	$96	
NoCo Gateway: NoCo-N	44	$132	*$3.1*	$47	$20	$0.64	$11	$210	
Alternative 3 - Add Julesburg Storage									
Metro Gateway: Metro	57	$171	*$3.8*	$60	$26	$0.83	$14	$272	**$578**
Metro Gateway: NoCo-S	20	$60	*$1.4*	$21	$9	$0.29	$5	$96	
NoCo Gateway: NoCo-N	44	$132	*$3.1*	$47	$20	$0.64	$11	$210	
Alternative 4 – Additional Delivery									
Metro Gateway: Metro	72	$216	*$5.1*	$76	$32	$1.04	$17	$344	**$703**
Metro Gateway: NoCo-S	20	$60	*$1.4*	$21	$9	$0.29	$5	$96	
NoCo Gateway: NoCo-N	55	$165	*$3.9*	$58	$25	$0.80	$13	$263	

Assumptions: [1] Capital ($M/mgd) = $3; [2]Annual operating costs (chemicals, equipment replacement, labor, power and miscellaneous); [3]Operating costs presented as 20yr present worth ($M/mgd) = $1.06; [4]Engineering & Permitting = 15% Capital; [5]Land Acquisition ($10,000/ac) = 116 ac (using relative SF as the Binney WPF 80 mgd and ratio based on flow); [6]Legal and Administrative = 8% of Capital.

Table 29. SPROWG Advanced Treatment Option Costs Comparison									
Alternative	Design Flow (MGD)	Capital Cost[1] ($M)	*Annual Operating Cost[2] ($M/yr)*	Present Worth Operating Cost[3] ($M)	Engineering & Permitting Costs[4] ($M)	Land Acquisition Costs[5] ($M)	Legal & Administrative Costs[6] ($M)	Subtotal ($M)	Total ($B)
Alternative 1 – Refined Initial Concept									
Metro Gateway (Metro + NoCo-S)	74	$518	*$7.22*	$107	$78	$1.07	$41	$746	**$1.19**
NoCo Gateway (NoCo-N)	44	$308	*$4.29*	$64	$46	$0.64	$25	$444	
Alternative 2 - Balzac First									
Metro Gateway: Metro	57	$399	*$5.56*	$83	$60	$0.83	$32	$575	**$1.22**
Metro Gateway: NoCo-S	20	$140	*$1.97*	$29	$21	$0.29	$11	$202	
NoCo Gateway: NoCo-N	44	$308	*$4.29*	$64	$46	$0.64	$25	$444	
Alternative 3 - Add Julesburg Storage									
Metro Gateway: Metro	57	$399	*$5.56*	$83	$60	$0.83	$32	$575	**$1.22**
Metro Gateway: NoCo-S	20	$140	*$1.97*	$29	$21	$0.29	$11	$202	
NoCo Gateway: NoCo-N	44	$308	*$4.29*	$64	$46	$0.64	$25	$444	
Alternative 4 – Additional Delivery									
Metro Gateway: Metro	72	$504	*$7.02*	$104	$76	$1.04	$40	$726	**$1.48**
Metro Gateway: NoCo-S	20	$140	*$1.97*	$29	$21	$0.29	$11	$202	
NoCo Gateway: NoCo-N	55	$385	*$5.36*	$80	$58	$0.80	$31	$555	

Assumptions: [1] Capital ($M/mgd) = $7; [2]Annual operating costs (chemicals, equipment replacement, labor, power and miscellaneous); [3]Operating costs presented as 20yr present worth ($M/mgd) = $1.45; [4]Engineering & Permitting = 15% Capital; [5]Land Acquisition ($10,000/ac) = 116 ac (using relative SF as the Binney WPF 80 mgd and ratio based on flow); [6]Legal and Administrative = 8% of Capital.

Section 6: Summary

Necessary water treatment will be determined by the needs of the project participants and the water quality at the location of the diversions. Drinking water regulations require municipal water providers to not exceed thresholds for listed contaminants. The level of these regulatory contaminants in the raw water is a key factor to selection of treatment processes. This section provides summary of the proposed treatment options costs comparison and recommended future steps.

6.1 Water Quality

The available raw water quality data for key parameters suggests the overall best condition for source water supply is near the Brighton/Henderson location. This location provides the lowest TDS and the sulfate and chloride levels are near MCL. As such, meeting as much of the Front Range municipal demand as possible from a diversion at this location would provide a relative advantage.

6.2 Treatment Costs

The range of total project costs (capital plus 20 years of O&M) for the RBF + Conventional WTP and AWTP options are summarized as follows:

- RBF + Conventional WTP: $560 million - $700 million

- AWTP including brine disposal: $1.1 billion to $1.5 billion

These are conceptual cost estimates based on limited raw water quality data, no specific site information, and assumed finished water quality objectives. Costs at this level of project development typically have a range of accuracy of -50% to +100%.

6.3 Recommended Future Studies

Additional investigations are recommended to determine the raw water quality and treatment requirements for the SPROWG Concept if it advances to future stages of consideration by prospective project participants.

- **Additional sampling program for better data.** The Nierbo Study is a compilation of water quality sampling data collected from multiple sample points in each reach of the South Platte River. These sampling points could be upstream or downstream of the actual proposed intake for the SPROWG Concept and represented different seasons and flow conditions. As such, the SPROWG participants should perform additional analysis of currently available data as well as additional sampling at desired diversion points to determine raw water quality and necessary treatment. The sampling program should consist of sampling water at the diversion points twice a month for a minimum of three years. The sampling and analysis program should test for all the parameters noted in Table 21.
- **Evaluate potential blending supplies.** The SPROWG Study was conducted under the assumption that SPROWG Concept water would not be blended with other lower TDS sources. A blending supply, depending on its quality, could reduce or eliminate the need for expensive membrane treatment and brine disposal to reach a desired water quality.
- **Better definition of the desired quality of delivered water supplies from a future SPROWG Project.** The SPROWG Study was conducted under the assumption that treated water deliveries would meet all primary and secondary drinking water standards, including a TDS concentration of approximately 400 mg/L. However, the project could deliver supplies at lower quality if the participants are able to provide additional treatment to meet their specific needs.
- **Nonpoint source treatment opportunities.** Nonpoint source treatment measures at a watershed scale could have benefits in improving South Platte River water quality and reducing treatment costs. This SPPROWG Study included a separate analysis of nonpoint source approaches. Further exploration of those options should be part of future treatability studies for SPROWG concepts.

References

Nierbo Hydrogeology, Historical Analysis of South Platte River Salinity (DRAFT), Colorado Water Conservation Board, 2019.

Farnsworth, *Regional Water Transmission and Treatment Feasibility Study,* Northern Colorado Water Conservancy District, 2016.

Attachment A: Plots of TDS Data from Nierbo Study

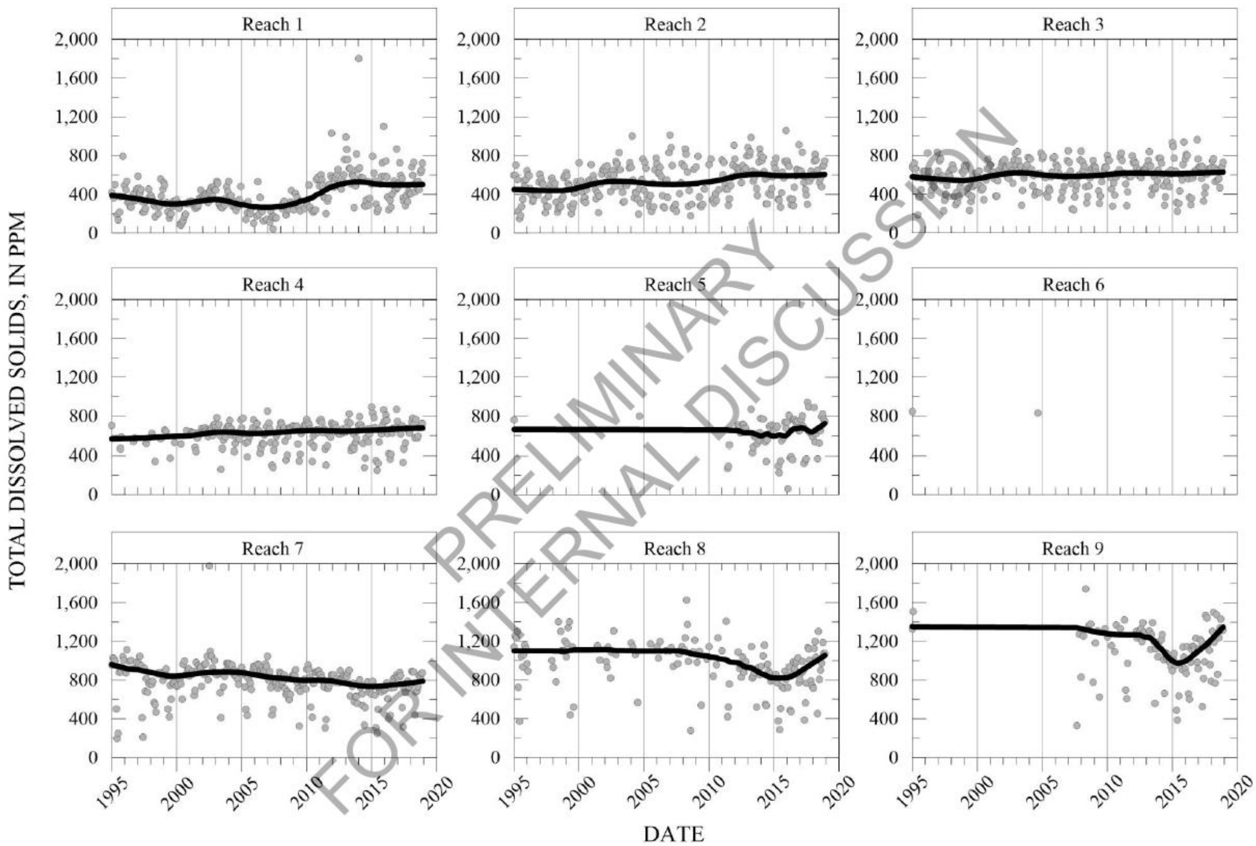

Figure 2. South Platte River, average monthly Total Dissolved Solids by reach with LOWESS trend line